

Measurement System

Hyperion

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1. Introduction

1.1. Installation

The software is designed to operate under MS Windows XP. With some limitations, Windows 98, NT4.0, and Windows 2000 are also supported.

To operate the hardware, a PC with two serial COM ports is required. The UART should provide for a FIFO to avoid loss of data.

Installation requires administrator privileges. After installation, regular user privileges will be sufficient.

Software installation consists of three steps:

- 1) Install the Python engine, you need administrator rights for this step. Select Python-2.3.4.exe from the CD. Select an appropriate installation location (e.g. c:\program files\python23, not the suggested default folder c:\Python23), select 'typical' and proceed installation. After installation, either reboot or log off, and on again. The latter step is required in order to re-evaluate the PATH variable. Do not proceed to step 2 without log out or reboot.
- 2) Install the GUI engine (a.k.a. Win32all). Select pywin32-xxx.win32-py2.3.exe and proceed installation. No further actions like log out or reboot are required.
- 3) Install the Hyperion package. Hyperion requires both Python and Win32all, so make sure both is installed (see 1 & 2). Proceed installation. No reboot is required.

An icon will be installed both to the desktop and to the start menu.

1.2. Update

Together with the update executable, you will find a description (readme.txt) detailing the upgrade. However, the rules indicated below apply:

- Upgrading just Inspector, it is usually most convenient not to uninstall the previous version¹. In this case, you must confirm **overwrite**, or your upgrade will not execute correctly. If you did not confirm overwrite, you can always restart the installation. In case more than one Python version is installed on your computer, these will be listed by the installer. Select one of the 2.3 versions.
- Upgrading the GUI library, there is no need to uninstall Inspector. You can either uninstall the old version, or just install the new GUI.
- To upgrade the main Python distribution, you can either uninstall the previous version, or just apply the upgrade. In both cases, make sure that the Python installation folder stays the same.

¹ Unless stated otherwise, the upgrade does not contain configuration files. Uninstalling the previous version, the configuration files are deleted too. Therefore, after installation of the upgrade, the hardware configuration is no longer available to Inspector, lacking any measurement capabilities. Therefore, you have to save (or write-protect) the configuration files Sensors.ini, Motors.ini and possibly Cam.ini and restore (or unprotect) the files after the upgrade. You will find these files in the folders <install-path>\lib\site-packages\pymess\Sensors, folders <install-path>\lib\site-packages\pymess\Motors and folders <install-path>\lib\site-packages\pymess\Grabber respectively.

If this is not possible, you have to uninstall Inspector first, next the GUI, and finally Python. Start a new installation as indicated above.

Notes:

- Both Inspector and the GUI library are linked with a dedicated Python release. At the time of writing, this is Python 2.3.x. Due to changes of the compiler and the dll libraries referenced, the distribution is **not** compatible with Python 2.4 or later.
- Please make sure, that you have only one Inspector installation on you computer (do a file search for Inspector.pyc, it should only be found in one place). If there is more than one installation, various types of defects have been observed, particularly after a file-open double click.

1.3. Uninstallation

Uninstallation should be done using the system control panel, section software. Please perform one-by-one the steps indicated below.

- Look up the item *Python2.3-Inspector <version>* in the software control page and press the remove button. Uninstalling Inspector does not delete your measurement files, or any output generated by Inspector.
- Look up the item *Python 2.3 pywin32 extensions (build <nr>)* in the software control page and press the remove button.
- Look up the item *Python2.3.<nr> >)* in the software control page and press the remove button.

It may also be necessary to manually remove measurement or output files generated by Inspector. Please make sure that you don't need these file any more prior to deleting.

1.4. Application and Specification of the Hyperion System

The "Hyperion" system implements a non-contacting profilometer for measurement of surface structures and performs calculations based on the profiles, e.g. roughness parameters.

Application:

Quality assurance and process control on microscopic structures. The system provides for the evaluation and calculation of geometric parameters (width, height, layer thickness, radius) and statistical parameters (roughness analysis).

Measurement features:

Two and three-dimensional acquisition of topographies.

Measurement axis specifications:

traverse length: 50x50 mm (optional up to 200 x 200 mm),
max. speed 50 mm/s, absolute positioning accuracy < 2 µm.
flatness +/- 0,5 µm / 50 mm,

Measurement speed:

0,1 - 50 mm/s.

Sample shape:

preferably coherent and flat surfaces up to 200 x 200 mm

Sample position:

horizontal

Standard system components:

PC with interfaces for sensor and stages,
17" TFT-Monitor, Keyboard, Mouse,

Measurement system with:

Granite base

Granite bridge

Stages

Sensor

Suspension

Manual z-adjustment

Plugs, sockets and cables

1.5. Installation, Place of Operation, Connection

The system will be set-up, installed and configured by our staff.

The place of operation must be free of vibrations, ambient temperature and humidity within the specifications (25°C, 30-80%rh, non-condensing).

Additionally the measurement room should be dust free and the system must be protected against direct sun light and draught.

The system is configured to accept standard mains supply of 230V AC (115V on special demand).

2. Hardware components

Important

It is strictly prohibited to change the system configuration. Other software may not be installed unless it is released by us in written. Because the system is optimised according to the functions it is also not allowed to exchange components of the PC or to install additional components.

All changes can lead to malfunctions followed by loss of warranty. Service assists, due to customer's modification of the system, will be charged.

2.1. System PC, Monitor, Keyboard, Mouse

The *PC* delivered is a standard desk top Windows XP^(R) computer system. Sensor and motors are interfaced via serial interfaces; usually no additional components are installed in the PC. The camera system may be based on an external monitor, frame grabber, or USB interface. Using the frame grabber, a PCI slot is required.

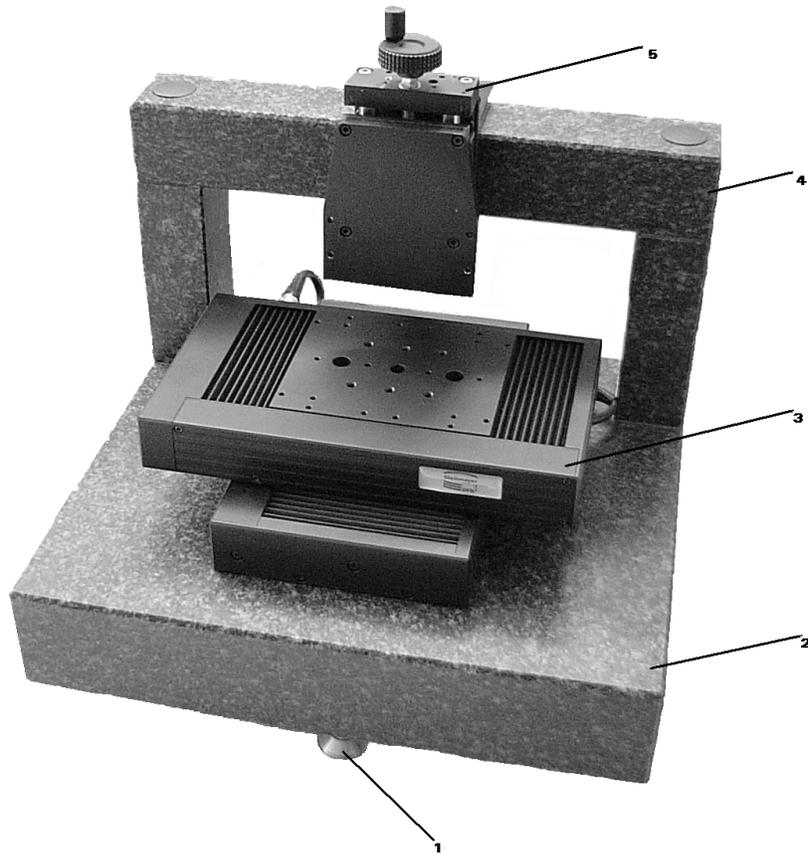
The *standard monitor* is a 17" TFT flat screen display.

Keyboard and *mouse* are standard PS/2 or USB devices.

2.2. Accessories, Cabling

Our staff will connect all cables, and a wiring diagram is enclosed in the manual and on-line help file., All plugs and sockets are clearly marked. Due to the modular design, few cables are required.

2.3. Measuring unit



- 1) Adjustable device bottoms for horizontal alignment of the measuring unit
- 2) Precision granite base for vibration isolation and stage bearing
- 3) Precision stages
- 4) Granite bridge
- 5) Fixture and manual height adjustment (z-adjustment) of the sensor

2.4. Sensor



- 1) Sensor control unit (depending on sensor type)
- 2) Sensor

Included in the delivery are following parts:

- sensor control unit,
- sensor,
- sensor cable,
- mains cable,
- RS232 zero modem cable,
- trigger cable,
- manual

Set-up and operation of the sensor and operation can be found in the enclosed sensor manual.

2.5. Ambient conditions

The system with its components is designed for use at room temperature (20°C) and relative humidity of 30 - 80%. The system may not be placed into direct sun light. The temperature gradient must be <0.5K/h. The place of operation shall be vibration free, otherwise correct measurements can not be guaranteed despite the heavy granite base.

2.6. Storage

In case the unit will not be used for a longer period the following actions must be taken:

- 1) Position the stages in centre position
- 2) Remove the sensor and store it in the sensor box
- 3) Store the box at a clean and safe location
- 4) Measuring unit should be protected from dust by cloth
- 5) Disconnect all units from mains supply

2.7. Maintenance, Adjustment

The basic "Hyperion" system is free of maintenance. Keeping it clean will extend its live time. We recommend to check the accuracy of the sensor attached either by yourself, using some calibrated standard once a year, order our technician for in-house check and calibration, or send the sensor *including sensor electronics* back to the manufacturer or distributor for service.

Cleaning the monitor, please refer to the respective manual. Be careful not to scratch the polarizer of the monitor. The system can be cleaned up with a smooth textile. Do not use aggressive detergents.

The granite base shall be properly levelled with the three adjustable device bases. Please turn the bases up or down, until the measuring unit is in horizontal position.

2.8. Warranty

We grant 24 months warranty upon the system according to our warranty regulations. Warranty periods from other suppliers (e.g. of the monitor) remain unchanged.

Important:

All changes and alterations of software and hardware are not allowed and leads to the loss of all warranty claims.

2.9. Service, Contact

For all questions or discussion of applications please contact your local supplier or agent. Phone number and address are listed in the About box of *Inspector* (select Help/Inspector from the main menu).

3. Software

Structure and operation principles of the Inspector software is very similar to standard Windows[™] software. The graphical user interface, e.g. main window, pull-down-menu and dialog boxes is operated like most other Windows applications.

3.1. Software start up

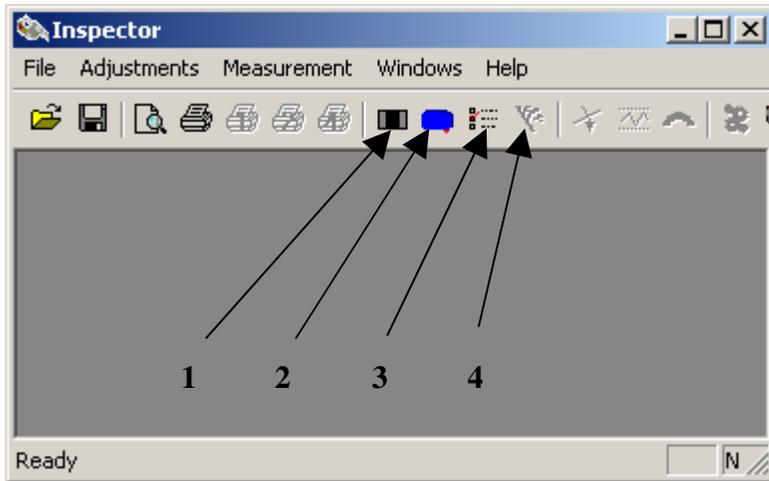
The Inspector software may be configured for automatic² or manual start-up. In the latter case either select *Inspector* from the *Start* button menu, double-click on the *Inspector* desktop icon,

² by placing a shell link within the Auto Start folder

or double-click the file Inspector.exe from an explorer window. If you have adhered to the recommended installation location, you will find Inspector.exe in the folder C:\program files\Python23.

3.1.1. Mainframe window

When the software starts up, Inspector's main window will open. The most important operations are available from the tool bar widget:



- 1) Icon Stage settings; identical to the menu selection *Adjustments/Stage settings*.
- 2) Icon Sensor settings; identical to the menu selection *Adjustments/Sensor settings*.
- 3) Icon Measurement Parameters; identical to the menu selection *Measurement/Parameters*.
- 4) Icon Start Measurement, identical to the menu selection *Measurement/Start Measurement*.

3.1.2. Reference drive, Initialisation of the stages

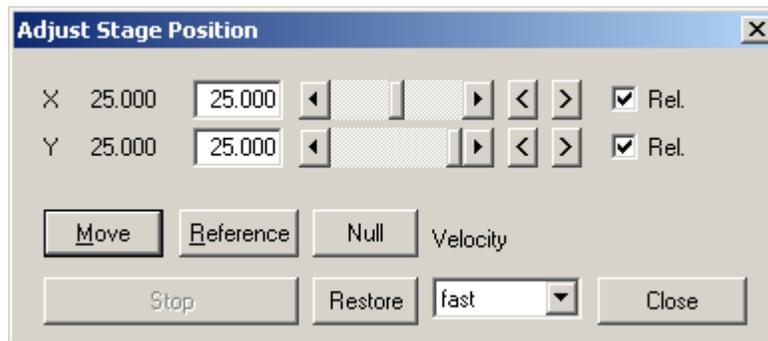


Figure 1: Stage Adjustment Dialogue

The stages attached to the Hyperion system usually employ an incremental position encoder. Therefore the position of the stages relative to some arbitrary reference is well-known, but not the absolute one. To resolve, a reference drive must be performed after each program. Referencing causes all stages to the most forward or backward (depending on configuration) position. As soon as the limit stop switch is activated, the stage decelerates, reverses motion and slowly releases the limit stop switch. After that, the axis' position counter is reset either to zero, or the configured length of the axis (depending on the direction of motion).

If the figures in the target position widgets are displayed in **red**, a reference drive is required. Prior to the reference drive, the stages may even be switched off-line and the joystick interface .

To start the reference drive, press the *reference* button. As soon as the reference drive is done, the position field is updated and the figure colour changes to black. You can stop a reference drive by pressing the ESC key.

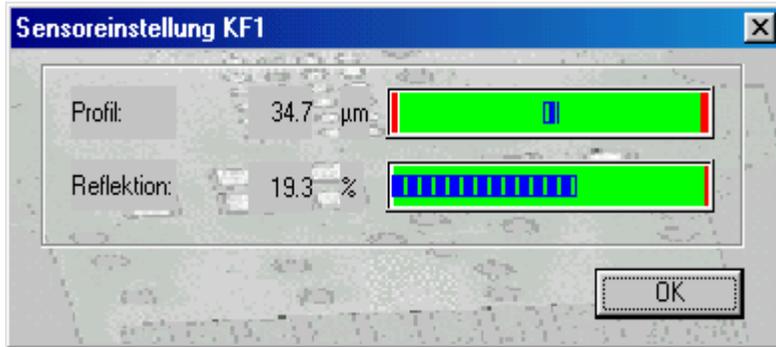
Important:

- ***Prior to performing a reference drive, make sure that no person or material is exposed to danger.***
- ***Furthermore please take care that the sensor will not be physically damaged by obstacles. Special attention must be given to sample fixtures and other projecting parts.***
- ***In case of emergency, abort the reference drive by pressing the ESC key.***

4. Measurement

Inspector is a metrology data acquisition and evaluation software. Data acquisition is an important step on the way towards meaningful results. The next few paragraphs detail on the different measurement modes and the meaning and implications of the various parameters of the measurement process. Although there are many parameters, these are arranged in functional groups with few interactions. The top-down arrangement simplify operation and allow for comprehensible operation.

4.1. Sensor adjustment



After initialisation of the stages, the sensor should usually be positioned to the centre of the measurement range. For all of the sensors (unless noted explicitly in the sensor manual), the profile reading will be zero at the nominal adjustment position.

4.2. Measurement Parameters

After having initialised the stages and setting up the sensor, the parameters of the measurement should be configured. Selecting the icon *Measurement parameters* in the tool bar, or the menu item *Measurement/Measurement parameters*, the dialogue indicated below surfaces³. On the left hand of the first page, the type of measurement will be configured. The right hand side provides for the most basic measurement parameters. Additional measurement parameters are available from the pages *Line* (relevant to line measurements only), *Surface* (relevant to surface measurements only), *Data, Options* and *Protocol* (applicable to all types of measurement).

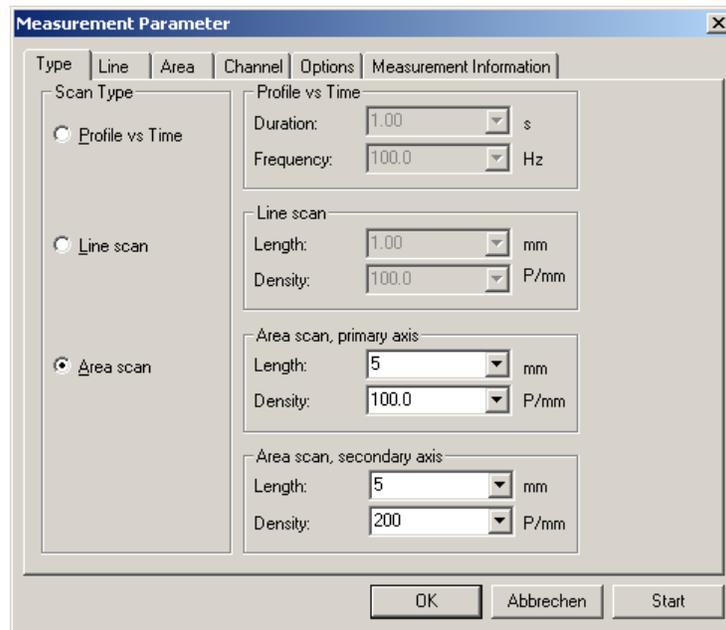


Figure 2: Measurement Parameter Dialogue

Using the radio buttons on the left-hand column the measurement type shall be selected:

- *Profile v.s. Time*: This type of measurement assesses the variation of some parameter v.s. time, without any motion of the stages. Point measurement is typically used for vibration analysis, assessment of long-term drift etc. Usually, an external stimuli is applied to the sample and the reaction observed.
- *Line scan*: This measurement acquires some parameter(s) along a straight line. It is typically used for 2D profile, roughness or edge detection measurements.
- *Area scan*: This type of measurement samples some parameter(s) within a rectangular area. The measurement is broken down into a set of line measurements, and the results are combined to create a 3D topography. The topography may either be used to assess profile values at certain positions, to extract cut-through profile between any two points (resulting in profiles similar to line measurements), to assess surface roughness parameters etc. Usually, area meas-

³ The dialogue shown is the standard dialogue for single-point sensors. Other sensors (e.g. surface scanning sensors like the confocal microscope) use a specialised dialogue providing for the configuration of their parameters. In case more than one sensor is installed, each sensor holds a unique set of measurement parameters. Therefore, prior to accessing the measurement parameters dialogue, make sure that the right sensor is activated.

urement yields information superior to line measurements, at the cost of increased measurement time.

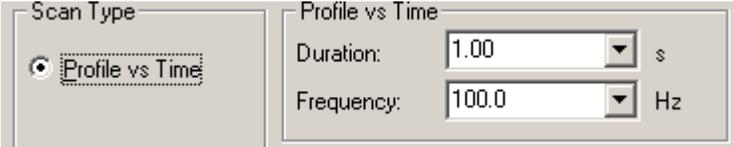
After selection of the measurement type, the associated configuration controls on the right-hand side become accessible. These controls provide for access to the most important measurement parameters, further parameters are available within the property pages Line, Surface, Data and Protocol. Depending on the system's configuration, further property pages (e.g. vertical stitching, also known as z range expander), may be available.

The next sections provide for details of the measurement parameters.

4.3. Profile v.s. Time measurement

Profile versus time measurement selects parameter acquisition versus some time interval. This type of measurement may be used for vibration analysis, investigation of thermal behaviour, observation of chemical reactions etc. The measurement may also be useful in situations where the stimuli for the sensor is applied externally, and can be considered as a function of time. This situation occurs frequently e.g. during integration of a sensor into an external machine, where the stages are beyond control of Inspector.

The controls *Duration* and *Frequency* input boxes get accessible once the radio button *Profile vs Time* is selected.



The screenshot shows a software interface for configuring a measurement. On the left, under the heading "Scan Type", there is a radio button labeled "Profile vs Time" which is selected. To the right, under the heading "Profile vs Time", there are two input fields. The first is labeled "Duration:" and contains the value "1.00" followed by a unit selector showing "s". The second is labeled "Frequency:" and contains the value "100.0" followed by a unit selector showing "Hz".

Figure 3: Profile vs time measurement parameters

Enter the desired measurement time into the *Duration* edit control, and the desired sampling frequency into the *Frequency* edit control. Minimum and maximum frequency depend on the sensor used. The sensor's data channels can be selected from the property page "Channel".

Note:

Minimum and maximum sampling rate are given by the sensor and sensor interface. If an invalid value is requested, an error message indicating the limits is issued once you press the *OK* or *Start* button.

4.4. Line scan measurement

The controls shown in Figure 4 are designated to configure the most important parameters of a measurement along a line.

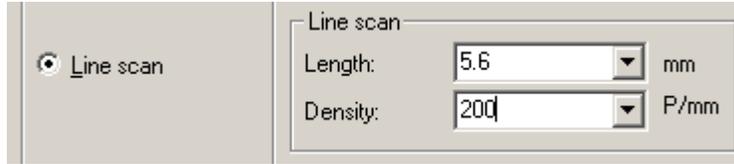


Figure 5: Line scan measurement parameters

Parameter *Length* indicates the sampling length. The measurement axis, together with parameters like *starting point*, *measurement direction* and *speed*, can be configured in the property page *Line*. Please consider that maximum line length and density may depend on the measurement axis selected⁴.

If the system is equipped with a heterogeneous stage configuration (e.g. different axis resolutions or units), the measurement axis shall be selected first. The measurement axis is configured within the property page *Line*.

The second parameter *Density* configures the number of samples per measurement axis unit (usually points per mm). The distance between successive samples can be calculated by taking the reciprocal value of the point density. A large point density results in a small distance from point to point. Depending on the application and the sensor used, realistic values shall be chosen. Extremely high point density usually does not provide additional information, but enlarges measurement and evaluation time drastically. The measurement spot diameter determines the reasonable point density value for the various sensors. Universally valid values cannot be given, instead, consider the rules of thumb below:

Sensor	Density
Autofocus, KF2/3, Tele	500-1000 points per mm
Chromatic Sensor:	200-400 points per mm

Supplemental information:

The number of data points per line measurement can be calculated by $1 + \text{Measurement length} * \text{Point density}$.

The valid point density range depends on the stage positioning speed limits, and on the sensor's data acquisition range: $f = v * D$, where f =sampling frequency, v =measurement speed, D =density. Once two of the three variables are chosen, the remaining one can be readily calculated. There are physical limits on each of the variables, bounding the area of valid parameters. A typical chart of measurement speed versus density looks like the one below:

⁴ This effect is particularly visible if a heterogeneous configuration like one linear axis and one rotary axis is attached. In these cases, valid configurations for the first axis may be invalid for the second axis or vice-versa. Therefore, please make sure the desired measurement axis is selected in property sheet *Line*, control 'Primary Axis'. Since changing the measurement axis occurs much less frequently than changing traverse length or sampling density, we have decided to place axis selection within a dedicated page, together with more advanced parameters.

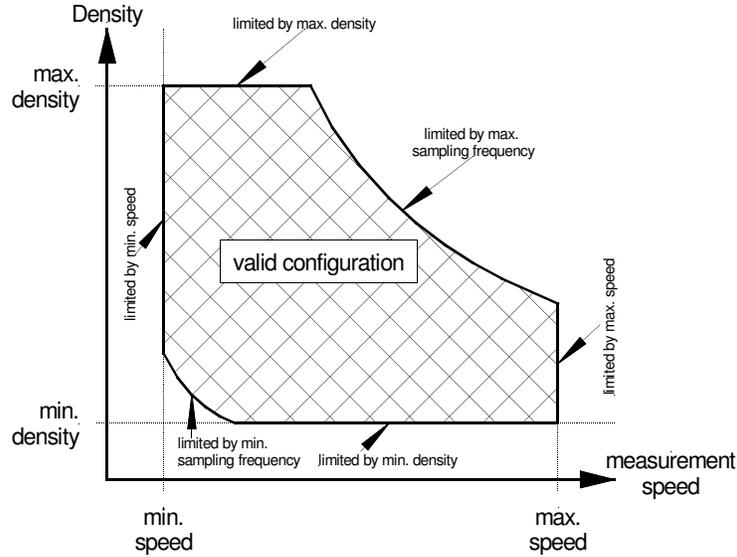


Figure 6: Valid Configuration, bounded by speed, density and sampling frequency.

Assuming the standard configuration of a Hyperion system, the following limits apply:

- minimum Density** >0
- maximum Density** 2000 (5000)⁵
- minimum Speed** >0mm/s
- maximum Speed** 50mm/s

	AF16	KF3, Tele	C1
minimum sampling frequency	17Hz	17Hz	33Hz
maximum sampling frequency	10000Hz	1000Hz	1500Hz

To avoid problems with vibration, acceleration and deceleration segments are added at the start and stop of the measurement line. These segments can each be assumed to have length of $\frac{\textit{measurement speed}}{4s}$, or a quarter of the measurement speed, in mm.

4.5. Area measurement

Area measurement is broken down into a sequence of line measurements. The area to be measured is scanned line by line. The most important parameters for the area measurement are length and width of the measurement area. These parameters are configurable using the controls *Area scan, primary axis/Length* and *Area scan, secondary axis/Length*. Similar to line measurement, the sampling density in primary and secondary direction can be set. By considering the measurement task and the sensor, realistic values should be selected. Extremely high number of measurement points does not lead to more information but enlarges the measurement and evaluation time drastically.

⁵ the physical resolution of the stages is 0.5µm, leading to 2000 points per mm. Values beyond 2000 pts/mm are realised by synthetic trigger pulse generation.

The image shows a software dialog box for configuring area scan parameters. On the left, there is a radio button labeled 'Area scan' which is selected. To the right, there are two distinct sections for axis configuration. The top section is titled 'Area scan, primary axis' and contains two input fields: 'Length' with the value '3.14' and unit 'mm', and 'Density' with the value '200' and unit 'P/mm'. The bottom section is titled 'Area scan, secondary axis' and also contains two input fields: 'Length' with the value '5.6' and unit 'mm', and 'Density' with the value '100.0' and unit 'P/mm'. Each input field has a small downward-pointing arrow on its right side, indicating a dropdown menu.

Figure 7: Area scan measurement parameters

Area measurement is composed of a series of line measurements, configured within the pane *Area scan, primary axis*. See section 4.4 for a description and limits of the primary axis' parameters.

The parameters of the secondary axis, height and line density, shall be configured within the pane *Area scan, secondary axis*. *Length* determines the height of the measurement area, *Density* the line-to-line spacing, both in units of the secondary axis.

In case of a heterogeneous axis configuration, make sure that the assignment of the primary and secondary axis is consistent with your requirements. The assignments are configured in the property page *Area*.

The maximum density of the secondary axis depends on the resolution (minimum step size) of the secondary axis. For best results, the primary and secondary axes densities should be some integer fraction of the resolution of the corresponding axis. Considering the standard configuration of the Hyperion system, density should be selected to $2000/n$ points per mm, n being any integer number ≥ 1 , yielding 2000, 1000, 666.66, 500, 400, 333.33, 285.7, 250 etc points per mm. While these numbers are not mandatory, they will provide for best results.

More advanced configurations of an area measurement, e.g. setting primary and secondary measurement axis, measurement speed, starting point and scanning frequency can be accessed from the property page *Area* and the sensor's data acquisition channels from the property page *Channel*. The measurement protocol is located within the page *Measurement Information*.

4.5.1. Line measurement parameters

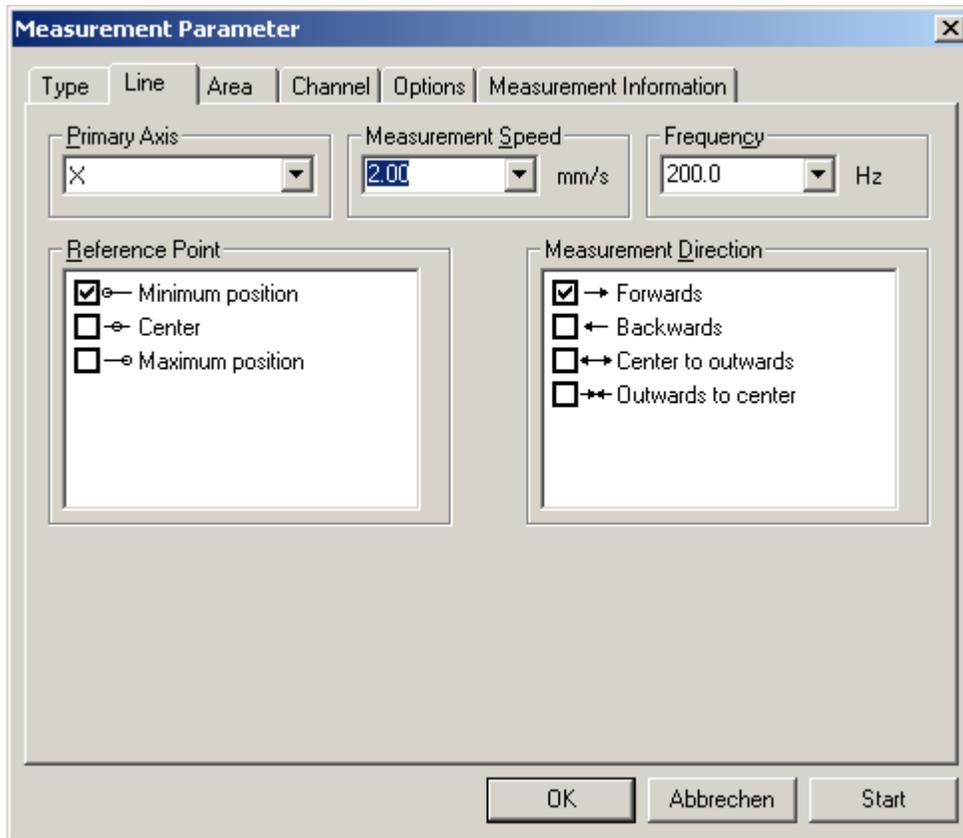


Figure 8: Line scan extended parameter dialogue

The register *Line* is provided for the configuration of the secondary parameters of a line scan measurement. To be able to perform a line measurement, at least one axis must be attached and properly configured.

Primary (or scanning) Axis:

A line measurement is done along a measurement axis. This axis is selected from the drop list **Primary axis**. In the standard system configuration with two linear stages, the axis travelling left to right is usually termed X axis. The axis which moves back to front is usually termed Y axis. The drop list includes only axes suitable as a primary axis⁶.

Measurement Speed:

The data acquisition of the sensor is synchronised with the movement of the stage. Hence, the sampling rate is the product of the scan speed and point density. Therefore, high speed or high point density (configured from the Type property page) requires high sampling rate, which must not exceed the sensor's capabilities. The maximum sampling rate is determined by the sensor type used.

⁶ The optional Z axis is usually unsuitable as a primary axis due to system setup (the axis moves in parallel to the measurement direction of the sensor).

Measurement velocity can be selected using the combo box *Measurement Speed*, the resulting measurement frequency will be calculated automatically and displayed in the control *Measurement frequency*.

In case the configuration requires a sampling rate beyond the sensor's limits, an error message will be issued. To resolve, either the Measurement *Speed* or the *Density* has to be reduced, the latter parameter is accessible in the property page Type.

Frequency:

Using the combo box *Frequency*, the desired sampling frequency can be configured. The corresponding measurement speed will be calculated automatically and displayed in the *Measurement Speed* control.

The range of valid measurement frequencies depends on the sensor. This information data can be found in the sensor manual, or taken from the table below:

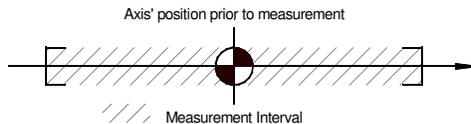
Sensor	AF16	KF3, Tele	C1
minimum sampling frequency	17Hz	17Hz	33Hz
maximum sampling frequency	10000Hz	1000Hz	1500Hz

Reference Point:

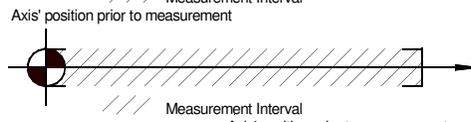
Prior to a measurement, the sensor must be positioned at the desired location using the stages. The measurement line may either start at this position, end at this position, or define the centre of the line scan. The alternatives are listed one by one within the list control Reference Point.

Usually, the stage is positioned at the centre of the scan line. In this case, the *Center* Reference Point should be selected. The measurement line will be symmetrical to the starting co-ordinates. The selections *Minimum* and *Maximum* are best explained by the images below.

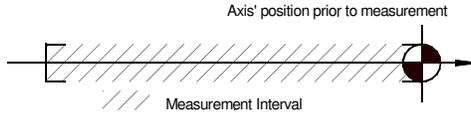
Reference Point *Centre*



Reference Point *Minimum*



Reference Point *Maximum*



Measurement direction:

Using the list control *Measurement Direction*, the direction of the measurement can be configured. It is possible to request a traversal in positive⁷ direction, negative⁸ direction, and two split-mode measurements. The small diagrams within the list control show the effect of the selection:

- **Forwards** means measurement from the smallest to the largest co-ordinate of the measurement axis.

⁷ positive: in direction of increasing axis co-ordinates.
⁸ negative: in direction of decreasing axis co-ordinates.

- **Backwards** means measurement from the largest to the smallest co-ordinate of the measurement axis.
- **Centre to outwards** splits the measurement into two parts. In the first half, a measurement is performed from the centre to the smallest co-ordinate. Then the stage drives back to the starting position without measurement. Next a measurement is performed from the middle to the largest co-ordinate. Both measurements will be merged by the software into one single measurement.
- **Outwards to centre** splits the measurement into two parts. In the first half, a measurement is performed from the smallest co-ordinate to the centre. Then the stage drives to the largest co-ordinate without measurement. Next a measurement is performed from the largest co-ordinate to the centre. Both measurements will be merged by the software into one single measurement.

The latter two sequences are useful for the autofocus sensor, e.g. if a sample with a hole shall be measured (Rule of thumb: measurement shall be performed always from the flat area towards the hole/edge). For the other sensors, forwards resp. backwards will do.

Please note, that measurement direction and reference point selection are entirely independent. The direction merely defines the way the measurement interval is traversed, while the reference point selection determines the position of the measurement interval relative to the stage position prior to measurement.

4.5.2. Area measurement parameter

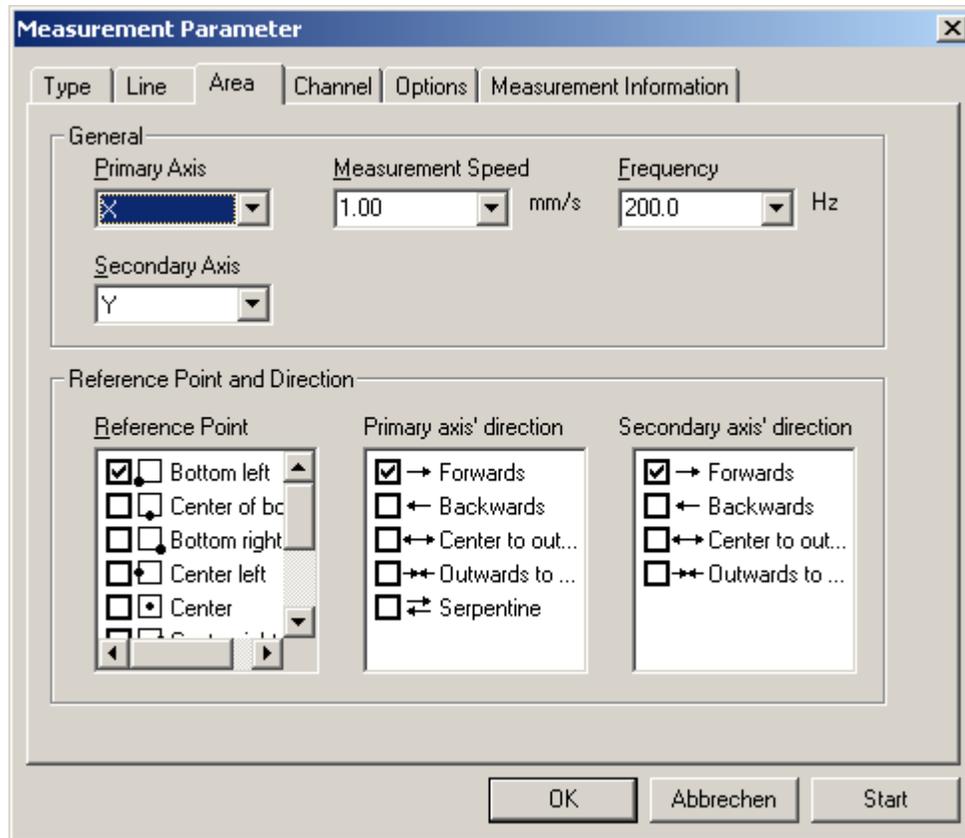


Figure 9: Area measurement parameter dialogue

The property page *Area* is intended to configure the measurement axes, scanning speed, sampling frequency, reference point, and scanning sequence of an area measurement. The configurations within this page do not influence Point vs Time and Line measurements. Width and height of the measurement has to be configured on the first property page *Type*. Area measurement requires two axes to be configured.

Measurement axis (primary axis):

An area measurement is broken down into a sequence of line measurements along the primary axis. This axis is configured in the field *Primary Axis*.

Transverse axis (secondary axis):

During the measurement, the secondary axis offsets the sample after each line scan by a small amount. The individual profiles are merged by the software to yield surface data. The secondary axis can be configured using the drop list *Secondary Axis*.

Note: In the standard configuration, the axis which drives left to right is called X axis, the axis which drives front to back is called Y axis. Since the primary axis of an area measurement corresponds with the scanning axis of a line measurement, most of the comments of section 4.5.1 apply.

Measurement speed:

The data acquisition of the sensor is synchronised with the movement of the stage. Hence, the sampling rate is the product of the scan speed and point density. Large measurement speed or high point density requires a high sampling rate. The maximum sampling rate is determined by the sensor type used. The speed of the primary axis can be set in the control **Measurement Speed**, the resulting measurement frequency will be calculated automatically and displayed in the control **Measurement frequency**. See the remarks in section 4.5.1 for details.

In case the configuration results in a sampling rate exceeding the sensor's limits, either the Measurement Speed or the Density has to be reduced, the latter parameter is available in the register Type.

Frequency:

The desired sampling frequency can be configured using the combo box **Frequency**. The matching measurement speed will be calculated automatically and displayed in the **Measurement Speed** control.

The range of valid measurement frequencies depends on the sensor. You can find the appropriate limits in section 4.4.

Reference point:

The list control is designated to configure the position of the measurement line relative to the stage position at the start of the measurement. Usually, the stage is positioned at the centre of the area, right above the feature of interest. In this case, the *Centre* reference point should be selected such that the measurement area will be symmetrical around the starting co-ordinates. To understand the other configurations, it is best to think of primary and secondary axis individually. For each of the two axes, Inspector offers three possibilities. The motion of the axis can be either to the left⁹, right¹⁰, or symmetric around the start position. The small icons in the list view visualise the reference position by a small dot, and the scan area relative to the starting point by a rectangle.

Usually, *Centre* should be configured as reference point, since measurement is symmetrical around the starting position. The other selections are either appropriate for automated measurement tasks, or in cases of known geometry and presence of an dedicated reference point (like a die on a wafer: take the lower left corner).

Note: The diagram visualises the configuration in terms of primary and secondary axis, in the same way the measurement result will be presented. The primary axis is visualised in east-west direction, the secondary axis in north-south direction. Depending on the assignment of the primary and secondary axis, the physical effect may be quite different (e.g. primary axis=Y, secondary axis=X) or may even need some forward kinematics (e.g. one linear axis, one rotary axis).

Primary axis' direction:

The motion sequence of the line scanning (primary) axis can be selected from this control. The small graphic shows the result of each selection:

- **Forwards** performs the measurement from the smallest to the largest co-ordinate.

⁹ more general: towards decreasing stage co-ordinates

¹⁰ more general: towards increasing stage co-ordinates

- **Backwards** performs the measurement from the largest to the smallest co-ordinate.
- **Serpentine** performs the line measurements alternating between forward and backward direction. This procedure saves some positioning time. The measurement sequence **Serpentine** shall be selected only with the confocal sensors with hardware trigger¹¹. Otherwise the lines will appear shifted relative to each other which will be most obvious on edges or steps. This effect may be acceptable only for low-resolution scans.
- **Centre to outwards** splits the measurement into two parts. In the first half, a measurement is performed from the centre to the smallest co-ordinate. Then the stage drives back to the starting position without measurement. Next a measurement is performed from the middle to the largest co-ordinate. Both measurements will be merged by the software into one single measurement.
- **Outwards to centre** splits the measurement into two parts. In the first half, a measurement is performed from the smallest co-ordinate to the centre. Then the stage drives to the largest co-ordinate without measurement. Next a measurement is performed from the largest co-ordinate to the centre. Both measurements will be merged by the software into one single measurement.

Notes:

- The latter two sequences are most useful for the autofocus sensor, if a sample with a hole shall be measured
(Rule of thumb: measurement shall be performed always from the flat area towards the hole/edge).
- The measurement sequence 'Serpentine' is applicable with the confocal sensors KF3 or Tele, if the trigger module is attached. Otherwise the lines will appear shifted relative to each other which will be most obvious on edges or steps.
- Standard measurements shall be performed using the forward or backward direction. If the KF3 or Tele confocal sensors are used, serpentine can be used to save some time.
- Measurement direction and reference point selection are independent of each other. The direction merely defines the way the individual line scans are traversed, while the reference point selection determines the position of the measurement area relative to the stage position prior to measurement. You may also want to review section 4.5.1 for a graphical representation of the influence of the reference position.

Secondary axis:

Similar to the settings for the primary axis, the motion profile of the secondary axis can be configured. For optical sensors, results are in almost any case identical, so that direction *Forwards* or *Backwards* is the preferred configuration.

- **Forwards** performs the sequence of line scans from the smallest to the largest co-ordinate of the secondary axis.
- **Backwards** performs the sequence of line scans from the largest to the smallest co-ordinate of the secondary axis.
- **Centre to outwards** splits the line scan sequence into two parts. In the first half, line scan measurements are performed from the centre to the smallest co-ordinate of the secondary axis. In the second half, line scans are performed from the centre to the largest co-ordinate of

¹¹ at the time of writing: KF3, KF3/Tele.

the secondary axis. The measurements will be merged by the software into one single measurement.

- **Outwards to centre** splits the line scan sequence into two parts. In the first half, line scan measurements are performed from the smallest co-ordinate to the centre of the secondary axis. In the second half, line scans are performed from the largest to the centre co-ordinate of the secondary axis. The measurements will be merged by the software into one single measurement.

4.6. Data recording

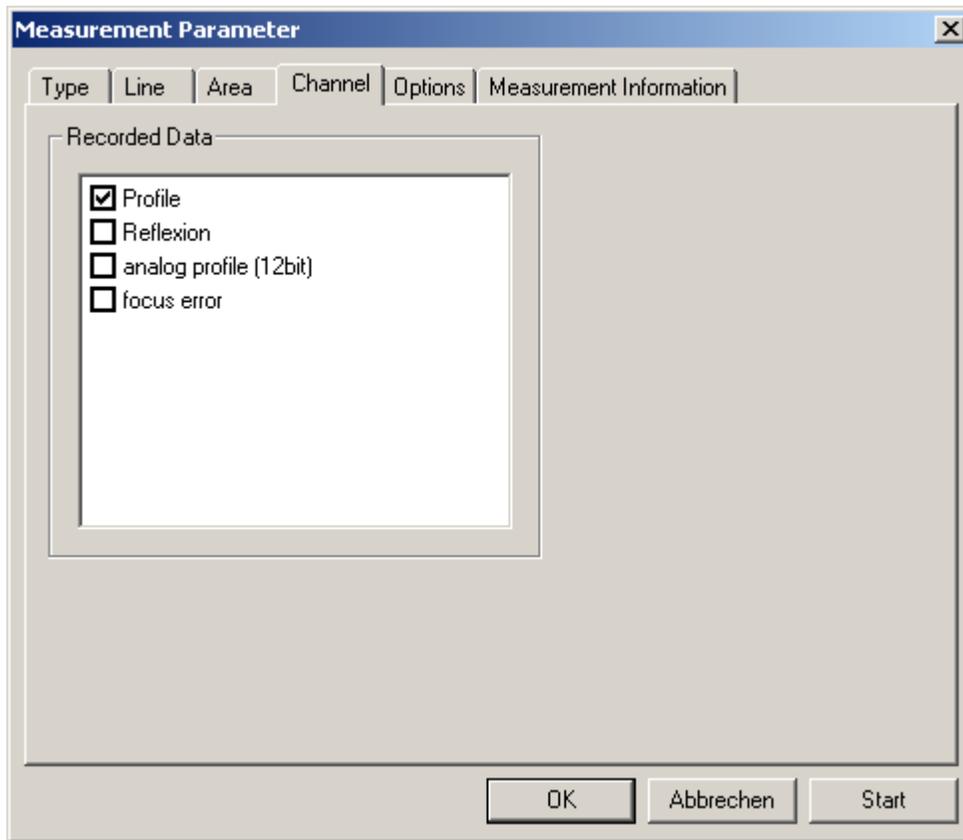


Figure 10: Sensor channel selection

This property page is provided for the configuration of the sensor channels recorded. The *Recorded Data* list box shows all data channels available for the sensor¹². Selected data sources are indicated by a check mark. Depending on the sensor, one or more channels can be selected simultaneously. The channel configuration is applicable to all types of measurement simultaneously.

Notes:

- The most important sensor channel is listed on top of the list. For all sensors presently available, this is the profile channel which bears the profile (height, topography) information.
- For optical sensors, the reflection channel should be acquired too. This channel shows the intensity ('brightness') of the reflected light, the information is frequently used to determine changes of the structure (e.g. edges or texture) or to determine regions of invalid data.

¹² In case of a multi-sensor configuration: the currently selected sensor.

4.7. Options

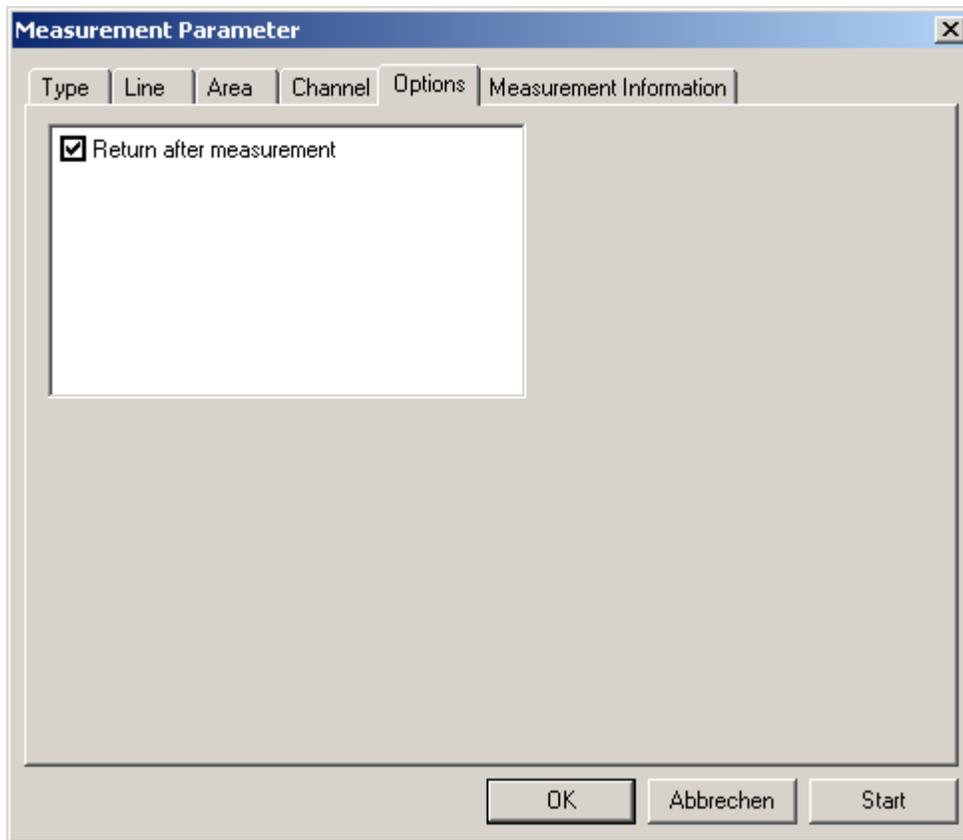


Figure 11: Measurement Options Dialogue

Configuration options which do not fit well within the previous categories have been collected on this property page. At present, only one option is available:

Return after measurement.

Activating this option requests the stages to return to the position present at the start of measurement once the measurement is finished. A new measurement (e.g. with higher resolution or larger measurement range) can be started without re-positioning.

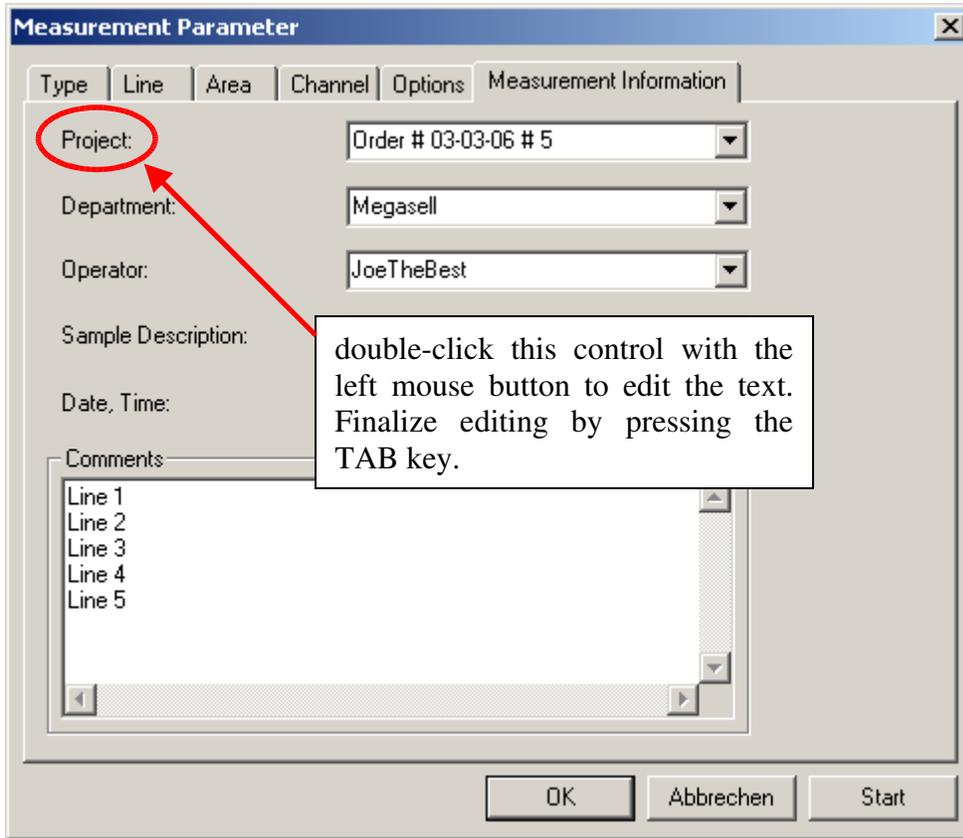
This option is helpful for manual measurements. For automated measurements this option is usually unnecessary or undesirable.

4.8. Measurement protocol

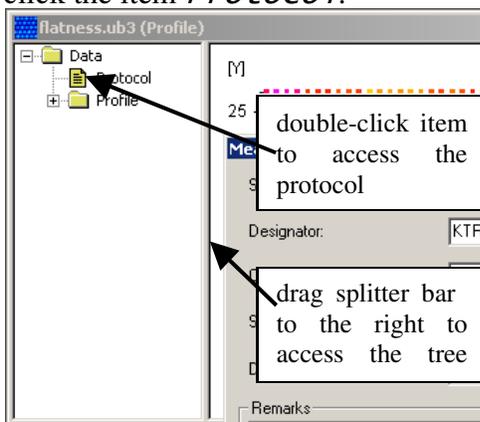
Information about the sample can be attached to each measurement. The protocol is located within the tab Measurement Information of the measurement parameter dialogue. Enter the information required into the edit fields of the form.

To edit the prompts (e.g. Project or Customer) double-click the gray string with the left mouse button. Now you can edit the prompt string. Finalise the operation using the TAB key. The modified prompt will be preserved for future invocations of the tab. Prompt strings and user inputs are arbitrary strings, and have no dedicated interpretation per se to Inspector.

The prompt and text strings are limited to 80 characters, with exception of the Comments field (2000 characters max)¹³. The protocol of a measurement is available either in the tree view section of the views, and also during HTML output.



Note: The protocol settings within the measurement parameter dialogue will be used for the *next* measurement. To check or edit the protocol of an *already present* measurement file, open the tree view of the file by dragging the interior splitter bar to the right, open the node *Data*, and double-click the item *Protocol*.



¹³ Saving the protocol, Inspector uses the native protocol field of the file format used. Usually, additional constraints of the file format apply.

5. Survey: Processing and display of measurement data

This section is a quick walk-through of the menu items available from the main menu or context menu of a measurement data window. Later chapters will enhance description of the software's features.

5.1. Menu item File

5.1.1. Open

Imports previously saved measurement files.

5.1.2. Save as...

Measurement data can be saved in various file formats.

5.1.3. Export data

This function exports a diagram, either by saving a bitmap (*.bmp) or meta file (*.emf) file, or via clipboard copy & paste. In either case, the diagrams can be imported into most presentation programs.

5.1.4. Print

Generates a hard copy of the active diagram. Different hard copy styles are available. In the most basic mode *Print this View...*, just the active diagram gets printed. Templated styles generate an intermediate HTML page showing a user-defined set of diagrams, or generate a pre-defined page layout from the data. The HTML output gets handled to the system's default browser for further processing. Some predefined HTML print templates are part of the Installation. It is also possible to process user-defined templates.

Note: The HTML Print intermediates can also be used for archival storage of measurement results. The page can be saved with the appropriate functions of the browser (usually File/Save As...).

5.1.5. Print Preview

The menu item Print Preview provides for a preview of the basic print mode *Print this View*. The templated styles generate HTML intermediate files in place of a printer output, so preview has to be performed from within the browser.

5.1.6. Printer Settings

Menu item Printer settings allows for the selection and configuration of the printer used by function *Print this View*. Using the templated styles, configuration has to be done from within the HTML browser.

5.1.7. Exit

This function will terminate Inspector.

5.2. Menu item "Process"

Note: This menu item is only available once there is something to process. Therefore, at least one measurement result must be opened. Opening a measurement result may be done by selecting the standard File/Open menu item, or by drag & drop of a measurement result into Inspectors frame window.

5.2.1.Export

The actual graphic can be copied via the menu item *Export, copy to clipboard*. From the clipboard the graphic can be used in many other applications (e.g. WORD). Usually the graphic can be copied to other programs via *Edit/Paste*. The graphic can also be saved via *Export, Save as graphic* in bmp or emf format. These files can be read by most text and picture processing software.

5.2.2.Levelling

The levelling operation removes the tilt of a line diagram, or surface. Usually after measurement, the profile is tilted due to geometrical reasons. The starting point on the surface is above or below the end point so that the profile or plane is inclined. Most of the fine structure of the profile is drowned by the tilt. Levelling removes the tilt by subtracting a regression surface or profile. Technically, levelling is a shear operation, not a rotation. Any points classified invalid by Inspector are excluded from the calculation of the regression surfaces.

5.2.2.1....by linear regression

Levelling by linear regression is used to align a profile. A straight line is fitted to all of the profile. Next, this line is subtracted point by point from the profile data, removing the overall inclination. This process minimises the sum of the squared profile values.

Note: This operation performs levelling by subtraction, not by rotation. The mean profile values are changed too, after levelling, the arithmetic sum of all profile values is zero ('centred around zero').

5.2.2.2....by operators selection

This procedure allows a levelling of the profile by segments, defined by the operator. Only surface or profile sections assigned by the operator are used to evaluate the regression surface or profile.

5.2.2.3....form removal

To suppress surface warpage, a non-linear function is fitted to portions of the profile or surface. selectable by the operator. The parameters of the function are calculated to minimise the sum of the squared difference of the profile and the function's values, resulting in a 'best fit' in the sense of the E2 norm. The fitted model function can either be subtracted point-by-point from the profile, removing warpage, or the function may be exported for further processing.

5.2.3. Mirroring

This operator is provided to swap ('mirror') profile values along any of the axes of the co-ordinate system. The transformations may be applied simultaneously.

<i>operation</i>	<i>description</i>	<i>formula</i>
Mirror horizontally	exchanges the profile values left to right	$g(x,y) = f(x_{\max}-x,y)$
Mirror vertically	exchanges the profile values top to bottom (surface only)	$g(x,y) = f(x,y_{\max}-y)$
Mirror profile	inverts the profile values	$g(x,y) = -f(x,y)$

In the section above, function f indicates source data, and g indicates destination data.

For more details please refer to chapter "Processing of line- and area data".

5.2.4. Matrix filters and types of filters

A matrix filter is used to reduce noise, improve image quality, or enhances certain surface details. Matrix filters comprise some quite general class of image processing functions. For each element of the destination profile (or surface), a function is applied to a small segment (or surface patch) of the source profile (or surface). From a bird's eye view, the result profile is pixel by pixel a function of a small vicinity of the source profile. Familiar functions are for example smoothing, edge enhancement or outlier removal.

The operator *Matrix filter* presents a selection of filters, which can be applied to the surface. The description following is just a superficial survey, for a more detailed description consult section "Processing of line- and area data".

5.2.4.1. Arithmetical mean value

The central point will be replaced by the arithmetical mean of the adjacent points. This filter type is used to smooth the surface, micro-roughness will be eliminated. The width of the filter can be selected in the field *Filter kernel size*.

5.2.4.2. Median

The median filter arranges the values of the central and adjacent points in ascending order and replaces the central point by the value of the point in the middle of the list. This filter is of special interest for filtering noisy measurements and outlier rejection, while preserving the structure of the surface. The filter width can be selected in the control *filter kernel size*.

5.2.4.3. Minimum

This operator replaces the central value by the minimum of the adjacent points. The filter width can be configured in the control *filter kernel size*.

5.2.4.4. Maximum

This operator replaces the central value by the maximum of the adjacent points. The filter width can be configured in the control *filter kernel size*.

5.2.4.5. Gaussian filter

The gaussian filter is similar to the arithmetical mean value filter, but gives more priority to the centre point in comparison to the adjacent points. The surface will be smoothed by this filter, much like the arithmetic mean filter. However, the gaussian filter is optimum regarding minimum stop band attenuation versus width of influence. The filter width can be set in the field *filter kernel size*.

Note: The gaussian filter is implemented as an IIR filter, not as a matrix filter. It is placed here since it performs a common matrix filter task, and enhances on the results.

5.2.4.6. Laplace

The Laplace filter is a rotationally symmetric smoothed second-order slope filter. It is frequently used to detect structures like valleys, craters and peaks. The filter width can be set in the field *filter kernel size*. Please note that the smoothing operation works best on larger kernel sizes.

5.2.4.7. First derivation

The gradient filter calculates the (smoothed) first derivation of a two dimensional function into a configurable direction. Setting the direction to 90° resp. 0°, yields results similar to the famous Sobel X and Y filters. The width of the filter can be selected from the control *filter kernel size*, the direction can be configured by pressing the >> button. Please note that the smoothing operation works best on larger kernel sizes. If you need a standard Sobel filter, consider using the custom filter.

5.2.4.8. Custom filter

In case the above described filters do not fulfil the requirements a customised kernel can be specified, implementing most arbitrary linear filter operations¹⁴. Specify the filter kernel's coefficients by pressing the >> button. Loading and saving the kernel is possible too on behalf of the Import and Export buttons. Applications of the custom filter include

- anisotropic filtering
- small-area un-normalized correlation (e.g. fiducial lookup)
- calculation of non-zero phase shift filters.
- multiplication of the channel's values with an arbitrary value.

5.2.4.9. Filter kernel size

The drop list Filter kernel size holds standard filter sizes from 3x3 to 15x15 elements. Select the desired size filter size from the control. Please note that processing time of most of the filters increases significantly with the kernel size chosen.

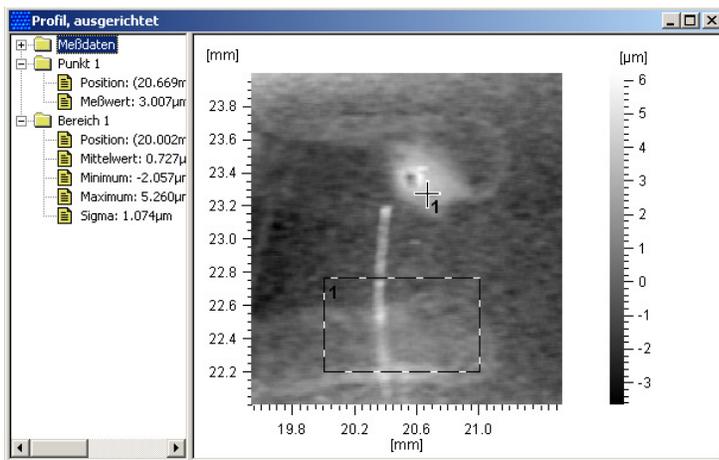
¹⁴ any filter function which can be represented by a (two-) dimensional IIR filter with kernel size up to 31x31.

5.2.4.10.Keep filtered data, keep residual data

These two check boxes select the result data of the dialogue. Checking the keep filtered data box, the filter's result is preserved. Checking the keep residual data check box generates and returns the difference of the input data and the filter's result. Depending on application, the residual, filtered data, or both of the results are valuable. The preview images display the results.

5.2.5.Reading profile values

For line graphic and for false colour projection, there are methods available to read measurement values at a point or within a range. After selection of the menu item *Access values*



.../... at a point or *Access values .../ ... within a region* markers or rectangles can be placed in the window by means of the left mouse key. If *access values at a point* is selected, the left mouse button creates a marker, while *access values within a region* starts the selection of a rectangular area until the button is released. The co-ordinates as well as statistical data will be shown in a dialogue and in the information pane of the window (usually hidden at the left border; to uncover the divider must

be dragged sufficiently far to the right).

5.3. Menu item View

5.3.1.Data channel

Here the channel for the display can be selected, e.g. *Reflection* or *Profile* presumed the channel was activated for the measurement. For more detailed description please refer to chapter "Processing of line- and area data".

5.3.2.Palette

Selection of false colours and structures for the display of heights.

5.3.3.Normalisation

This kind of scaling is also known as "isotropic scaling". If there is a check mark to the left of the item, indicating normalisation, the measurement axes are displayed true to scale. otherwise the diagram fills up the imaging area¹⁵.

5.3.4.Show scales

This menu item enables or disables display of the axes' legends.

¹⁵ in case of 3d images, the horizontal axes are drawn with a relative length of 100%, and the vertical axis will be drawn with a relative length of 30%. This selection usually leads to more comprehensible results.

5.3.5. Scaling

Menu item Scaling provides for manual scaling of the vertical axis. The upper and lower display limits can be interactively configured, or minimum-to-maximum scaling can be requested within the dialogue.

5.3.6. Isometric view

Menu item Isometric View creates a "3d landscape" image of the active measurement data¹⁶. Once the isometric view gets active, some additional display options get available:

5.3.6.1. Rotation Angle/ n°

The popup menu items select rotation of the profile around the vertical axis to n° counter-clockwise. 0° means no rotation at all.

5.3.6.2. Tilt angle

The popup menu items select the rotation of the profile around the horizontal axis to n° . 0° selects a view perpendicular to the profile.

5.3.6.3. Palette Colour Coded, Photo 1, Photo2

A palette is a pattern to map profile values to different colours. Inspector provides for three different colouring strategies. Each strategy utilises different colouring layouts and may implement lighting effects.

- Palette pattern *Colour Coded* maps any individual profile value to a colour of the palette, independently of the adjacent profile values. Therefore, any two profile values of the same value receive the same colour. For the standard palettes, the reverse relation also holds: Pixels of the same colour have the same profile value¹⁷. The lower display limit receives the first colour entry of the palette, the upper display limit the last colour entry.
- Palette *Photo 1* is used to simulate lighting effects, like specular highlights, diffuse reflection and ambient illumination. The palette pattern maps any profile value to a colour much like *Colour Coded*, but the brightness also depends on the slope of the surface path containing both the data point of interest and its close surroundings. Therefore, any two profile values of the same value receive the same colour, but may differ significantly in brightness.
- Palette *Photo 2* also simulates lighting, but maps any profile value to the very same colour. The final brightness only depends on the slope of the surface path containing both the data point of interest and its close surroundings. The visual impression just depends on the local structure (elevations and depressions).

Note: Either *Photo 1* or *Photo 2* palette must be selected to be able to access the light source position dialogue.

5.3.6.4. Position of light source

Having selected one of the photo palettes, the position of a virtual light source can be configured. The virtual light source enhances the structure of the surface (elevations and depressions) depending on the situation of the surface patches relative to the light source.

¹⁶ or brings a currently displayed 3d diagram of the data to the front. If you want more than one 3d image of the same data, please select *Windows/New Window* from the main menu.

¹⁷ within the limits of quantisation.

5.3.7.2D Profile

Menu item *2D Profile* creates a new line diagram window from surface data, or looks up such a window and brings it to the front. Upon creation, the diagram will show the bottom most line. Arbitrary lines can be selected from the *Line Selection* dialogue, see the section below.

Note: Usually, only one line diagram window of each individual measurement data channel will be available. If you want to create another line diagram window, activate the line diagram window, and select Windows/New window from the menu.

5.3.7.1.Line Number

This menu item is provided to select a profile from a surface data set, either line by line, column by column, or an arbitrary line section. Please refer to chapter "Operations on line data" for details.

6. Operations on Line Data

6.1. Abstract

Line data represent a one-dimensional function of location or time. Line data can also result from a section of an area *measurement*. A line diagram is frequently used to assess properties like slope, step height, cross-section area, or statistical properties like roughness parameters.

6.2. Importing of line data

Line data can be imported by using menu item *File/Open* from the main menu or by Drag&Drop from an Explorer window.

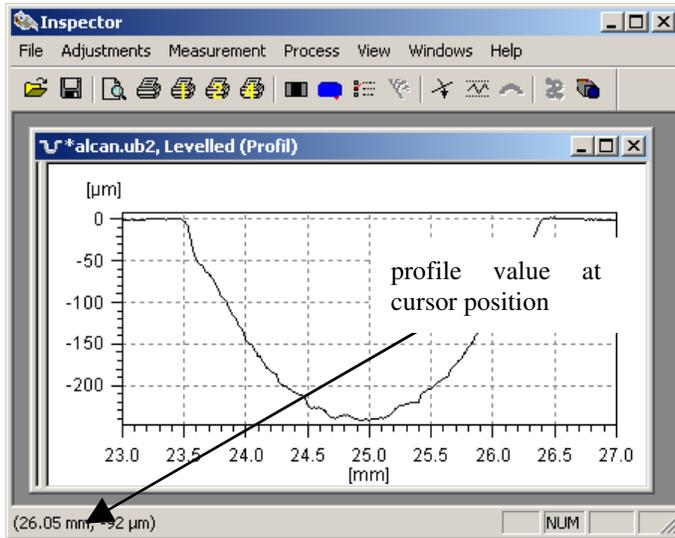
6.3. Saving of Line data

In order to save the data, menu item *File/Save* or *File/Save as...* shall be used.

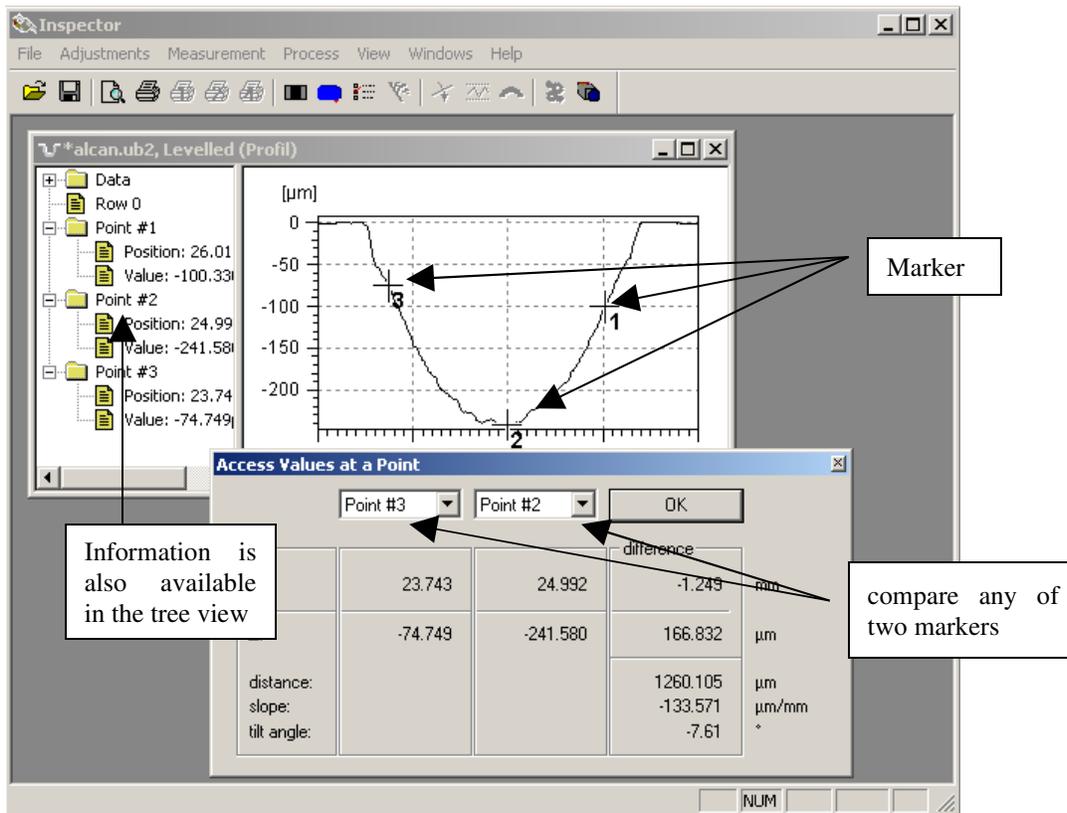
Note: In case the active view displays a line extracted from an area measurement, only line data is saved. To save the area data, activate any area data view (select e.g. *Colour Area View* from the popup menu, or *View/Colour Area View* from the main window), and use the *File/Save* menu item of the area view.

6.4. Display of Line data

The measurement at the mouse cursor's position is displayed in the status line of Inspector.



More detailed information can be obtained using the menu item *Access Values*. Selecting the menu item, the program is waiting for a left mouse button click within the diagram area. Once the button is pressed, a position marker is created and the co-ordinates of the profile will be shown in the Access Values dialogue.



Dialogue Access Values provides for information and comparison of any pair of position markers. Select the markers to be compared from the drop down boxes. The column "difference" shows the difference between the first and the second marker in lateral and vertical direction. The

distance value is the length of the hypotenuse connecting both points, *slope* is the ratio of the vertical (profile value) difference to the horizontal displacement. *Tilt angle* is the angle of the line connecting both points, which is the arcus tangens of slope. *Distance* and *tilt angle* are available only if the X and Z units are compatible.

If you want to place another marker, just press the button "Next Point". Otherwise, the dialogue will be automatically dismissed as soon as the dialogue window gets inactive (or press the close button of upper right corner of the dialogue).

Note: The dialogue can also be accessed later by clicking the Point #<n> nodes of the tree view twice with the left mouse button.

Information from an segment of the measurement can be requested using menu item **Process/Access Values.../...within a region**. The starting point of the region of interest is selected by pressing the left mouse key within the profile diagram. Keep the left button pressed, and drag the mouse to the end of the segment. Release the left mouse button. The result will be displayed in the dialogue Access Values within a Region. *X1* and *Y1* indicate the start and the end of the segment; *average* is the arithmetical mean value within the segment; *minimum* (*maximum*) show the minimum (maximum) measurement value and *std. dev.* indicates the standard deviation of the measurement values.

Once again, the column *difference* show the differences of the respective values of the two zones, *distance* is the length of the line connecting the two centre points of the regions (i.e. $(X1+X2)/2$ and the avg value); *slope* is the ratio of the difference of the average values and the zone's horizontal centre point, and *tilt angle* is the angle between x-axis and line connecting the zone's centre points (which is identical to the arcus tangens of slope). Distance and tilt angle are only available for compatible X and Z units of the diagram.

6.5. Data export

Line data can be saved in various data formats, including some plain-text ASCII-format. The actual graph bitmap can be saved to the clipboard via **Process/Export/Copy to Clipboard**. The clipboard data exchange may be used to import the diagram into many other programs.

Furthermore, the bitmap may be saved using the menu item **File/Export data** to save the diagram either in bitmap (BMP) or meta file (EMF) file format¹⁸.

6.6. Levelling

6.6.1. Abstract

Raw measurement results frequently suffer from surface tilt, e.g. the first point of the profile is well below the end point, so that the profile is inclined. Hence, it is possible, that the macroscopic elements (here: inclination) cover the microscopic structures of interest. To correct for this effect, the measurement data can be corrected before the evaluation.

The easiest way to remove the surface inclination consists of calculation of a best fit straight line over all data points. In advanced situations, it is necessary to calculate the fit by nonlinear functions or to control the set of controlling points.

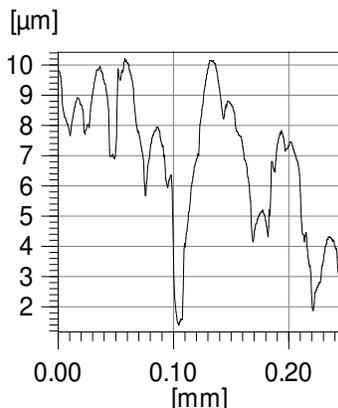
¹⁸ The line diagram and legend are exported in vector and native format. Vector formats can be resized without undue loss of quality.

The following sections describe applications and limitations of the various procedures. All levelling procedures subtract the fitted function from the profile. This is different to a rotation.

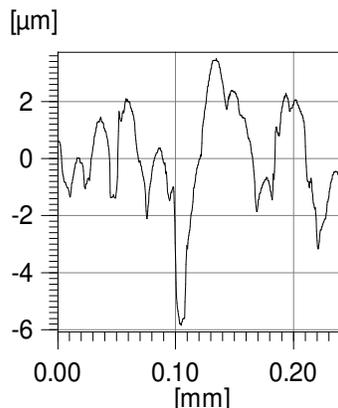
6.6.2. Levelling by linear regression

Levelling by regression is used to align the whole profile altogether. A straight line is fitted to all¹⁹ of the profile. Next, this line is subtracted point by point from the profile data, removing the overall inclination. This process minimises the sum of the squared profile values. Consequently, the average value of the whole profile is zero.

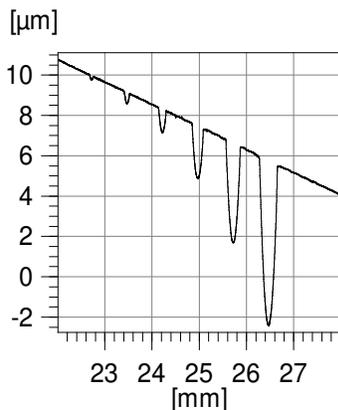
Linear over-all regression works best on random or periodic profiles. In situations like the one shown in the second example, move on to levelling by operator's selection.



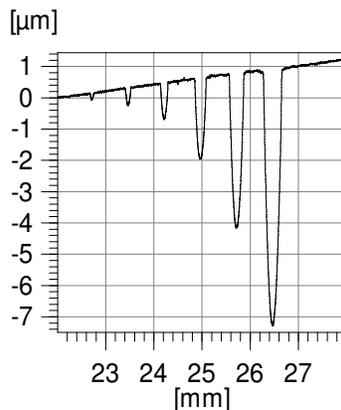
Before Levelling



After Levelling



Before Levelling



After Levelling

Due to the grooves, the profile remains tilted. See the next section for a solution

Notes:

- This operation performs levelling by subtraction, not by rotation.

¹⁹ valid points of the profile. Invalid points (these are not shown in the line diagram) are discarded. Regions can be validated and invalidated either automatically or interactively.

- If the best fit straight line is required instead of the levelled profile, please use *Levelling/... form removal*.

6.6.3. Levelling by operator's selection

This operator calculates the best fit straight line which minimises the sum of the squared deviations from the profile to the line within selected regions of interest only. In mathematical sense, the equation $\sum_{x_i, y_i \in ROI} (mx_i + b - y_i)^2 = \min$ is solved for m and b to minimise the sum. This is a two parameter linear model, and solved by standard mathematical procedures. Afterwards, the straight line is subtracted from the profile values, yielding the result. This type of levelling is different from the previously introduced operator by the selection of the regions of interest.

Once the operator is activated via *Process/Levelling/by operator's selection*, the dialogue below will be created:

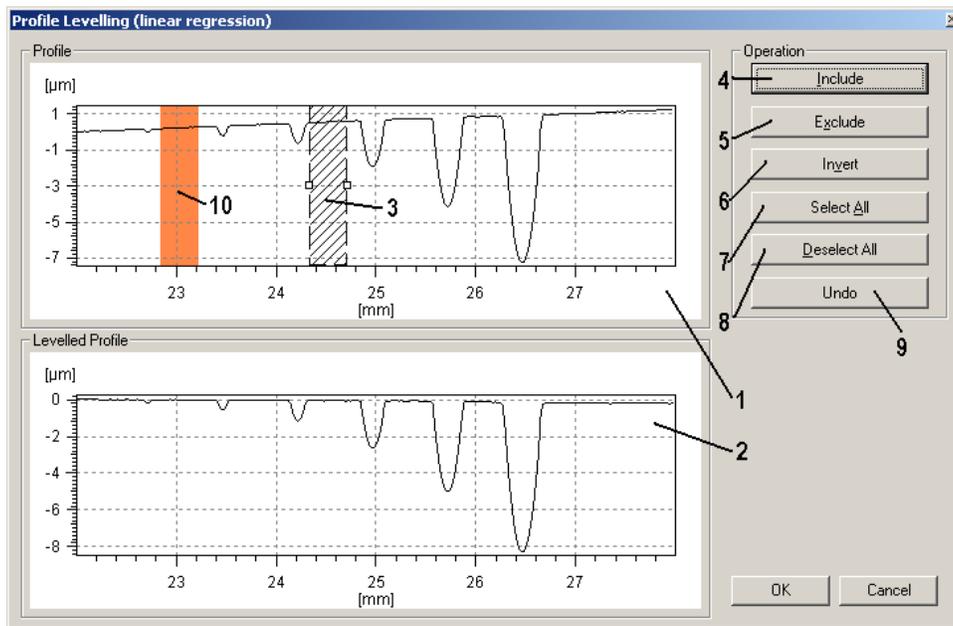


Figure 12: Levelling by operator's selection dialogue

The upper left pane (1) of the dialogue shows the profile, the lower left pane (2) shows the result of the regression.

The selection window (3) can be shifted or sized using the mouse. Once the window placed at the desired position, the section can be included into the regression by clicking the *Include* button (4). The section (10) gets marked by orange background colour, and the values are taken into consideration for the calculation. In the beginning, the selection ranges are empty.

In some cases it is useful to exclude profile segments from the analysis. This is done by selecting the range to be excluded and pressing the *Exclude* (5) button.

Invert (6) exchanges the roles of included and excluded ranges (i.e. any data point which was excluded gets included and vice-versa), *Select all* (7) includes all data and *Deselect all* (8) deletes all data from the selection.

The general procedure shall be explained by means of an example: The profile of a groove standard suffers from surface tilt. Trying to remove the tilt using overall linear regression (**Levelling/linear regression**) results in failure. It is necessary to exclude the arc segments from the calculation of the best fit straight line. Depending on the situation, valid regions can be included or invalid regions can be excluded. In this case the second procedure is easier to accomplish:

Procedure:

- 1) Click on the window with the line graph to make it active.
- 2) select **Process/Levelling/ by operator's selection** to open the dialogue **Profile Levelling**
- 3) By selecting the button **Select All** (7), all points of the profile get included to calculate the regression.
- 4) Place the selection window right above the first groove and set the width a bit larger than the groove. Discard the region from the regression by clicking **Exclude** (5). Repeat this procedure, until all arc segments are excluded. Every time a region is added to or removed from the selection, the result preview is updated.
- 5) As soon as all valid/invalid regions are marked, the regression result shall be accepted by pressing **OK**.

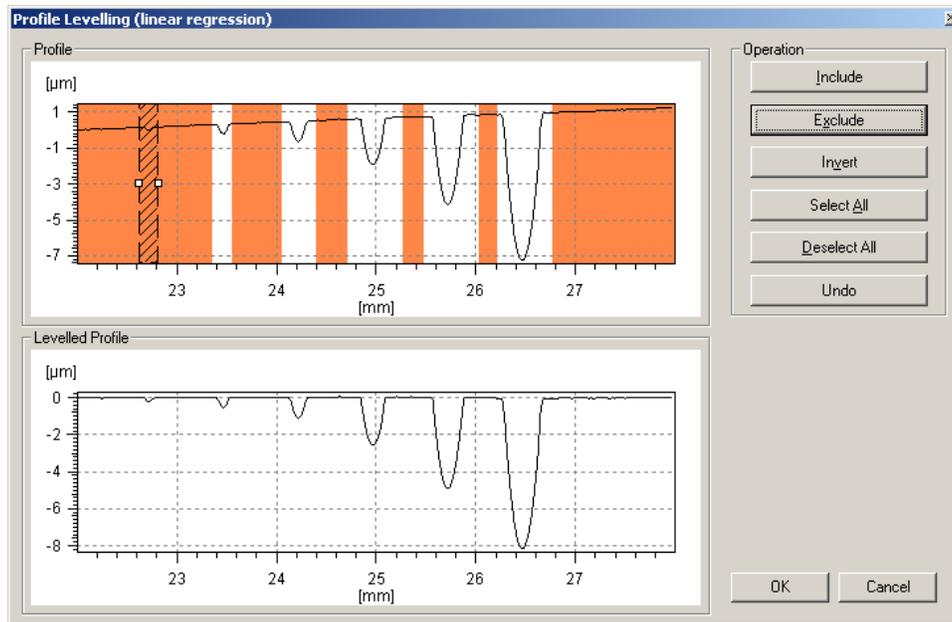


Figure 13: Selection procedure before excluding the last region

Hint: Each measurement point is used at most once for the calculation of the regression line, even if the ranges are overlapping. Repeated inclusion does not increase the weight of a segment. Measurement points classified invalid (either automatically or manually, see *Masking Operations*) are always disregarded.

6.6.4. Levelling by form removal

In some cases it is necessary to fit an analytical function to the profile and to subtract the function from the graph. Typical examples include vaulted structures or low frequency straightness devi-

ation of samples like paper, thin film, plastics. Here a subtraction of a straight line is not sufficient.

After selecting **Process/Levelling/Form removal** from the main menu, the dialogue **Levelling a Profile (polynomial)** gets created, similar to the one described above. Additionally, the dialogue hosts the controls **Levelling Strategy** and check boxes for the desired results.

Available regression functions are:

Constant (Zero order).

By choosing this function, the graph will be shifted along the Y-axis, until the sum of the squares of the resulting profile values becomes minimal. The slope of the diagram does not change, it is just shifted vertically towards zero, such that the arithmetical mean value of the whole profile after levelling is zero.

Line (First order):

The software fits a line to the profile, which minimises the sum of the squared deviations from the profile to the line. This is the very same operation than described above.

Parabola (Second order):

The software calculates the parameters a_i of the model $y = f(x) = a_0 + a_1 * x + a_2 * x^2$, such as the sum of the squared deviations from the parabola to the profile is minimised within the regions of interest.

Polynomial (n):

The software calculates the coefficients of the function $y = f(x) = \sum_{i=0}^n a_i * x^i$, such as the sum of the squared deviations from the profile to the polynomial is minimised within the regions of interest. Selection of $n = 1$ results in a levelling straight, $n = 2$ results in a parabola.

***Polynomial (n):** (note the '*')

This item at the end of the list can be configured by the operator. After selection, the button '>>' is activated, which opens the dialogue to configure the order of the polynomial. Apart from the editing ability, it is the same as the Polynomial described before.

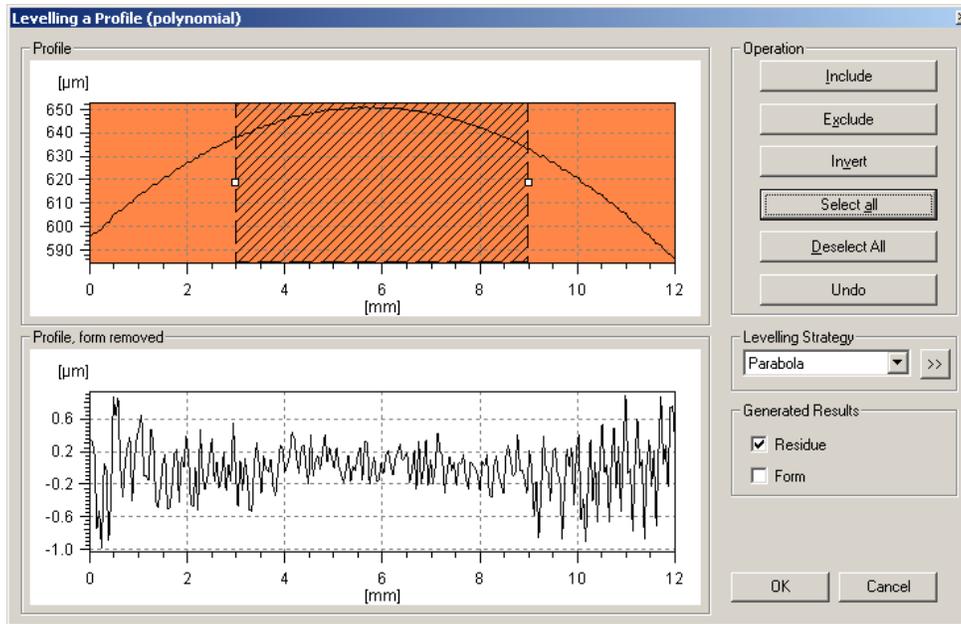


Figure 14: Form removal Dialogue

Before closing the dialogue, select the type of result you are interested in. Checking *Residue* generates the difference of the profile and the fitted function, *FORM* requests the fitted function. After pressing OK, Inspector creates a new view for each of the results requested. Depending on the application one or both profiles will be required.

Notes:

Polynomials exhibit the following typical characteristics:

- Polynomials of lower order exhibit a smooth shape. The number of inflection points depends directly on the order.
- Polynomials are functions without discontinuities in value, slope and curvature.
- For the polynomials of the approximation function only $n+1$ (whereas n means order of the polynomial) parameters (a_i of above formula) are available. Therefore, polynomials are unable to approximate the profile arbitrarily accurate. With increasing polynomial order the approximation becomes better but more waves appear, especially at the periphery. Outside of the selection range, large deviations regarding from the profile will occur.
- Each measurement point is used at most once for the calculation of the regression, even if the ranges are overlapping. Repeated inclusion does not increase the weight of a segment.
- Measurement points classified invalid (either automatically or manually, see *Masking Operations*) are always disregarded.

6.6.5.Z Axis Translation

The z axis translation operator subtracts an arbitrary offset from each measurement point. The operation is useful either to centre the profile around zero (in this context, it is the same operation as Levelling/Form removal/Zero order applied to the entire profile) or to combine multiple ('layered') measurements using reference markers and/or knowledge of the offset.

During dialogue box creation, the edit box reference level is preset to the arithmetic mean value of the profile.



After pressing the OK button, the value entered into the reference level edit box is subtracted point by point from the profile. This strategy applies both to line and surface profiles. If you want to offset a profile by a given value (e.g. to extract absolute height differences from independent measurements), the negative value of the desired offset has to be entered.

This operator generates a new profile, the source data will not be modified.

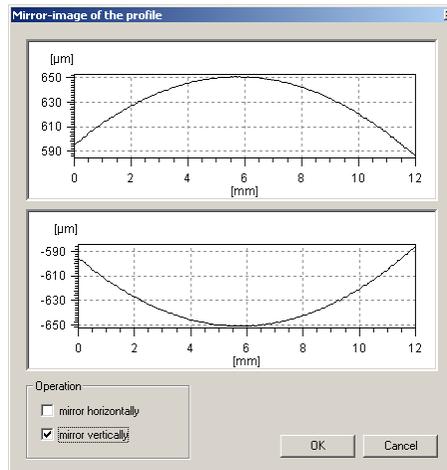
6.7. Reflection of Line data

6.7.1. Abstract

For evaluation purposes, it is sometimes helpful to reflect the profile in horizontal or vertical direction, e.g. for the reconstruction of impressions (skin, roller surface).

6.7.2. Mirroring of line data

The following dialogue available from the main menu *Process/Mirror* is used for reflecting line data:



Profile data may be reflected along the two major axes:

- 1) Horizontal mirroring (along the horizontal axis), swap the profile left to right
- 2) Vertical mirroring (along the vertical axis), invert the profile value.

Applying horizontal reflection, the data points at the end and at the beginning of the measurement line are exchanged. The co-ordinates of the primary axes are swapped too. Vertical reflection multiplies the profile values with a factor of -1.0.

6.8. Filtering of line data

6.8.1. Abstract

Processing of line data sometimes requires modification of each data point by a function of its adjacent points. An example is a smoothing filter, where a data point is replaced by some (weighted) sum of all adjacent points. Other applications are edge extractions or non-linear data manipulation (median filter, erosion filter, dilatation filter). Filters of these type are called matrix filters due to their origins in image processing.

6.8.2. Filtering of Line data

After selection of the menu item *Process/Matrix Filter* from the main menu, Inspector creates the dialogue shown below:

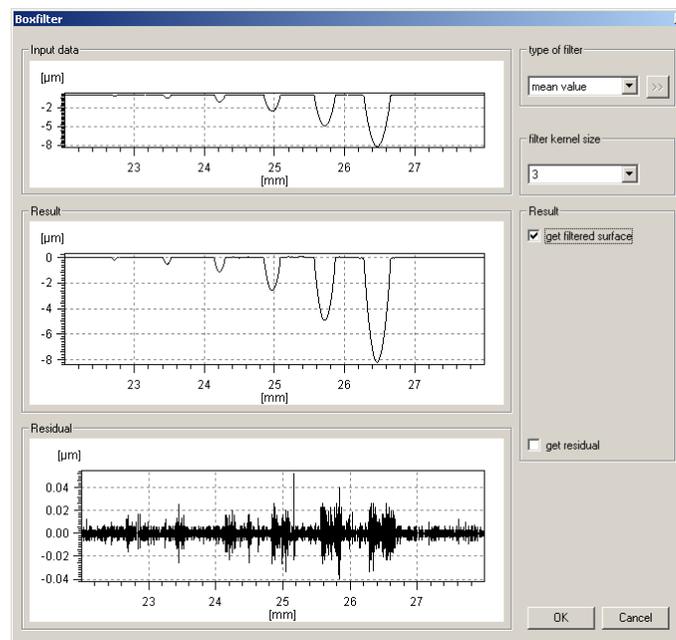


Figure 15: Matrix Filter Dialogue

The type of the filter shall be selected from the drop list *type of filter*, the required filter width (number of adjacent points considered for filtering) from the control *filter kernel size*.

The graph on top shows the original data, the graph in the middle shows the data after filtering and the lower graph shows the point-by-point difference (residue) from original profile and the filtered profile.

The matrix filters process the profile data point by point according to the following algorithm (n indicates the filter width):

- 1) Determine the points adjacent to the measurement point, i.e. take $(n-1)/2$ data points left of the measurement point, the data point and $(n-1)/2$ data points right of the measurement point. For $n=3$ it means the point to the left, the central point and the point to the right.
- 2) Apply a function to these n points.
- 3) Replace the central data point by value of the function. This result is saved externally.
- 4) When all points have been processed, copy the externally saved points back to the Result.

6.8.2.1.Types of filter

This section illustrates the available types of filters and shows some example for reasonable application. The filters are often used for image processing, the names used by the software are drawn from this terminology.

6.8.2.1.1.Filter ,Mean Value'

Here a profile value will be replaced by the mean value of its adjacent points. This filter is best suited to reduce white noise from the raw data. The image above shows the effect: in the filtered profile (middle), the noise is reduced, while the noise is present in the residue image (bottom). Applying this filter, please consider the broadening effect on edges. Furthermore, this filter produces values, which are not present in the raw data (e.g. $n=3$, $y = \frac{1+1.3+1}{3} = 1.1$). The filter is less suited to eliminate periodical signals (e.g. high-frequency sinusoidal signals) due to its poor sideband suppression. In cases like this, the Gaussian filter should be preferred.

6.8.2.1.2.Filter ,Median'

If a set of data is sorted in ascending (or descending) order, the median is the value in the middle of the list. That means, there are as many values larger than the median value, as there are smaller values.

The median filter is very effective to remove single outliers, without much influence on other values. In comparison to the arithmetical mean value filter, there is much less influence (smearing) on edges. With increasing size, the median filter leads to a characteristic structure, repeating the same value. The example shows (bottom graphics), that the median filter works preferably on the horizontal sections, reducing noise.

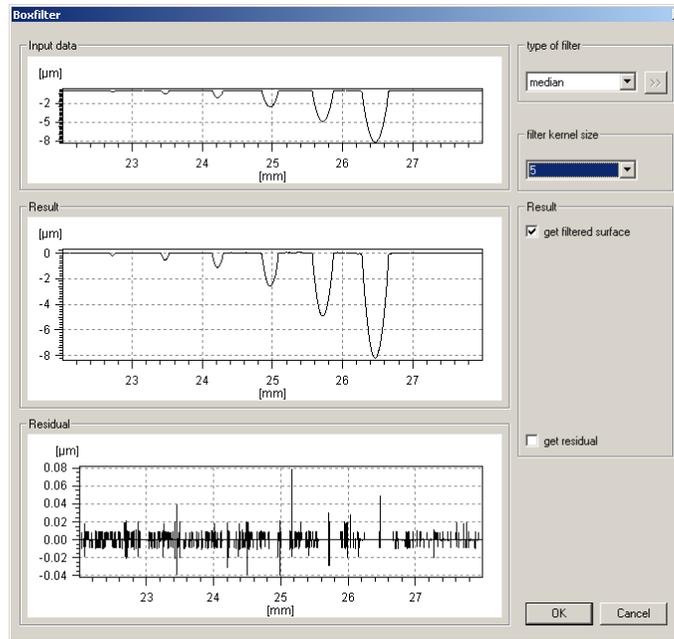


Figure 16: Selective noise suppression of the median filter

6.8.2.1.3. Filter 'Minimum' (or Erosion Filter)

The minimum filter replaces the central data point by the minimum of the centre and the adjacent points. This can be useful e.g. around a hole. The edges of the hole are too steep for acquisition, resulting in data losses. A suitable application of the minimum filter eliminates these points and results in a profile without artifacts around the edges.

6.8.2.1.4. Filter 'Maximum' (or Dilatation Filter)

The maximum filter replaces the central data point by the maximum of the centre and the adjacent points. This characteristic can be used on thin layers, where a sensor usually focuses to the upper layer, but sometimes on the substrate too. The maximum filter eliminates the objectionable points if they appear sporadically.

6.8.2.1.5. Filter 'Gaussian'

The gaussian filter calculates a weighted sum of the central and adjacent points, much like the arithmetical mean value. The central points has the largest weight, slowly decaying towards the periphery. The Gaussian filter is best regarding the compromise of cut-off frequency (frequency domain) and lateral width (spatial domain). This means, that high frequencies are well suppressed by the filter, without spreading structural elements (e.g. edges) too much. Regarding noise suppression it is almost identical to the mean value filter, without the ripple sometimes observed by the mean filter.

The Gaussian filter creates data points which are not included in the raw data. Usually, the filter leads to nice smooth graphs.

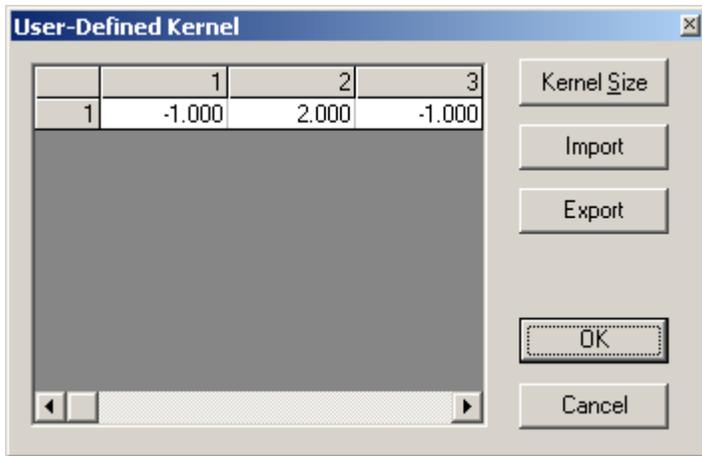
6.8.2.1.6. Filter ,First Derivative‘

This filter calculates the difference quotient of first order $\partial = \frac{y_{-m} - y_m}{x_{-m} - x_m}$, this is the discrete form of the derivative. The slope is given in units of (Z-axis unit)/(X-axis unit), e.g. $\mu\text{m}/\text{mm}$. For the conversion to degrees, the arcus tangens must be used.

6.8.2.1.7. Custom Filter

If none of the filters mentioned above satisfies your needs, you can define your own filter. Most linear filters can be expressed as the convolution of a matrix (called filter kernel) with the surface data. The filter coefficients can either be taken from a table, or derived numerically. In any case, applying the custom filter requires some knowledge of filter theory.

The filter will be activated and the value can be set by selecting **Custom Filter/>>>**. The following input dialogue appears:



First the size of the kernel should be configured. It must be a value between 1 and 32, odd numbers are preferred. Thereafter, the values of the matrix can be set, by clicking to a field and typing a number into the cell. The kernel can also be exported or imported.

Please note, that the kernel will be reflected left-right during convolution, due to mathematics.

The kernel can also be loaded from or saved to a file. The file format is indicated below:

C_0 C_1 C_2 ... C_{n-1} <newline>

The coefficients C_i must be convertible to floating point numbers (format: [+/-] digit* [. digit* [e [+/-] digit+]]). Empty lines are discarded, the same applies to lines starting with a hash (#). Each line must consist of the same number of columns as the first one, the number of non-comment lines corresponds with the kernel height (this must be 1 for a line profile filter).

6.9. Roughness parameter

Inspector provides for the calculation of profile, roughness and waviness parameters according to various standards. Although roughness parameters are standardised *only* on line diagram data, it is common practise to extrapolate the definitions to surface data. Therefore, the parameters have

been move to a dedicated chapter. Please consult chapter 8 for definition and interpretation of the individual parameters.

6.10.FFT

Fourier (or frequency) domain represents another way to look at data. While the usual spatial domain deals with properties like slope, length and profile, the frequency domain deals with periodic properties like amplitude, frequency and phase. There is a lot of theory regarding the relation of spatial and frequency domain, it should suffice to assume that there is a transformation between the two. Both domains bear essentially the same information, but with different representations. Fourier transform is defined on both line- and area data²⁰. See chapter 9 for details and applications.

6.11.Masking Operators

6.11.1.Abstract

Real-word data is frequently only partially defined, either from physical²¹ or sensor related²² constraints. In situations like this it is helpful gathering additional information apart from the profile. For optical sensors, the reflection signal is frequently used for qualification and automatic classification of such areas.

In addition to each sensor data channel, Inspector provides for a good-bad discrimination for each individual data element. Either automatic or manual discrimination is available. Automatic discrimination is based on the reflection channel. Therefore, for optical sensors it is a well-advised to acquire the reflection channel in addition to the primary profile.

6.11.2.Masking operation based on reflectivity (reflection threshold)

Selecting *Process/Masking operators/Reflection threshold* from the main menu, the *Select Reflection Threshold* dialogue will be created:

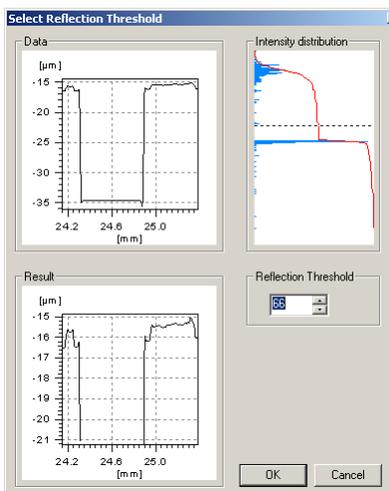


Figure 17: Select Reflection Threshold Dialogue

²⁰ in fact, on any integer dimension.

²¹ e.g. a hole passing entirely through a sample

²² e.g. due to limited measurement range, or surface related effects like transparency, surface slope, or reflectivity.

The graph on the upper left side shows the raw profile, the graph below the masked profile, after disabling all points whose reflection value is below the threshold. The intensity distribution graph on the upper right shows the amplitude distribution (blue) and the cumulative probability distribution (red) of the reflection values.

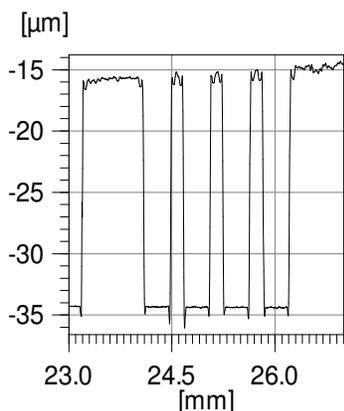
In the example above, a segment of a shear blade of a razor is visible. In the middle of the profile there is a hole and the connecting surface of the sample fixture shows through. To mask this region, the reflection threshold can be increased until the connecting surface is suppressed. The transition in the example is at the peak of the amplitude distribution, somewhat higher than 62 % reflection.

Move the threshold up or down either by entering the desired threshold into the edit box Reflection Threshold, or operating the spin button control to the right of the edit box. Masking is a non-destructive operation (i.e. it can easily be undone), so you may try different threshold values to get best results.

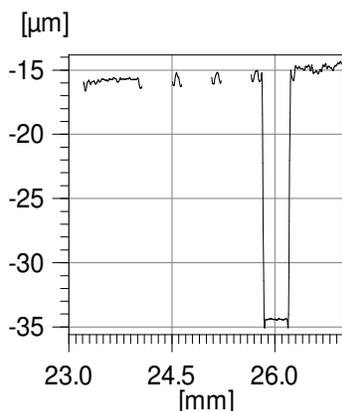
Note: The mask will be loaded and saved in the data formats FRT, SUR, UBx.

6.11.3. Manual masking operation

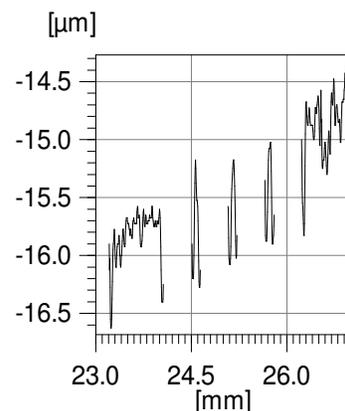
In some situations it is convenient to perform manual masking, e.g. to exclude some segment of data irrelevant to your objective. Select menu item *Process/Masking operators/Exclude Rectangle*, press the left mouse button at the start of the undesired segment, drag the mouse to the left end and release the mouse button. The segment specified gets invalidated and is no longer visible in the diagram. A somewhat contrived example follows:



The razor blade profile. Objective: The connecting structure shall be removed manually.



Most of the connecting structure has been removed.



The final segment has been removed.

The operator *Process/Masking operators/Include Rectangle* validates a segment in the very same way than the exclude operator described above. To undo all masking operations, select *Process/Masking operators/Include all Points*.

Note: Masking effectively removes data points from further consideration. Although a visual result similar to the rightmost image is easily available by selecting the vertical diagram scale limits,

the effect on calculations is very different (e.g. levelling of the rightmost image will align the top line neatly around zero, roughness parameters are calculated only on the visible segments etc).

6.11.4. Interpolation of invalid elements

Sometimes is convenient to replace invalid regions by some interpolation, if only for visual appeal or due to advanced processing like film thickness evaluation, grain extraction and so on. Select *Process/Masking Operators/Interpolate masked points* to request the dialogue Substitution of invalid elements.

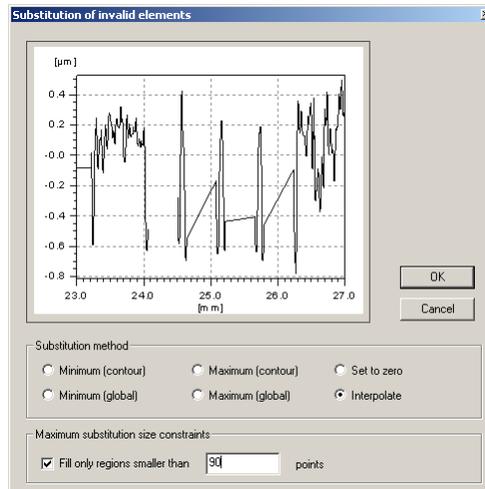


Figure 18: Substitution of invalid elements

The diagram pane shows a preview of the substitution's result. Several substitution methods are available:

- **Minimum (contour).** This function replaces a segment of invalid points by the minimum of the last valid point to the left and the first valid point to the right.
- **Maximum (contour).** This function replaces a segment of invalid points by the maximum of the last valid point to the left and the first valid point to the right.
- **Set to zero:** This function replaces a segment of invalid points by zero
- **Minimum (global).** This function replaces a segment of invalid points by the minimum valid value of the diagram.
- **Maximum (global).** This function replaces a segment of invalid points by the maximum valid value of the diagram.
- **Interpolate:** This function replaces a segment of invalid points by a straight line connecting the last valid point to the left with the first valid point to the right.

It is also possible to impose a constraint on the maximum size of the segment to be substituted by checking the *Fill only regions smaller than (n) points* check box. This feature is particular useful to fill small segments due to automatic reflection thresholding while keeping away from substituting large gaps. Enter the maximum size into edit box. The preview image gets updated after some time to reflect interpolation constrained by the size threshold provided.

Note: Interpolation is a modifying operation. Pressing the OK button, a new measurement data item is created.

6.12. Selection of a channel

6.12.1. Abstract

A measurement graph consists of one or more independent data sources. Frequently, both the profile and reflection channel are acquired during measurement. The profile channel is of most interest, but the reflection channel provides additional information. In many cases the reflection channel enables the detection of regions of different structure. A classical example are chromium stripes on glass. Chromium is highly reflective, but the reflectivity of glass is low. The stripes are clearly visible in the reflection signal, but may be hard to detect in the profile signal (since the thickness of the chromium may as small as a few nm).

6.12.2. Selecting a channel

All channels of a file are listed in the popup menu *View/Data Channel*. The presently active channel is indicated by a check mark, other channels can be displayed by selecting it in the sub-menu.

Note: Usually, each channel can be displayed only once. If the channel is selected for the second time, the window already showing this channel is activated. To create a second view, select *Window/New Window*.

6.13. Selection of a line

6.13.1. Abstract

The next section is relevant only in case of surface data profile sections (working on surface data, but displaying a line section from the surface). An area file consists of more than one line. *INSPECTOR* enables to extract a profile along a row, column, or arbitrary profile section and to treat the section like any line measurement.

6.13.2. Selecting a line

After selection of *View/Line Number* from the main menu the dialogue below is shown:

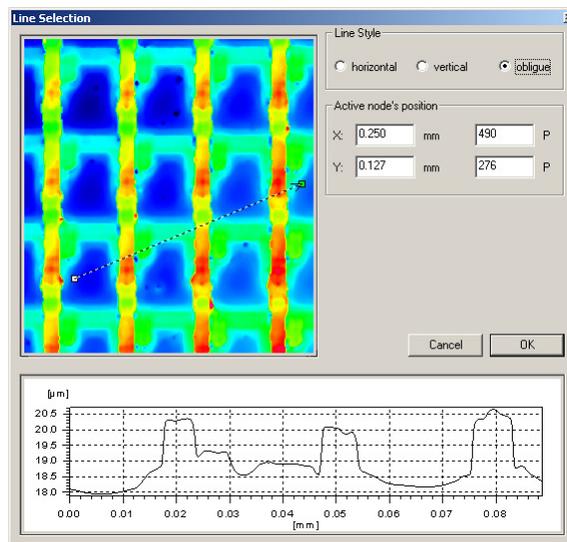


Figure 19: Line Selection Dialogue

The upper left pane shows the surface data, the lower pane a preview of the profile extracted. The type of extraction can be selected from the controls *Line Style*. It is possible to extract a horizontal, a vertical or an oblique section. In the latter case, the section is generated by bilinear interpolation of the surface data.

The co-ordinates of the active node of the section can be defined interactively or numerically, either by world co-ordinates or row/column number. The active node is depicted as a green box at the start or end of the section. To activate a particular node, move the mouse cursor on top of the node²³. For interactive placement, click on the desired node and move it to the desired position while keeping the left mouse button depressed. In the vertical or horizontal mode, the node is constrained in one direction.

The line selection dialogue may also be used to show the position of the section within the surface data, even in situations with multiple sections (e.g. if you have created independent sections via Windows/New Window).

6.14. Scaling of line data

6.14.1. Abstract

In many cases certain parts of a profile are of special interest, or fixed scaling is desirable. In cases like these, manual scaling is required.

6.14.2. Selection of the vertical limits

The dialogue designated for manual scaling is available via *View/Scaling* from the main menu. After selection of the latter menu item, the dialogue below gets displayed:

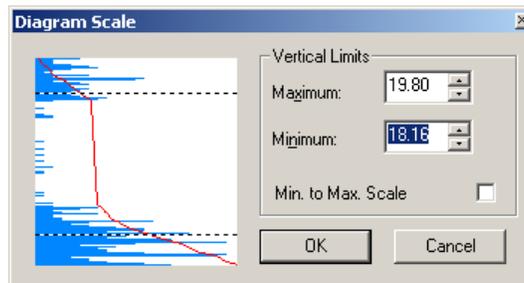


Figure 20: Ordinate Display Limits Dialogue

The histogram shows the frequency of occurrence (blue) as well as accumulated frequency ('bearing area', red). Frequency of occurrence indicates the probability of the appearance of the values. So any striking 'area' (defined as width*height) consisting of blue peaks indicate the presence of a significant proportion of (possibly widely distributed) sample surface.

The vertical limits can be manipulated using the edit boxes. The values can be entered numerically or changed by using the spin button controls to the right of the edit controls. The dotted lines in the histogram pane represent the limits chosen.

Notes: Changing the limits is neither destructive, nor does it affect calculation results. To restore automatic min-to-max scaling, check the Min to Max Scale button.

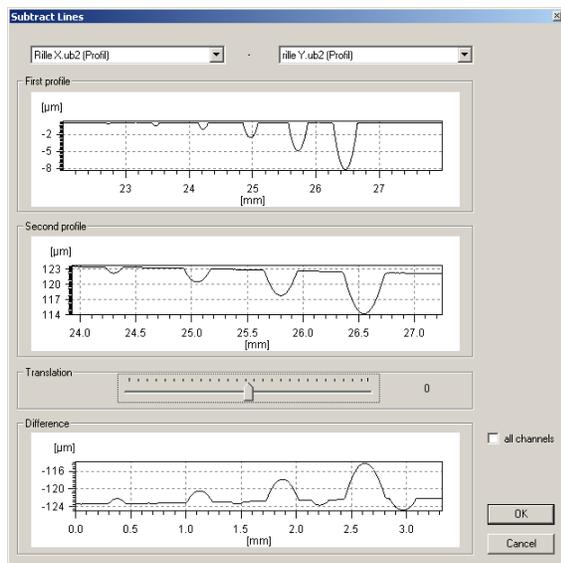
²³ it is not necessary to click on it

6.15.Subtraction of lines

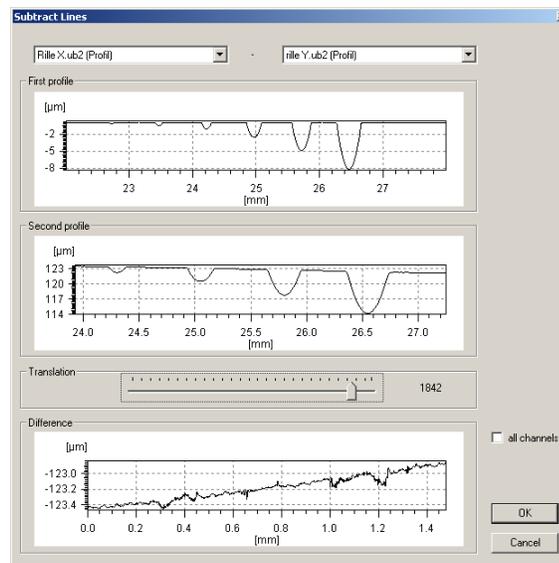
Line subtraction calculates the difference between two profiles. For useful results, two profiles taken from different spatial or temporal locations, differ by some subject of investigation, e.g. layer thickness or form variation. To be able to determine absolute values, suitable reference positions must be provided, or the absolute value must be known from other sources. Other applications are period estimation, or correlation though you may consider using FFT and correlation instead.

As a prerequisite to line subtraction, you will need at least two profiles opened simultaneously²⁴. Prepare the two profiles as required by your objective (e.g. by levelling or filtering).

Select menu item Process/Difference of Profiles to create the Subtract Lines dialogue. On top of the dialogue, two drop lists contain all line measurements currently opened within Inspector. Pick the first profile desired from the left drop list, it will be shown on the topmost diagram pane. Select the second profile from the rightmost drop list to be shown in the centre diagram pane. The bottom most pane previews the result of the subtraction.



Starting situation



After adjustment of the lateral translation

In most cases, the profiles have to be shifted left or right for match of the surface features to match well. This has to be accomplished using the slider control *Translation*. The images above show some example of the operation.

The first thing to note is the different length of the profiles, they even have different sampling densities. The starting translation, zero, is obviously a poor match (see result preview). Dragging the slider far to the right, the major grooves come to a match. In the vicinity of the match, the result profile shows some characteristic flip. Fine trimming can be achieved most easily using the cursor left and cursor tight keys, which translate the profiles element by element.

²⁴ You can also use two sections of a surface. To create the second profile section of the area, clone the first line diagram using menu item *windows/New window*.

Once the translation has been established, the resulting profile can be accepted by pressing the *OK* button. In addition to the result shown in the bottom most pane, it is possible to perform the subtraction on all data channels common to both source profiles by checking the *all Channels* check box.

Notes:

- The source profiles may have different length and sampling density (as can be seen in the example above). It is however recommended that the dimensions are not too different.
- The units of both secondary axis and profile values can be different, as long as the units are convertible. Inspector converts the units of the second profile to units of the first profile.
- In case the units of the axes' units are not convertible, Inspector performs point-by-point subtraction. Depending on the situation this makes sense, or not. The behaviour has been implemented to allow (e.g.) processing of data imported from inferior file formats, when the units are unknown. This is frequently the case for csv-imported data.
- Scale variations, either lateral or vertical, are not acceptable. Note that lateral scale variations are introduced by sample rotation.
- Subtraction of unrelated profiles or channels is interesting at best.

7. Operations on Area Data

7.1. Abstract

Area data is arranged in a rectangular grid. This arrangement describes a function of two (discrete) variables $z = f(x,y)$. Area data is usually superior to line data for the qualification of surface characters. The large number of measurement points, acquired from an region, offers a higher statistical confidence, but also requires advanced processing tools.

7.2. Loading of area data

Area and line data can be opened via the menu item *File/Open* from the main menu or via Drag & Drop from the explorer, much the same as line data. *INSPECTOR* determines the type of data (line or area) and opens the corresponding document. Following data types are available for import:

Extension	defined by	Profile data	Area data	Binary/ASCII
FRT	FRT GmbH	+	+	Binary
PRO	Digital Surf GmbH	+	-	Binary
SUR	Digital Surf GmbH	-	+	Binary
UA2	UBM GmbH	+	-	ASCII
UA3	UBM GmbH	-	+	ASCII
UB1	UBM GmbH	+	-	Binary
UB2	UBM GmbH	+	-	Binary
UB3	UBM GmbH	-	+	Binary

7.3. Saving of Area Data

To save area data, select *File/Save* or *File/Save as...* from the main menu.

Notes:

- If the active view shows a line diagram profile of the area data, the profile displayed will be saved.
- Measurement does not save the data. At the time the last view is going to be closed, *Inspector* prompts for saving the data.

7.4. Display of Area Data

7.4.1. Abstract

Area data can be displayed as either line profile (corresponds to one measurement line), colour keyed view (height values are coded by colours) or isometric view (also known as 3D-display). Every display type has advantages and disadvantages, a compromise of easy reading, overview and clarity is required. The type of display can be selected from the main menu *View/isometric view*, *View/Profile* or *View/Colour area view*.

7.4.2. Profile display

A line of the measurement data is displayed as profile. The profile values are clearly visible, but the local correlation (e.g. with the adjacent profile) is lost. This type of display is best suited to measure or to process profile details.

Profile display can be activated via *Process/Profile*. The new window shows the first line (line number 0). To show another line the menu *View/Line number...* must be used. Please refer to the previous chapter for details.

7.4.3. Colour keyed view

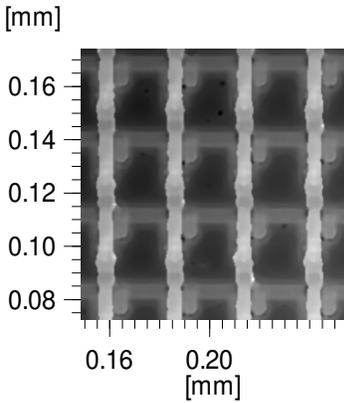
In this view style, the surface data is arranged in a rectangular array. Profile values are represented by different colours of the palette used, different profile values result in different colours.

7.4.3.1. Display options

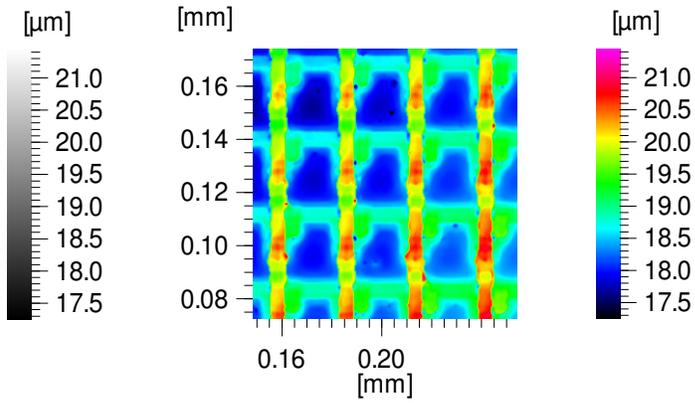
7.4.3.1.1. Palette

A palette provides a mapping from profile value to a colour. You can access the different palettes from the popup menu *View/Palette*. The rainbow palette is designated for an approximate quantitative analysis, while the monochrome palettes are preferable to visualise the topography.

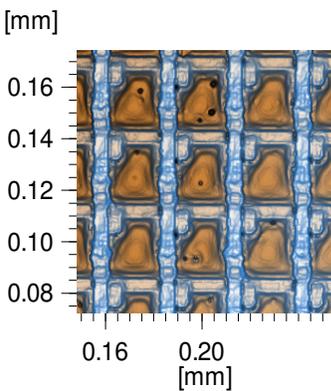
Note: If you need to know the profile at a certain point (or within a rectangular area), use the marker operator, available from the menu item *Process/Access Values*.



A typical monochrome palette.



A typical multicolour palette



A typical enhanced palette

Each of the different palette styles has unique advantages and disadvantages.

Palette	Advantage	Disadvantage
Monochrome	topography is easily recognisable	low contrast, absolute value is not readily readable due to smooth colour transition.
Multicolour	medium contrast, regions of same elevation are easily recognisable.	topography is not readily visually apparent. Small surface details usually hard to discern.
Enhanced	structure is clearly visible, excellent contrast. Surface details get highlighted.	colour does not readily map to elevation, but is influenced by local surface slope.

7.4.3.1.2.Normalisation

This type of scaling is also called true-to-scale, because the ratio of width to height of the diagram is the same as the ratio of the length of the primary to secondary axis of the measurement data. This view option can be activated and deactivated by selecting the menu item *View/Normalisation*.

7.4.3.1.3.Co-ordinate system

The primary and secondary axis, together with the scale bar, can be activated or deactivated selecting the menu item *View/Show Scale*.

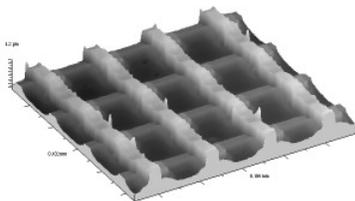
7.4.4. Isometric View

The isometric view is generated by a mapping of the measurement data to a plane (the screen of the monitor), where any two parallel lines (in the 3D data) remain parallel after mapping to the plane.

7.4.4.1. Display options

7.4.4.1.1. Palette

Various palettes are offered as colour palettes and structure palettes. The colour palettes offer a clear mapping of the profile value to the colour in the image, and vice versa, regions of the same colour have the same height. The structure palettes simulate the reflection of light of an imaginary light source and the individual surface patches towards the viewer's eye. The brightness and saturation of the colour varies according to the amount of light received by the viewer.



Colour coded palette

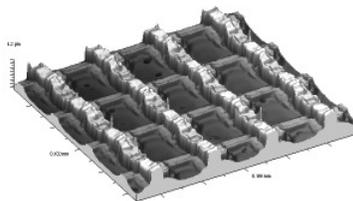


Photo palette I

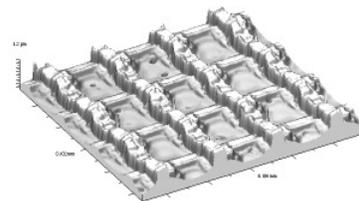


Photo palette II

The properties of each palette type are summarised below:

Palette name	Type of Mapping	Consequences
Colour coded	Profile values are linearly mapped to the colours of the palette.	Pixels of the same colour have the same profile value. Low contrast, low detail visibility due to smooth colour transitions. The monochrome palettes usually work better than rainbow.
Photo palette I	Profile values are linearly mapped to the colours of the palette. Brightness of a pixel depends on orientation of a small surface patch to simulate lighting (diffuse and specular reflection). Colour perceived is a component by component multiplication combination of base colour, diffuse and specular intensity.	Pixels of the same pure colour have the same profile value. Pretty good contrast, details are visible. Depending on palette, certain surface patches may be too dark (in this case, override automatic scaling and decrease the lower display limit somewhat, or choose another palette).
Photo palette II	Each profile value is mapped to the same colour. Brightness of a pixel depends on orientation of a small surface patch to simulate lighting (diffuse and specular reflection). Colour perceived is a linear combination of	Height comparison is difficult. High contrast, details clearly visible, natural appearance of the surface.

(one and only) base colour, diffuse and specular colour.

Notes:

- If the structure palette is used, experiment with the gloss slider setting in the *Illumination* dialogue to get best results.
- When using the structure palette, the position of the virtual light source can be selected in the dialogue *Illumination*. This feature is not available for colour coded palettes.

7.4.4.1.2.Normalisation

This menu item selects the scaling of the diagram's base. If this option is activated, the base is scaled according to the ratio of the length of the primary and secondary axis²⁵, if deactivated, both base axes have the same length.

7.4.4.1.3.Co-ordinate system rulers

The menu item *View/Show scale* shows or hides the co-ordinate system rulers.

7.4.4.1.4.Rotation angle

The popup menu *View/Rotation Angle* configures the view direction (around the Z-axis) of the isometric view. At the 0° position, the X-axis of the surface is in parallel to the horizontal axis of the monitor. The graphics on the screen rotate anti-clockwise with increasing rotation angle. Therefore, viewing of the surface from arbitrary directions is possible.

7.4.4.1.5.Tilt angle

This parameter controls the scaling of the z axis of the data. Low values result in a bird's eye view, right from above. With increasing tilt angle, the surface is visible from the side, much like a worm's eye view. Usually, tilt angles of 10 to 30 degrees provide the best visualisation.

7.4.4.1.6.Position of light source

Having selected one of the photo palettes, the position of the virtual light source can be configured. Select menu item *View/Position of light source* to open up the illumination dialogue.

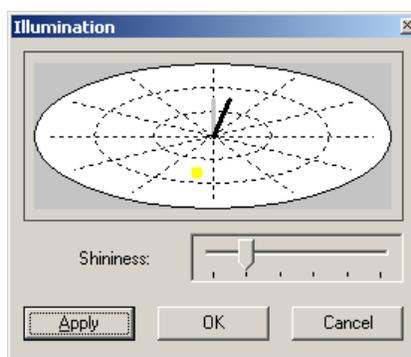


Figure 21: Illumination dialogue

²⁵ in some unit common to both axes, e.g. meter

The yellow dot symbolises the light source ('sun'), the black line shows the elevation and direction of the shadow much like on a sundial. The closer the light source is positioned to the border of the base, the lower the elevation of the light source.

By clicking within the elliptical base, the light source position can be changed. Pressing the *Apply* button, the isometric view will be updated. *OK* closes the dialogue, *Cancel* restores the selection at the time the dialogue was created.

The *shininess* slider controls the gloss of the surface. The more the slider is dragged to the right, the smoother the surface appears. The default position is usually acceptable unless either the measurement data set is large, or the amplitude of the measurement is quite small relative to the extent of the surface. In such situations, move the shininess slider further to the right.

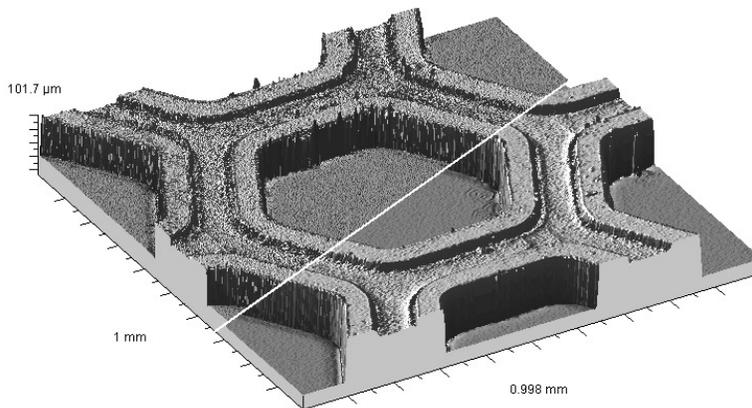


Figure 22: Structure palette without (left) and with (right) normal smoothing

Notes:

- The dialogue is modeless. Therefore, the palette, rotation or tilt angle can be changed in the main window without closing the illumination dialogue.
- The shininess slider determines the extent of surface normal smoothing (but does not smooth the profile. It just averages the directions of the light reflected). Normal smoothing is generally required, since the vertical scale usually is much larger than the horizontal scale, making even glossy objects appear rough and dull.

7.5. Processing of area data

7.5.1. Data export options

Data can either be exported in various binary formats, which are accessible only by certain metrology applications, in ASCII format(s) for easy external processing, or in form of a diagram or bitmap. In the latter case, the diagrams are useful for external presentation software.

7.5.1.1. Surface data export

Area data can be saved in various data formats, including an easy-to-process ASCII file format. Select File/Save as from the main menu, choose the file format from the file format drop list, select a file name and press the save button. This operation is similar to the operation of any Windows^R software you will encounter.

Extension	defined by	Profile data	Area data	Binary/ASCII
FRT	FRT GmbH	+	+	Binary
PRO	Digital Surf GmbH	+	-	Binary
SUR	Digital Surf GmbH	-	+	Binary
UA2	UBM GmbH	+	-	ASCII
UA3	UBM GmbH	-	+	ASCII
UB1	UBM GmbH	+	-	Binary
UB2	UBM GmbH	+	-	Binary
UB3	UBM GmbH	-	+	Binary

7.5.1.2. Diagram bitmap export

The diagram displayed can be transferred to the clipboard using the menu item *File/Export/Copy to Clipboard*. From the clipboard, the diagram can be used in many other programs. At the time of exporting the data you can configure the size of the image, and the duplication of overlays like markers.

You can also choose to save the diagram to disk by selecting *File/Export/Save as bitmap*.

Notes:

- Inspector is able to generate huge images.
- Some images²⁶ are exported as a metafile. Consequently, these images can be resized later without loss of quality, provided that the importing program does not convert the metafile to a bitmap internally.

7.5.2. Levelling

7.5.2.1. Abstract

Raw measurement results frequently suffer from surface tilt, e.g. one corner of the topography is well below the other corner, so that the profile is inclined. Hence, it is possible, that the macroscopic elements (here: inclination) cover the microscopic structures of interest. To correct for this effect, the measurement data can be corrected before the evaluation.

The easiest way to remove the surface inclination consists of calculation of a best fit straight line over all data points. In advanced situations, it is necessary to calculate the fit by nonlinear functions or to control the set of controlling points.

The following sections describe applications and limitations of the various procedures. All levelling procedures subtract the fitted function from the profile. This is different to a rotation.

²⁶Colour keyed view, line diagram, abbot diagram.

7.5.2.2. Levelling by linear regression

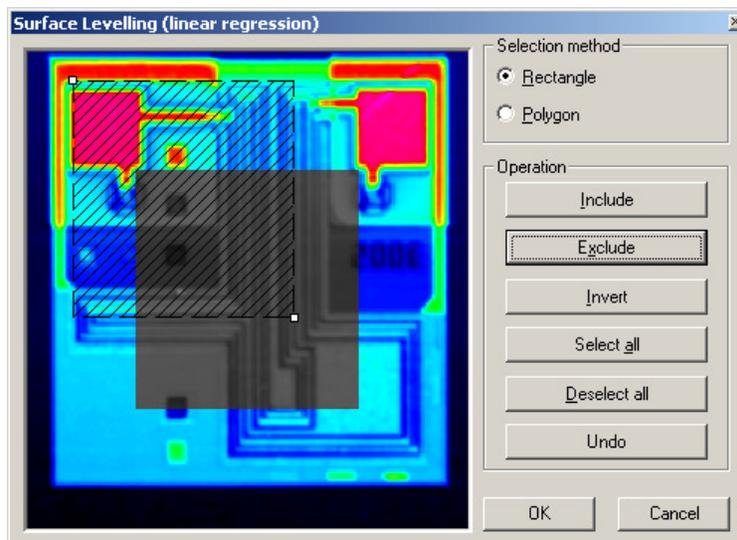
Levelling by regression is used to align the surface over all. A plane is fitted to the entire surface. Next, this plane is subtracted point by point from the surface data, removing the inclination. This process minimises the sum of the squared surface profile values (after subtraction).

Notes:

- This operation performs levelling by subtraction, not by rotation.
- There is no user interaction necessary nor possible. If you need to be more specific about the surface patches to be levelled, select ***Process/Levelling/by operator's selection***.
- If the best fit plane is required instead of the levelled surface, please refer to ***Levelling/form removal***.

7.5.2.3. Levelling by Operator's Selection

This operator calculates the best fit plane which minimises the sum of the squared deviations from the surface to the plane within selected regions only. When the operator is activated via ***Process/Levelling/by operator's selection***, the dialogue gets shown:



The colour coded view displays the raw data. Regions used to calculate the regression are indicated by the rainbow palette, excluded regions by the gray palette.

The regions included or excluded can be defined either by rectangular areas, or by a polygon. Selection of the operation mode radio is accomplished by clicking the radio button 'Rectangle' or 'Polygon'.

7.5.2.3.1. Area selection via rectangle

In the rectangular mode a hatched area with two grip points top-left and bottom-right is shown. Once the mouse cursor is above the hatched area, it can be shifted by pressing the left mouse button and dragging the rectangle to the desired position while keeping the button pressed. Release the mouse button when finished.

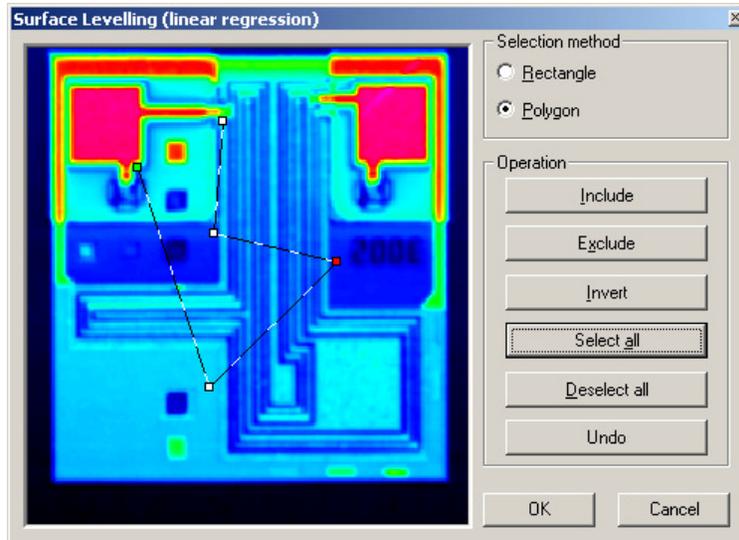
Width and height of the area can be changed if the mouse pointer is set positioned atop a grip point. The mouse cursor style changes to a double-pointed arrow pointing north and south. Press

the left mouse button and drag the grip to change the upper left or lower right vertex of the rectangle.

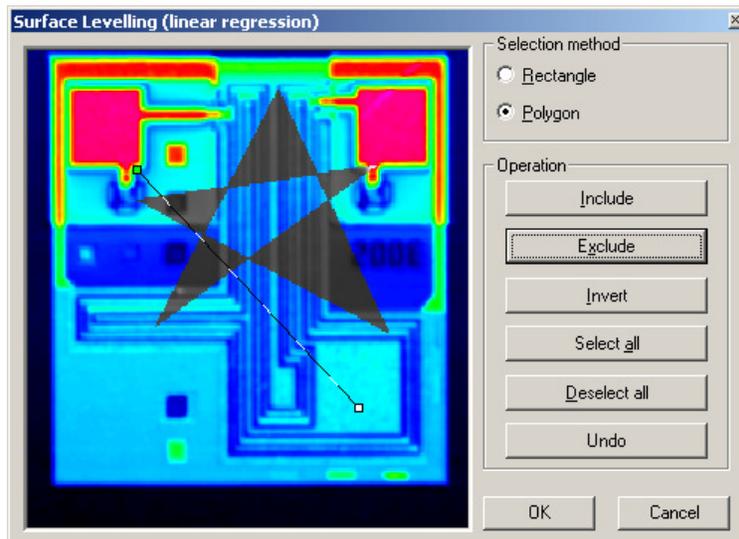
Include and exclude areas can be combined as described below.

7.5.2.3.2. Area selection with Polygon

In the polygonal selection method, arbitrary polygons can be defined. Each selection starts with two points, successive points are appended to the end of the polygon list by clicking at the desired position.



You can also move the controlling points. Position the mouse cursor on top of a controlling point, the colour of the point changes to red. Press the left mouse button, and drag the controlling point to the desired position. If the left mouse button is clicked outside of any controlling point, a new one is created. The first and the last point of the polygon list will be connected automatically. In case the polygon is self-intersecting, the area selection strategy is 'winding'.



The included and excluded areas can be combined as described below.

7.5.2.3.3. Processing of the selected area

Each area defined can either be combined with previously defined areas. The operations available are requested by selecting one of the boxes at the right side of the window:

- Include: The selected area is added to the selection (union operation)
- Exclude: The selected area will be eliminated from the selection (intersection with the complement operation).
- Invert: Included and excluded ranges are exchanged to each other (complement operation).
- Select all: all data are considered.
- Deselect all: all included areas are deleted.
- Undo: The last area selection will be recovered

Note:

Each point is considered either once or not at all in the calculation of the regression plane. Points within overlapping 'include'-areas are only taken once.

7.5.2.4. Levelling by form removal

In some cases it is necessary to fit an analytical function to the surface and/or to subtract the function from the surface. Typical examples are the removal of a vaulted structure or long wave straightness deviation of samples like paper, thin film or plastics. In these cases, the subtraction of a regression plane is not sufficient.

After selection of *Process/Levelling/Form removal* from the main menu, a dialogue is created similar to the one described before, with the addition of the control *Type* and check boxes for the desired results.

Available approximation functions are:

1) **Constant:**

This operator will shift the surface along the vertical axis, such that the sum of the squared surface values is minimised. In practice, the profiles within the selected range will be aligned around zero, the arithmetic mean is zero.

2) **Plane:**

The software calculates a levelling plane as described in the chapters before.

3) **Parabola (equivalent to polynomial(2,2)):**

The software calculates the coefficients a, b_1, b_2, c_1 and c_2 of the levelling function $z(x, y) = a + b_1 * x + b_2 * x^2 + c_1 * y + c_2 * y^2$, so that the sum of the squared error $\sum_{x,y} (z(x, y) - f(x, y))^2$ becomes minimum.

4) **Polynomial (n,m):**

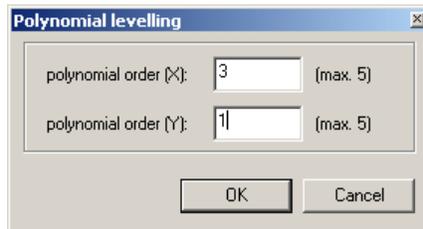
The software calculates the coefficients a, b_i and c_i of the function

$z(x, y) = a + \sum_{i=1}^n b_i * x^i + \sum_{i=1}^m c_i * y^i$, }, such that the sum of the squared error

$\sum_{x,y} (z(x, y) - f(x, y))^2$ is minimised. Selecting n=m=1 results in a plane, n=m=2 in a parabola, n=2, m=1 results in an function which is quadratic in the primary direction, and linear in secondary direction.

5) ***Polynomial (n,m):** (note the '*')

This item at the end of the list can be configured by the operator. After selection, the button '>>' becomes active. Clicking the button opens the dialogue to configure the order of the polynomial n,m individually. Apart from the editing ability, this operator is the same as the fixed polynomial described above.



Before closing the dialogue, specify the type of result desired using the check boxes 'Levelled' or 'Regression'. These check boxes determine, whether the residual (profile after subtraction of the function fitted) and/or the approximation function itself is required.

Notes: Polynomials exhibit the following typical characteristics:

- 1) Polynomials of low order exhibit a smooth shape. The number of waves or inflection points depends directly on the order of the polynomial.
- 2) Polynomials are functions without discontinuities in value, slope and curvature.
- 3) For the polynomials of the approximation function only n+1 (whereas n means order of the polynomial) parameters (a_i , b_i, c_i in the formula above) are available. Therefore, polynomials are unable to approximate the profile arbitrarily accurate. With increasing polynomial order, the approximation becomes better but more waves appear, especially at the periphery. Outside of the selection range, the fit is generally poor.

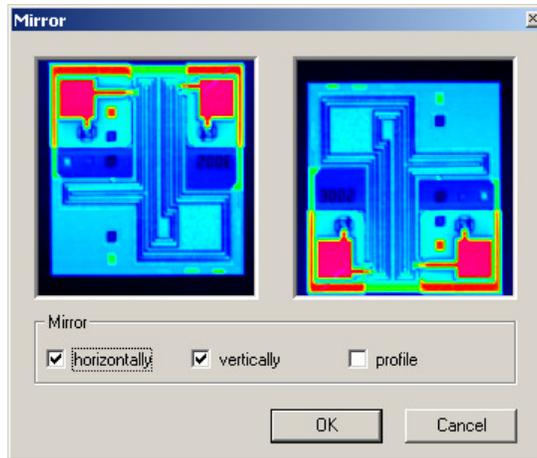
7.5.3.Reflection of area data

7.5.3.1.Abstract

For evaluation purposes, it is sometimes helpful to reflect the profile along one or more of the three principal axes, e.g. for the reconstruction of impressions (skin, roller surface).

7.5.3.2.Reflection of a surface

The following dialogue, available from the main menu item *Process/Mirror*, is used for reflecting profile data:



Surface data may be reflected along the three major axes:

- Horizontal reflection (along the primary axis, left to right)
- Vertical reflection (along the secondary axis, top to bottom)
- Reflection of the profile (multiply each profile value by -1.0)

Applying horizontal reflection, the data points at the end and at the beginning of the measurement line are exchanged. Vertical reflection exchanges the first with last lines.

Select the type of reflection from the check buttons 'horizontally', 'vertically' or 'profile'. One or more reflections can be requested simultaneously.

Note: Mirroring along the horizontal or vertical axis, start and end of the axis concerned is mirrored too, i.e. the lettering goes right to left, or up to down. In this way, no co-ordinates are lost.

7.5.4. Filtering of area data

7.5.4.1. Abstract

Processing of line data sometimes requires modification of each data point by a function of its adjacent points. An example is a smoothing filter, where a data point is replaced by some (weighted) sum of all adjacent points. Other applications are edge extractions or non-linear data manipulation via ranking operators (median filter, erosion filter, dilatation filter). Filters of this type are called matrix filters since they operate on a small rectangular section of the surface.

7.5.4.2. Matrix filter

After selection of the menu item *Process/Matrix Filter* the following window is opened:

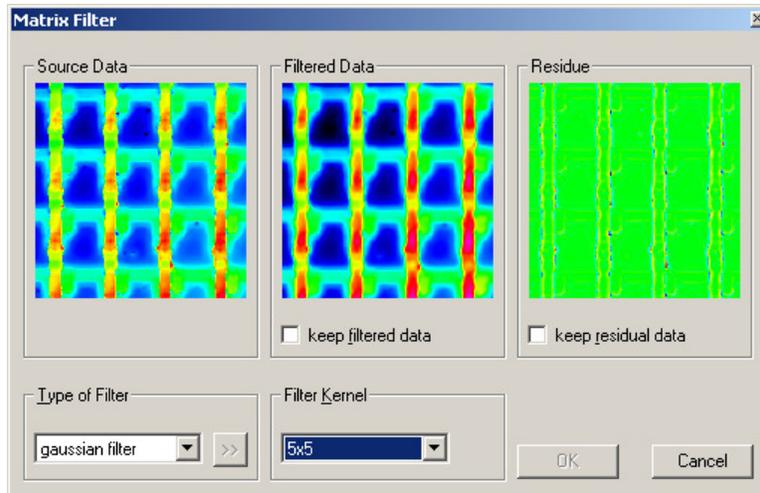


Figure 23: Matrix Filter dialogue

The left profile shows the original data (source data), the profile in the middle shows the profile after application of the filter and the right profile shows the difference between original data and applied filter data.

Select the type of the filter from the combo box 'Type of Filter', and the dimensions of the filter from the combo box 'Filter Kernel'.

In principle the matrix filters are calculating the result measurement point by measurement point according to the algorithm indicated next, whereas n means the filter width:

- 1) Determine the environment of the measurement point. It means: take $(n-1)/2$ data points left of the measurement point, the actual data point and $(n-1)/2$ data points right of the measurement point. For $n=3$ it means the left adjacent point, the actual point and the right adjacent point.
- 2) Apply the desired function to these n points.
- 3) Save the calculated data point, and repeat 1-3 until done.

The calculated data points in step 3) form the filtered data, the difference of source data minus calculated data points form the residue.

7.5.4.3. Filter types

This chapter describes the available types of filters and shows some example for reasonable application. The filters are often used for image processing, the names in the software are adapted to this terminology.

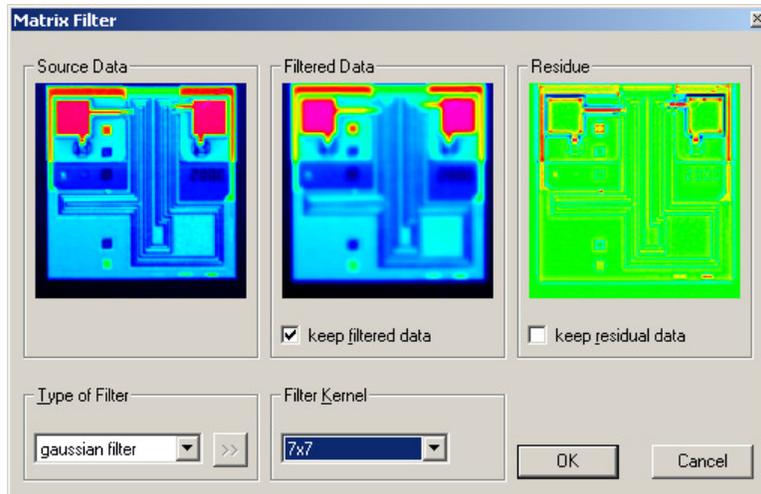


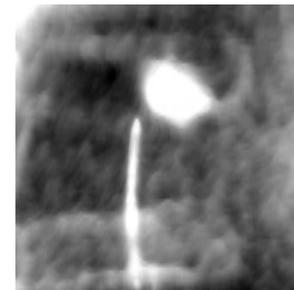
Figure 24: Matrix Filter dialogue

7.5.4.3.1.,Mean Value' filter

The mean value filter derives the filtered data by the mean value of the source data's environment. The filter is best suited to suppress white noise. The filtered profile (middle) is cleared of noise, the noise can be found in the difference image (right), at the cost of blur. If the filter is applied consider the effect of edge smoothing. Furthermore, it creates values which can not be found in the original. This filter is less suited to eliminate high frequency signals. Here the Gaussian filter should be preferred.

7.5.4.3.2.,Median' filter

The median of a data set is the value from which is both larger than half of the points, and smaller then the other half. In other words, once the data set gets sorted, the median is the element in the centre of the ranking.

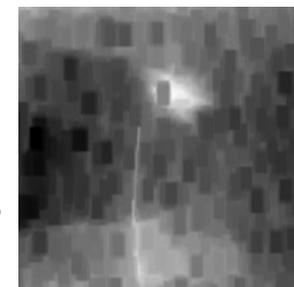


The median filter is suitable to effectively eliminate insulated outliers from a set of data without much influence to regular structures. In comparison to the arithmetical mean value filter edges will be less rounded. At excessively size, the median filter leads to a characteristic macroscopic structure (clouds, see right).

7.5.4.3.3.,Minimum' (or Erosion) filter

The minimum filter replaces the central data point by a minimum of its environment. It can be used to replace some positive outliers, or to literally erode some structure. In this sense, it may be successfully applied to automatic reflection thresholding (by 'relocating structure boundaries inwards').

Similar to the median and maximum filter, the minimum filter tends to create conspicuous artefacts.



7.5.4.3.4.,Maximum' (or dilatation) filter

The maximum filter replaces the central data point by the maximum value of its environment. This character can be used on thin layers where a sensor mostly measures on the upper side but sometimes on the lower side. The maximum filter may be able to remove the objectionable points if they appear only sporadically.

7.5.4.3.5.,Gaussian' filter

The gaussian filter calculates a weighted average of the proximity of the data point. Values close to the centre are given large weight, values towards the periphery low weight. The filter is rotationally symmetric, and the cross section of the shape looks like the well-known gaussian function $e^{-\frac{x^2}{\sigma^2}}$. The gaussian filter has the interesting property of having minimum spatial width for a given cutoff frequency and vice-versa. This means that higher frequencies are well suppressed by the filter without influencing edges too strong. Usually the filter leads to nice smooth graphs. Regarding noise suppression it is almost identical to the mean value filter, but high frequency component suppression is superior. In technical terms, the gaussian filter does not suffer from side lobes like the average filter does.

Note: The gaussian filter as presented in the dialogue is not implemented as a matrix, but as an IIR filter. This implementation was necessary to preserve the 'no side lobes' property.

7.5.4.3.6.,Laplacian' filter

The Laplace filter is a rotationally symmetrical tilt angle and edge filter according to the definition $\Delta\omega = \frac{\partial^2\omega}{\partial x^2} + \frac{\partial^2\omega}{\partial y^2}$, so it is the sum of the second derivations in X- and Y-direction. Differential operators are noise sensitive, to compensate this effect, *INSPECTOR* is using the modification '*Laplacian of Gaussian (LoG)*' known in literature. In this variant, the surface is conceptionally Gaussian filtered first, and thereafter the differential quotient calculated.

7.5.4.3.7.,Gradient' filter

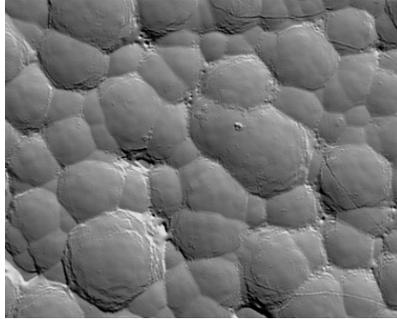
The gradient filter calculates the derivation of the surface with respect to a certain (configurable) direction. The special cases of 90° and 0° are known as Sobel X resp. Sobel Y filter. After selection of the gradient filter, the configuration button ">>" is activated. Clicking this button, a simple dialogue pops up to enter the direction. The angle has to be entered in the mathematical direction (0° means right, 90° means up). Similar to the Laplacian filter, the gradient filter uses the variant Gradient of Gaussian. The surface is low-pass filtered, and the differential operation is done on the filtered data.

Hint: The gradient filter is often used for extraction of edges. Applied to a colour coded view, it results in some photo-realistic display²⁷ (preferred colour setting: grey). See below for an example.

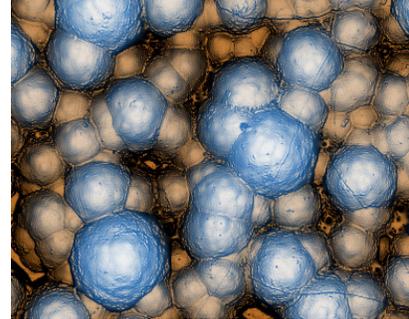
²⁷ this simple effect is frequently exploited in various metrology programs. Inspector provides photo palettes for enhanced visual clarity instead.



Source data



Fake photo-realistic image generated by gradient filter

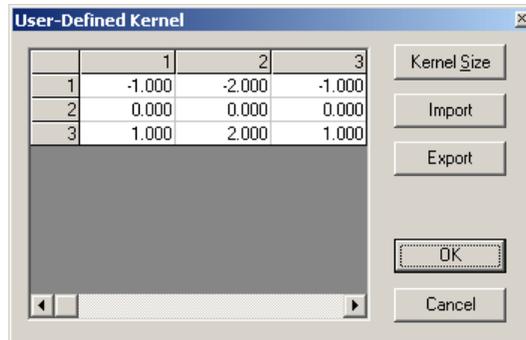


Inspector's photo palette for comparison

7.5.4.3.8. Custom filter

If none of the filters mentioned above satisfies your needs, you can define your own filter. Most linear filter can be expressed as the convolution of a matrix (called filter kernel) with the surface data. The filter coefficients can either be taken from a table, or derived numerically. In any case, applying the custom filter requires some knowledge of filter theory.

After selecting the 'custom filter', the button '>>' is activated. You can enter the kernel width, height and the coefficients by clicking this button. For additional information, see 6.8.2.1.7



First the value for Kernel size should be defined. The size must be chosen between 1 and 32, odd numbers are preferred. Thereafter the values of the matrix can be set by clicking to a cell and entering the number. To fill the table quickly, use the cursor keys to move from cell to cell. The kernel can also be exported or imported using the Import and Export buttons.

7.5.5. Masking operations

7.5.5.1. Abstract

Real-world data is frequently only partially defined, either from physical²⁸ or sensor related²⁹ constraints. In situations like this it is helpful gathering additional information apart from the profile.

²⁸ e.g. a hole passing entirely through a sample

²⁹ e.g. due to limited measurement range, or surface related effects like transparency, surface slope, or reflectivity.

For optical sensors, the reflection signal is frequently used for qualification and automatic classification of such areas. This is even more useful for area data, due to the vast number of data points which will render manual masking toilsome at least.

In addition to each sensor data channel, Inspector provides for a good-bad discrimination for each individual data element. Either automatic or manual discrimination is available. Automatic discrimination is based on the reflection channel. Therefore, for optical sensors it is a well-advised to acquire the reflection channel in addition to the primary profile.

All masking operations are accessible using menu item *Process/Masking Operators*.

7.5.5.2.Masking operation based on reflectivity (reflection threshold)

Selecting *Process/Masking Operators/Reflection Threshold* from the main menu, the dialogue *Select Reflection Threshold* gets created:

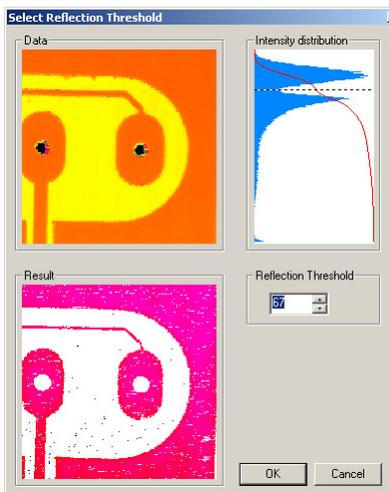


Figure 25: Select Reflection Threshold Dialogue

The graph on the upper left side shows the raw profile, the graph below the masked profile, after disabling all points whose reflection value is below the threshold. The intensity distribution graph on the right shows the amplitude distribution (blue) and the cumulative probability distribution (red) of the reflection values.

The screen shot shows a segment of a PCB. In the middle of the profile the copper is removed. To mask the copper-free area, the reflection threshold can be increased until the isolating material is suppressed. In the example the transition from the frequency peak of the isolating material to the highly reflective copper is at 67% reflection.

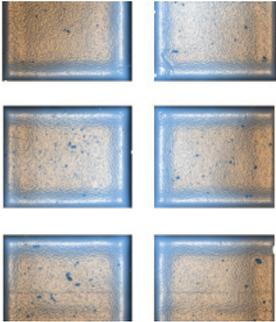
Move the threshold up or down either by entering the desired threshold into the edit box Reflection Threshold, or operating the spin button control to the right of the edit box. Masking is a non-destructive operation (i.e. it can easily be undone), so you may try different threshold values to get best results.

Notes:

- The mask will be loaded and saved in the data formats FRT, SUR, UB3.
- In the example above, some erosion filtering of the *reflection* channel will remove spurious unmasked pixel in the copper-free area. The copper surface may be manually closed afterwards, or interpolated automatically exploiting the maximum fill size feature.

7.5.6. Manual masking operation

In some situations it is convenient to perform manual masking, e.g. to exclude some segment of data irrelevant to your objective. Select menu item *Process/Masking operators/Exclude Rectangle*, press the left mouse button at the start of the undesired rectangle, drag the mouse to the other end of the rectangle and release the mouse button. The segment specified gets invalidated and is no longer visible in the diagram. As an example, there is sample with several test surface patches. The objective is to determine the roughness of the patches *only*:

Situation	Roughness parameter
 over-all evaluation	sRa 4.94 μm sRq 6.85 μm
 bare metal masked	sRa 1.52 μm sRq 2.77 μm

The results are quite different .

The operator *Process/Masking operators/Include Rectangle* validates a segment in the very same way than the exclude operator described above. To undo all masking operations, select *Process/Masking Operators/Include all Points*.

Note: Masking effectively removes data points from further consideration.

7.5.7. Interpolation of invalid elements

Sometimes it is convenient to replace invalid regions by some interpolation, if only for visual appeal or due to advanced processing like film thickness evaluation, grain extraction and so on. Select *Process/Masking Operators/Interpolate masked points* to request the dialogue Substitution of invalid elements.

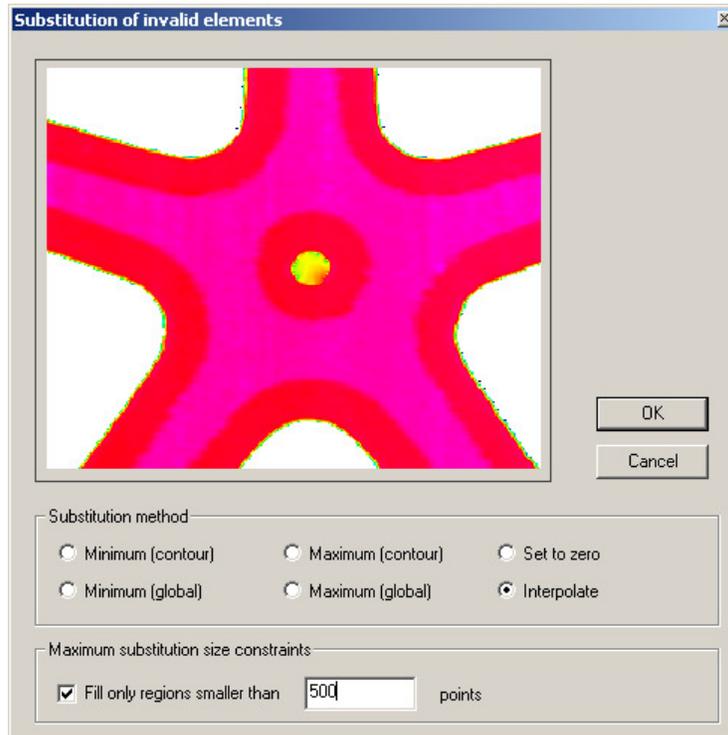


Figure 26: Substitution of invalid elements dialogue

The substitution implemented by Inspector is based on closed contour filling. For each region of invalid points, a contour is generated. In the next step, the value of each invalid point enclosed in the contour is interpolated based on the averaged contributions of all points of the enclosing contour. Other points, or other contours have no influence on the outcome. This strategy leads to interpolated surface patches exhibiting behaviour much like membranes (e.g. soap bubble membranes) do:

- The interpolated surface is continuous with the periphery. It is a seamless fit.
- The tension of the membrane (expressed as sum of the second order deviations of each interpolated points) is minimised³⁰.
- It is possible to fill areas up to a user-configurable size, periphery length or complexity.
- Although the surface patch represents some satisfactory solution from the analytical and visual point of view, close observation will reveal the lack of surface texture. The patch usually appears much smoother than the environment it is generated from.

The diagram pane shows a preview of the substitution's result. Several substitution methods are available:

³⁰ It is close to the global minimum, but not exactly. The exact solution requires much more computation.

- Minimum (contour). This function replaces all invalid points within the contour by the minimum of the contour points. This behaviour fills the invalid region much the way some liquid would do, running out at the lowest point of the periphery.
- Maximum (contour). This function replaces all invalid points within the contour by the maximum of the contour points. This behaviour fills the invalid region much the way some smoke lighter than air would do, leaking from the highest point of the periphery.
- Set to zero: This function replaces invalid points by zero
- Minimum (global). This function replaces invalid points by the minimum valid value of the diagram.
- Maximum (global). This function replaces invalid points by the maximum valid value of the diagram.
- Interpolate: This function replaces all invalid points by an averaged value of its bounding contour(s) as described at the start of this section.

It is also possible to impose a constraint on the maximum size of the segment to be substituted by checking the *Fill only regions smaller than (n) points* check box. This feature is particularly useful to fill small segments (e.g. due to automatic reflection thresholding) while keeping away from substituting large holes. Enter the maximum size³¹ into edit box. The preview image gets updated after some time to reflect interpolation constrained by the size threshold provided. In the example at the start of this section, only the small hole in the centre is filled.

Note: Interpolation is a modifying operation. Pressing the OK button, a new measurement data item is created.

7.5.8. Selection of a channel

7.5.8.1. Abstract

A measurement data set consists of one or more independent data sources called channels. Frequently, both the profile and reflection channel are acquired during measurement. The profile channel is of most interest, but the reflection channel provides additional information. In many cases the reflection channel enables the detection of regions of different structure. A classical example are chromium stripes on glass. Chromium is highly reflective, but the reflectivity of glass is low. The stripes are clearly visible in the reflection signal, but may be hard to detect in the profile signal (since the thickness of the chromium may be as small as a few nm).

7.5.8.2. Selecting a channel

All channels of a file are listed under *View/Data Channel*. The presently active channel is indicated by a checkmark, other channels can be displayed by selecting it in the submenu.

Note: Usually, each channel can be displayed only once. If the channel is selected for the second time, the window already showing this channel is activated. To create a second view, select *Window/New Window*.

³¹ size=number of invalid elements within contour. Try different numbers and check the preview for the intended result.

7.5.9. Scaling of area data

7.5.9.1. Abstract

In many cases just parts of a topography are of special interest, or fixed scaling is required to visually compare two measurements. In this case, the *Scaling* function is used.

7.5.10. Selection of the vertical limits

The dialogue designated for manual scaling is accessible by the main menu item *View/Scaling*. After selection, the dialogue below gets displayed:

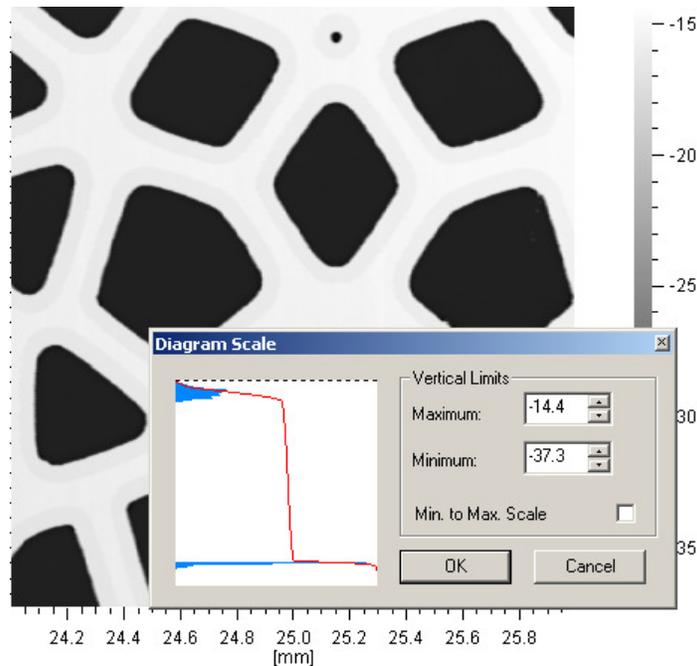


Figure 27: Ordinate Display Limits Dialogue

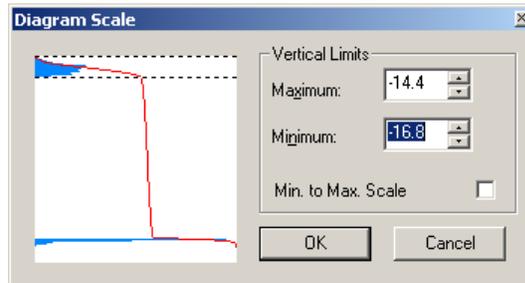
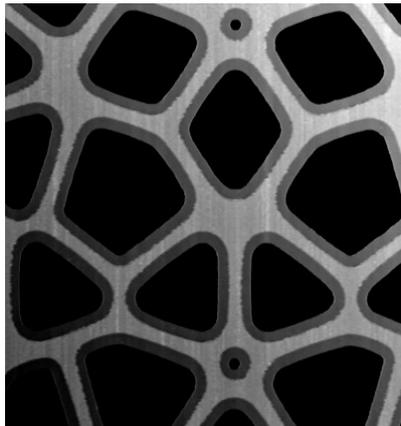
The histogram shows the frequency of occurrence (blue) as well as accumulated frequency ('bearing area', red). Frequency of occurrence indicates the probability of the appearance of the values. So any striking 'area' (defined as width*height) consisting of blue peaks indicate the presence of a significant proportion of (possibly widely distributed) sample surface. Depending on your objectives, it can be interesting to remove one of the other portion of the surface.

The vertical limits can be manipulated using the edit boxes. The values can be entered numerically or changed by using the spin button controls to the right of the edit controls. The dotted lines in the histogram pane represent the limits chosen.

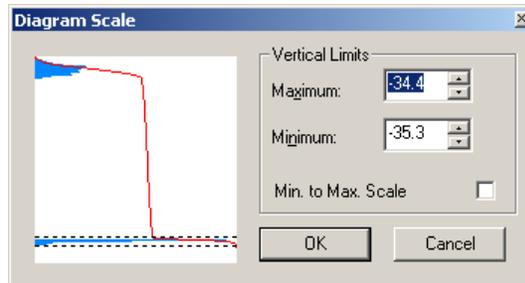
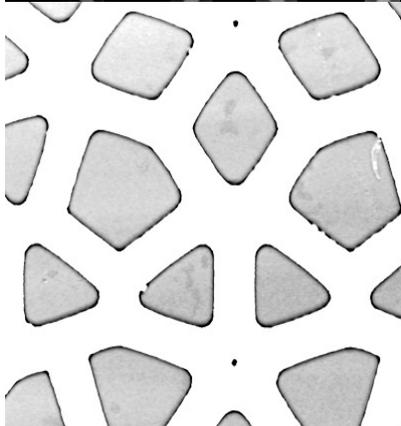
Notes: Changing the limits is neither destructive, nor does it affect calculation results. To restore automatic min-to-max scaling, check the Min to Max Scale button.

In the example above, two different peaks of the amplitude distribution are visible. The upper peak corresponds with the top surface of the razor blade, while the lower peak indicates the connecting surface. Between the two peaks, there is essentially no material. In cases like the one presented, raise the lower limit just below the top surface peak to get the best visual experience.

On the other hand, if one were interested in the connecting surface alone, lower the upper display limits just above the connecting structure's peak.



Display restricted to the top surface



Display restricted to the connecting surface

7.5.11. Selection of the type of display

7.5.11.1. Abstract

An area data set consists of some lines. *Inspector* makes possible to extract a profile along a row, column, or arbitrary profile section and to handle the section like any other line measurement.

Area data can be displayed either as a line profile, colour coded area diagram (height values are coded by colours) or isometric view (also known as 3D-display). Every display type has advantages and compromises, e.g. of easy reading, overview, and clarity. The type of display can be selected by the menu item *View/Isometric View*, *View/Colour Area View*, *View/Profile* and *View/Abbott Diagram*

7.5.11.2. Profile display

Any section or slice through the area data can be displayed as a profile. The analysis capabilities have been illustrated previously within chapter 6. Starting from a colour area or isometric view, a new line display can be created by the menu item *View/Profile*. The Profile display initially shows the bottom most line of the area data. Once the profile diagram is created, one can select another slice as already described in section 6.13.

Note: Usually, only one profile display per measurement data channel is available. If you try to create another diagram, the first one gets activated. If you really need another profile section, select *Windows/New window* from the line diagram.

7.5.11.3. Colour keyed display

In the colour keyed display, the measurement data is presented from the bird eye's view straight from above. Each measurement element is represented by a rectangle of a colour determined by the palette used.

Starting from a line diagram³² or isometric display, a new colour keyed display can be created by the main menu item *View/Colour Area View*.

Note: Usually, only one colour keyed view per measurement data channel is available. If you try to create another diagram, the first one gets activated. If you really need another colour keyed view, select *Windows/New window* from the colour keyed diagram already existing.

7.5.11.4. Isometric display (3D-display)

The data file is displayed in form of a projection of the 3-dimensional structure onto the window. Several palettes (including lighting) are available, and the projection parameters rotation and tilt are configurable. Starting from a line diagram³³ or colour keyed view, an isometric view can be created by the main menu item *View/Isometric View*.

Note: Usually, only one Isometric view per measurement data channel is available. If you try to create another Isometric diagram, the first one gets activated. If you really need to duplicate a view, select *Windows/New window* from the isometric display already existing.

8. Roughness Parameters

8.1.1. Abstract

Quantitative evaluation of profiles based on parameters is standardised in several national and international standards. Inspector provides for the most common of these parameters. *Please note that roughness parameters are specified on line profiles only.* Any surface roughness parameter calculation requires generous extrapolation of the standard's text, and must be treated with utmost caution. Never the less, it is widespread practise to quote surface roughness parameters.

Profile parameters are calculated either from the raw profile, the levelled raw profile, the high-pass filtered profile (with or without groove suppression) or from low-pass filtered profile.

All roughness parameters directly or indirectly depend on the raw profile. The standards require a sampling length (lt) of either 0.175mm, 0.56mm, 1.75mm, 5.6mm or 17.5mm. The sampling length has to be selected based on the expected roughness of the surface. Coarse surfaces require a larger sampling length, fine grained surfaces a short length. DIN4288 states the requirements below:

RzISO	Ra	Sampling length
-------	----	-----------------

³² only if the line diagram is based on area data.

³³ only if the line diagram is based on area data.

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<20nm	<4nm	0.175mm
20-100nm	4nm-20nm	0.56mm
0.1-0.5µm	20nm-100nm	1.75mm
0.5-10.0µm	0.1-2.0µm	5.6mm
10.0-50.0µm	2.0-10.0µm	17.5mm

Inspector allows for arbitrary sampling distances, however, the parameters calculated at a non-standard sampling length are not covered by standards (by definition).

The filter's primary purpose is to separate the profile into form related components, and roughness components. Separation is based on the wavelength of the various components. Low-frequency components (long wavelength) are assigned to the form, short-wavelength components to the roughness.

The standards require for a low-pass gaussian filter with a cutoff (at 50% attenuation) wavelength of 0.025mm, 0.08mm, 0.25mm, 0.8mm or 2.5mm. The cutoff wavelength l_c comprises 1/7 of the sampling length l_t . Next, the profile is segmented into 7 parts, each of width l_c . The first and last section is necessary for the operation of the filter, and is not used for the roughness parameter calculation.

The remaining 5/7 of the profile is called evaluation length, which is either 0.125mm, 0.4mm, 1.25mm, 4mm or 12.5mm. Some of the parameters are evaluated over the whole evaluation length, others are calculated on each of the five individual segments, and the results are combined afterwards (averaged, taken the maximum, 3 of 5 results).

According to standards, the raw profile is treated by a gaussian low-pass filter, the difference of the raw profile and the low-pass filtered signal comprises the high-pass filtered signal. The Parameters centred around R_k require a gaussian low-pass filter with groove suppression.

Notes:

Roughness parameters are standardised on profile sections **only**, surface roughness parameters are **not standardised**. Therefore, extrapolation of the calculation procedures are treated differently among the manufacturers of metrologic instruments. Inspector applies the rules listed below:

- The surface is filtered by a (two-dimensional) gaussian filter. The operator may select different cutoffs in primary and secondary direction. The recommended cutoff values are 1/7 of the primary and secondary sampling length.
- One-dimensional integral expressions are replaced by their two-dimensional counterparts. Normalisation factors $1/L$ will be replaced by $1(L*H)$.
- Parameters based on the entire evaluation length will be evaluated on the entire evaluation surface.
- Parameters based on five individual segments are evaluated on 25 segments of the surface. These individual segments are not necessarily square.

Invalid and/or masked points are neither used during filtering nor parameter evaluation. The standards **require** the evaluation of the whole profile, so you may be better off to get a good measurement, which may be impossible to achieve on some samples. Exclusion of invalid points may lead to failures calculating certain parameters.

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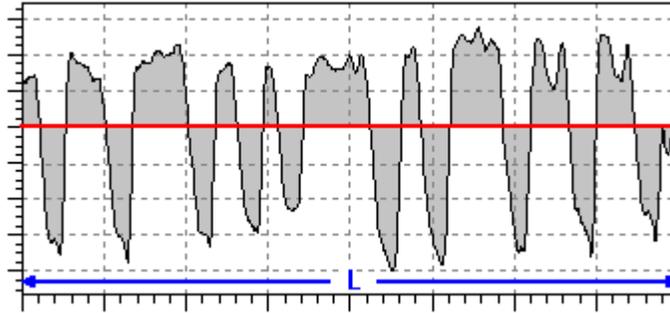
Filter operations in Inspector are neither based on the FFT transform, no they are performed in the frequency domain. So you do not have to worry about end discontinuities.

It is impossible to convert from one roughness parameter to another, unless the whole profile is known.

8.1.2. Roughness parameter Ra

This widely used parameter consists of the arithmetic mean value of the absolute values of the high-pass filtered signal:

$$Ra = \frac{1}{L} * \int_0^L |z(x)| dx$$



The parameter Ra is identical to the shaded surface, divided by the evaluation length. The 'mean line' is indicated in red. Values beneath the mean line are multiplied by -1 before averaging. Ra is the most-frequently used parameter.

Inspector uses the extrapolation indicated below for calculation of the Ra parameter on surfaces:

$$sRa = \frac{1}{L} * \frac{1}{H} * \int_0^H \int_0^L |z(x, y)| dx dy$$

Implications:

- + : Compares surfaces of similar surface characteristics.
- + : Ra value is quite insensitive to singular events (spikes, pores) of the profile.
- : No qualification of the surface shape possible

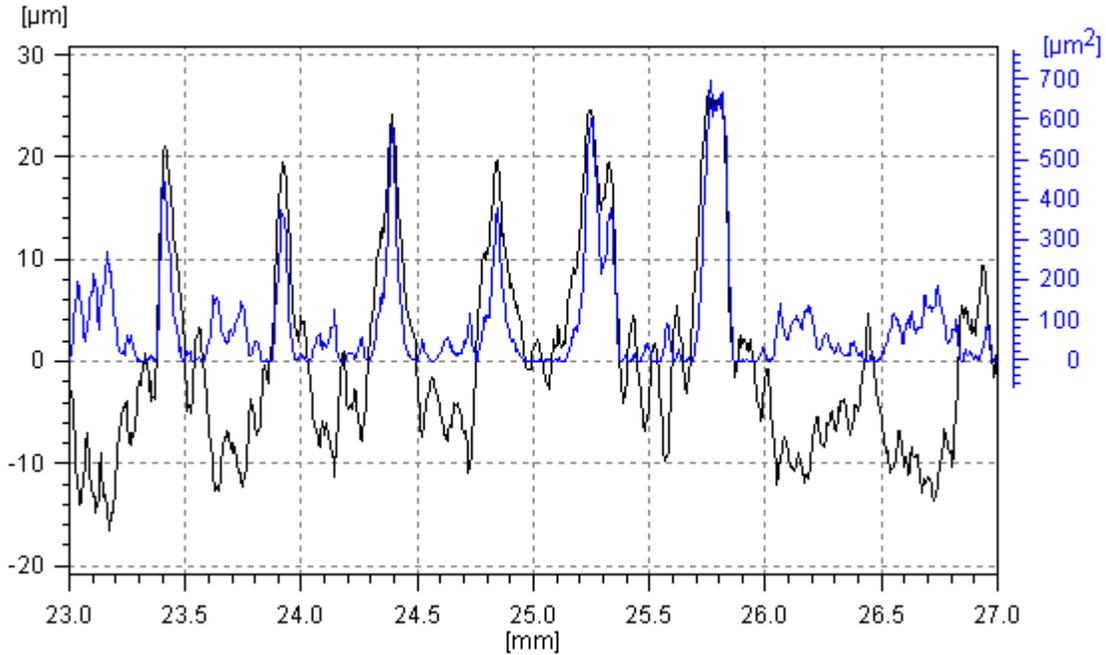
Standard:

DIN 4768, ISO/DIS 4287/1

8.1.3. Roughness parameter Rq

The parameter Rq is calculated based on the square root of the mean of the squared roughness profile values.

$$Rq = \sqrt{\frac{1}{L} * \int_0^L z^2(x) dx}$$



Looking at the graph above, Rq is the square root of the surface of the blue line, divided by the evaluation length. The parameter is an 'effective value' by definition, and is frequently called root-mean-square (RMS) value.

Inspector uses the extrapolation indicated below for extrapolation of the Rq parameter on surfaces:

$$sRq = \sqrt{\frac{1}{L} * \frac{1}{H} * \int_0^H \int_0^L z^2(x, y) dx dy}$$

Implications:

- +: Parameter with extended statistical significance compared to Ra
- +: Parameter is quite insensitive to singular events
- : No qualification of the surface shape possible

Standard:

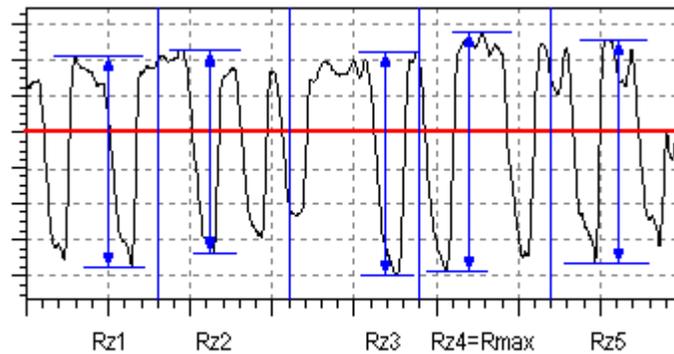
DIN 4768, ISO/DIS 4287/1

8.1.4. Roughness parameter RzDIN, Rmax

These parameters are based on individual evaluations of the five segments of the high-pass filtered profile. Within each segment the minimum and maximum value, and the difference $R_{zi} = \max_{z_i} - \min_{z_i}$ is determined. RzDIN is defined as the arithmetic mean value of the five individual R_{zi} , and Rmax is defined to be the maximum of R_{zi} .

$$RzDIN = \frac{1}{5} \sum_{i=1}^5 Rz_i$$

$$Rmax = \max_{i=1}^5 Rz_i$$



In the image above, $RzDIN = (R_{z1} + R_{z2} + R_{z3} + R_{z4} + R_{z5}) / 5$, and Rmax equals R_{z4} .

Inspector uses the following extrapolation on surfaces: The high-pass filtered profile is divided into 5x5 tiles. Within each tile, the minimum (\min_{ij}) and maximum (\max_{ij}) values are determined, and $Rz_{ij} = \max_{ij} - \min_{ij}$. sRzDin and sRmax are defined as indicated below:

$$sRzDIN = \frac{1}{25} \sum_j \sum_{i=1}^5 Rz_{ij}$$

$$sRmax = \max_{i,j=1}^5 Rz_{ij}$$

Implications :

- + : Parameter based on peaks and valleys
- : Rmax: sensitive parameter, due to the dependency on singular events.
- : No qualification of the surface shape possible

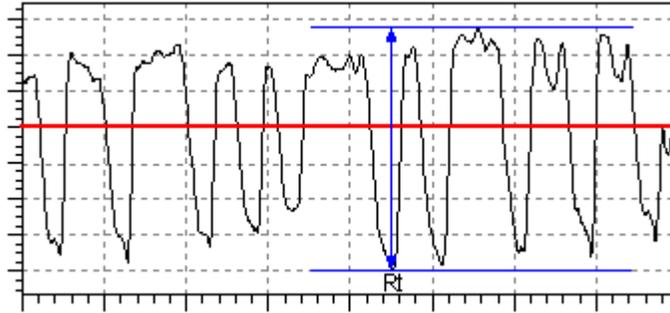
Standard:

DIN 4768/1

8.1.5. Roughness parameter Rt (Ry)

The parameter Rt (also known as Ry) determines the difference between the maximum and minimum profile value of the high-pass filtered signal.

$$Rt = \max_i(z_i) - \min_i(z_i)$$



Rt is identical to the upper and lower extremes of the profile.

In the same way, Inspector uses the difference of the maximum and minimum values within the evaluation surface of a surface.

$$sRt = \max_{i,j}(z_{ij}) - \min_{i,j}(z_{ij})$$

Implication:

- : Sensitive parameter, due to the dependency on singular events.
- : No qualification of the surface shape possible

Standard:

DIN 4762/1E

8.1.6. Roughness parameter Rp and Rpm

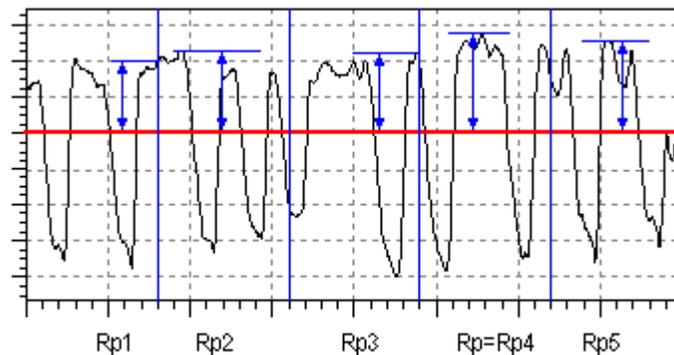
Parameter Rp (Rpm) is also known as (average) Maximum Profile Peak Height. Within each of the five segments of the high-pass filtered signal, the maximum profile Rp_i is determined. Rp is the maximum of the Rp_i , and Rpm is the arithmetic mean of the five Rp_i :

$$Rp_i = \max_{Li} (z(x))$$

$$Rp = \max_{i=1}^5 Rp_i$$

$$Rpm = \frac{1}{5} \sum_{i=1}^5 Rp_i$$

There are two closely related parameters Rv and Rvm, which are based on the valley values Rvi. These infrequently used parameters are not directly available in Inspector. Instead, invert the profile ahead of calculation: Rv transforms to Rp, and Rvm becomes Rpm.



In the diagram above, Rp becomes the maximum profile value Rp_i within the five segments (Rp_4), and Rpm equals the sum of the five Rp_i , divided by five.

To calculate sRp and sRpm for surfaces, Inspector splits the evaluation surface into 5x5 tiles. Within each tile, the maximum profile value Rp_{ij} is determined. Using these definitions, sRp and sRpm are defined:

$$sRp = \max_{i,j=1}^5 Rp_{ij}$$

$$sRpm = \frac{1}{25} \sum_{i=1}^5 \sum_{j=1}^5 Rp_{ij}$$

Implications :

- : Rp: Sensitive parameter, due to the dependency on singular events.
- : No qualification of the surface shape possible.

Standard:

DIN 4762/1E

8.1.7. Roughness parameter L_o and L_r

Parameter L_o calculates the arc length of the high pass filtered signal. For each adjacent pair of points, the length of the connecting line is determined and accumulated. Parameter L_r is the ratio of L_o divided by the evaluation length.

$$L_o = \int_L \sqrt{1 + \dot{y}^2(x)} dx$$
$$L_r = \frac{L_o}{L}$$

L_o represents the arc length of the profile, or the length of the profile, if it were stretched out as far as possible.

In case of area data, Inspector assigns parameter sL_o the area of each triangular patch comprising the surface. sL_r is calculated as the ratio of sL_o and the projected area (i.e. width*height of the surface) of the evaluation surface.

$$sL_o = \sum_{i,j} A_{ij}$$

, where W,H stand for the width and height of the evaluation surface.

$$sL_r = \frac{sL_o}{W * H}$$

Standard:

DIN 4762/1E, ISO/DIS 4287/1

8.1.8. Roughness parameter Sk and K

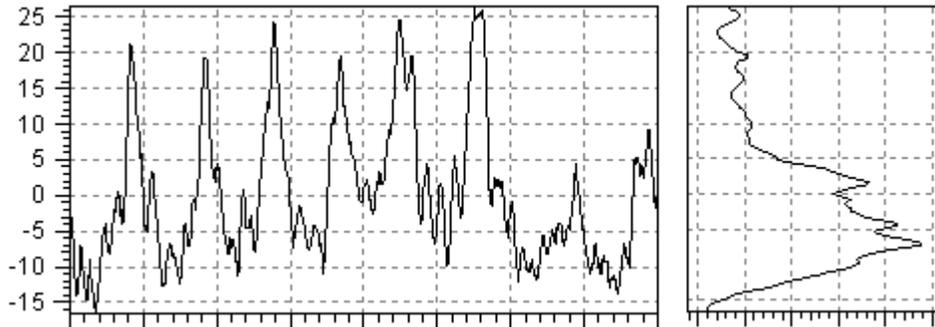
Sk is also known as skew, K as kurtosis of the amplitude distribution. Formally, these parameters constitute the third and fourth moments of the amplitudes of the high pass filtered signal.

Sk constitutes some measure of the asymmetry of the profile's amplitude distribution, a negative value characterises a profile with predominant valleys, a positive skew is typical for marked elevations. Glide bearing manufacturers e.g. strive to produce contact surfaces having a shallow surface (wear) while keeping embedded valleys or pores (lubricant volume). Surfaces of this type are characterised by a Sk smaller than zero.

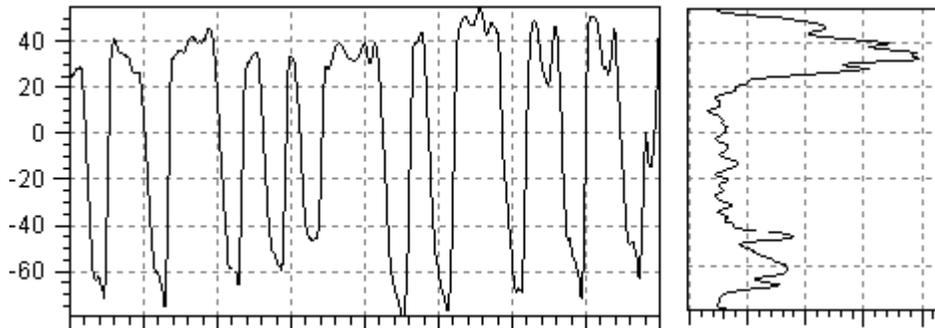
The kurtosis parameter classifies the similarity of a surface relative to a gaussian distribution. A random surface has a K of 3.0, significant deviations (both towards larger and smaller values) point out to recognisable surface structures.

$$Sk = \frac{1}{R_q^3} \int z^3(x) dx$$

$$K = \frac{1}{R_q^4} \int z^4(x) dx$$



Acute profile, Sk>0 (+0.9), K ~2.9



Shallow surface with pores, Sk<0 (-0.33), K ~1.9

The extrapolation of Sk and K for area data is straight-forward, Inspector uses the following definitions:

$$sSk = \frac{1}{sR_q^3} \int \int_{WH} z^3(x, y) dx dy$$

where W,H stand for the width and height of the evaluation surface.

$$sK = \frac{1}{sR_q^4} \int \int_{WH} z^4(x, y) dx dy$$

Implications:

- + : Characterises the type of surface (negative Sk indicates shallow surface)
- : Both parameters depend on profile values with high order. Outliers have significant influence on K and Sk (a single outlier e.g. can boost Sk from 3.0 to 6.0).

Standard:

DIN 4762/1E, ISO/DIS 4287/1

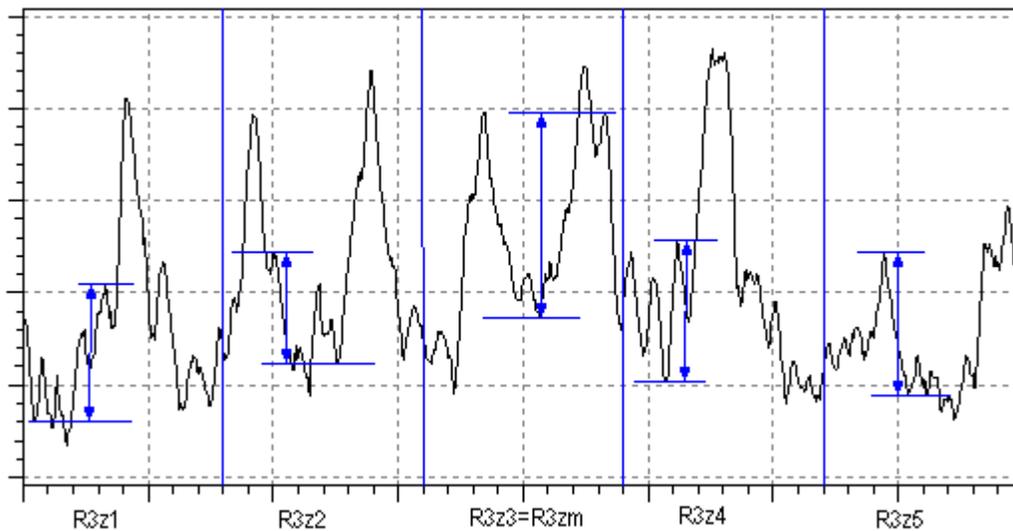
8.1.9. Roughness parameters R3z and R3zm

These parameters are based on peak height averaging. The high-pass filtered profile is divided up into five non-overlapping segments of equal length. Within each segment, the individual roughness R3zi is defined to be the difference between the value of the third peak and third valley. Two peaks (or valleys) are considered different only if there are values in-between which deviate from the larger of the two peaks (the lower of the two valleys) by a vertical threshold VC. Furthermore, the lateral distance between the peaks must exceed the horizontal threshold HC. Peaks or valleys at the boundaries of the segments get discarded.

Parameters HC and VC have to be specified in the dialogue.

$$R3z = \frac{1}{5} \sum_{i=1}^5 R3z_i$$

$$R3zm = \max_{i=1}^5 (R3z_i)$$



Determination of the third peak and third valley within each segment.

Inspector uses the following extrapolation in the case of area data:

- Parameters R3zi is calculated as the difference of the third peak and third valley within the 25 surface patches.
- HC is interpreted as a radial distance.

$$sR3z = \frac{1}{25} \sum_{i,j=1}^5 sR3z_{ij}$$

$$sR3zm = \max_{i,j=1}^5 (sR3z_{ij})$$

Implications:

+: R3z is less sensitive to single events than RzDIN/ISO

-: HC resp. VC have significant influence on the results, so they always have to be specified and mentioned.

Standard:

Daimler Benz internal standard N31007 (1983)

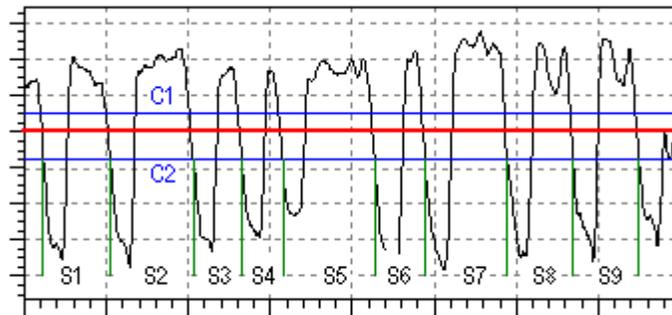
8.1.11. Roughness parameters D, NrS, S, Sm

These parameters rate the number and density of grooves of the high-pass filtered signal. A groove is characterised by excursion of the limits established by the parameters C1 and C2, which have to be specified in the roughness dialogue. Depending on the sign of the first profile value, the number of either raising or falling edges will be determined. In the context of this section, an edge is a sequence of profile values starting at C1 (C2) and going to C2 (C1) without returning to C1 (C2) before.

D is called groove count (or unfortunately 'density'). The parameter is defined as the number of edged crossing the span C1-C2 in either direction within the evaluation length.

NrS represents the normalised groove count, i.e. D divided by the evaluation length. S represents the number of grooves per 10mm of evaluation length.

Sm stands for the averaged (mean) distance between grooves.



The example exhibits 10 falling edges, $L=4\text{mm}$, so $D=10$, $NrS=25$, $Sm=0.4\text{mm}$.

The parameters are not available for surface measurements.

Standard:

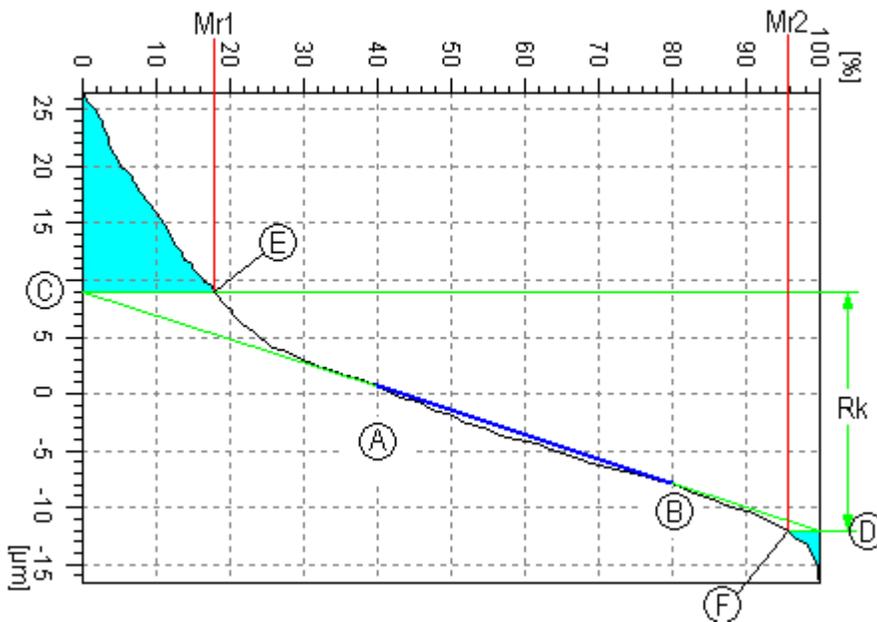
DIN 4762/1E, ISO/DIS 4287/1

8.1.12. Roughness parameters R_k , R_{pk} , R_{vk} , Mr_1 , Mr_2

The parameters are derived from the abbot diagram of the high-pass filtered signal. The high pass filter used is a standard gaussian filter with added groove-suppression processing.

R_k is called core roughness, R_{pk} reduced peak height, R_{vk} reduced groove depth. Mr_1 resp. Mr_2 constitute the smallest and largest bearing ratio of the core roughness.

The bearing area (abbot diagram) diagram of the high-pass filter constitutes the starting point of the parameter calculation. The abbot diagram gets subdivided into peaks, core and valleys according to the following algorithm:



Push a line connecting two points separated by 40% tp (horizontal axis) along the abbot diagram (blue line) and determine the position with least slope. Since the separation is fixed, this condition is identical with 'determine position with the smallest Htp' (vertical axis). Start and end of the line are termed A and B in the diagram above.

Extend the blue line to $tp=0\%$ (position C) and $tp=100\%$ (position D). R_k is the vertical difference between C and D, it is identical with 2.5 times the smallest Htp determined above.

The intersection of the abbot diagram with the horizontal line through C yields position E, the least material share Mr_1 of the core profile. In the same way, the intersection of the horizontal line through position D and the abbot diagram yields position F, the maximum material share Mr_2 .

Next, the reduced peak height R_{pk} is determined. The area of the abbot diagram above the horizontal line connecting C and E (the cyan area on the top) is transformed into a triangle of equivalent surface, with base line C-E. The height of this triangle is called R_{pk} .

In the same way, the reduced groove depth R_{vk} is derived from the height of the triangle with base line D-F, having the same area as the area enclosed by line D-F and the abbott diagram (the cyan path on the right side).

These parameters are defined on the accumulated amplitude distribution, or abbott diagram. Therefore, calculation is the same for line and surface data.

Standard:

DIN 4776

8.1.13. Waviness parameter W_t

W_t is the depth of the waviness in DIN 4774. The parameter is calculated from the largest and lowest point of the low-pass filtered profile within the evaluation length L .

$$W_t = \max_{x=0}^L(w(x)) - \min_{x=0}^L(w(x))$$

The surface parameter sW_t is calculated the same way, it is the difference between the largest and lowest point of the waviness surface.

$$sW_t = \max_{x,y=0}^{W,H}(w(x, y)) - \min_{x,y=0}^{W,H}(w(x, y))$$

Standard:

DIN 4774

Note: The parameter is sensitive to surface tilt, it is defined this way. You are advised however to level your profile ahead of evaluation.

8.1.14. Profile parameter Pa

Pa is just the arithmetic mean value of the source profile (neither levelled nor filtered) along the whole measurement length.

$$Pa = \frac{1}{L} * \int_L z(x) dx$$

The surface parameter sPa is the arithmetic mean of the measured surface, neither levelled nor filtered.

$$sPa = \frac{1}{W * H} * \int \int_{H W} z(x, y) dx dy$$

Note: Do not level the profile, else Pa and sPa will always be zero.

8.1.15. Profile parameter Pt

Pt is the difference between the largest and lowest profile value after levelling the entire profile.

$$Pt = \max_L(z'(x)) - \min_L(z'(x))$$

$z'(x)$ is derived from the profile by subtracting a least-squares regression line from the profile.

Parameter sPt is the difference between the largest and lowest point of the area measurement after subtracting a least-squares regression plane.

$$sPt = \max_{W,H}(z'(x, y)) - \min_{W,H}(z'(x, y))$$

Standard:

DIN 4771

Note: Pt and sPt are different from the flatness and co planarity of the profile or surface.

9. Fourier Domain Operations

9.1.1. Abstract

The Fourier transform is a transformation which maps values from the spatial domain into the frequency domain. Mathematically, the transformation is a basis transformation from the vectors of the spatial domain $\langle 1,0 \rangle, \langle 0,1 \rangle$ to the orthogonal trigonometric polynomials $\cos(2\pi \frac{i}{N})$ and $\sin(2\pi \frac{i}{N})$ in the frequency domain. The spatial and frequency domains describe the same³⁴ signal with different emphasis, periodic components usually are clearly visible in the frequency domain.

9.1.2. Technical Considerations

The following sections provide technical notes about the properties of the Fourier transform which can usually be skipped on the first reading. Interpretation of Fourier transform results however require some knowledge of the assumptions and consequences of the transformation. The FFT algorithm is just some clever arrangement of mathematical operations to calculate the Fourier transform efficiently. Implementations can be found in many text books, so it can be treated as a black box here. The discussion concentrates on 2D Fourier transform.

Any discrete Fourier transformation **assumes** that the signal is **periodic** in the spatial domain. This means, that the profile is tiled in X and Y direction. The first value of the signal immediately follows the last value at the 'right' end, the same applies for the Y direction. In the figure below the signal is shown in orange, and the tilings in blue.

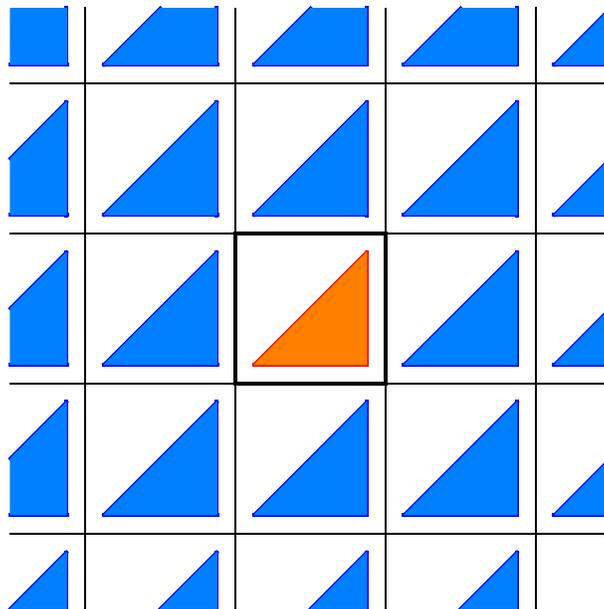


Figure 28: Periodic tilings

³⁴ the signals are not identical though, since the basis vectors of the frequency domain are periodic, while the spatial data usually is not. Furthermore, the transformation is continual, and can not converge to a discontinuous signal. The 'energy' of the difference of the signals however can be made arbitrarily small. Consult a mathematics textbook for details.

In practise, measurement data is neither periodic, nor does the measurement length exactly represent one period (or multiple thereof) of some imaginary tilings. The discrepancy impacts the results in the frequency domain, including amplitude readings and leakage. Many measures are known to reduce the spurious signals. In each case, some compromise in the spatial domain versus effects in the frequency domain is performed.

The so-called *windowing functions* diminish the erroneous signals in the frequency domain by multiplying the values of the spatial domain by some smooth function which is 1.0 in the centre and fades to 0.0 towards the borders. There are a lot of windowing functions, each having some specific influence on the frequency domain³⁵. By employing a windowing function, a (usually irreversible) distortion of the spatial data always occurs. At the time of writing, Inspector does not implement windowing.

Another strategy used frequently is to reduce the differences between the horizontal and vertical borders by levelling. To use this approach, select *Process/Levelling/by operator's selection*, select most of the measurement area leaving only a small rim, and select exclude.

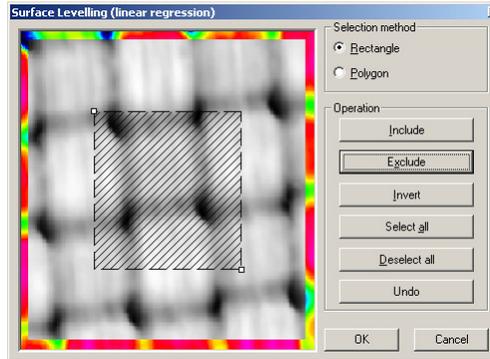
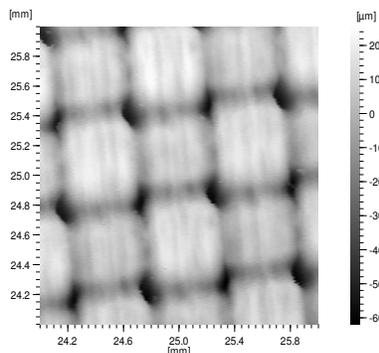


Figure 29: Levelling along the rim

This strategy is frequently sufficient to reduce the average value of the whole profile, else select *Process/Levelling/Z axis translation*, accept the translation, and press return. It is recommended to remove the DC component or average value as illustrated, or it will usually be the dominant component in the frequency domain.

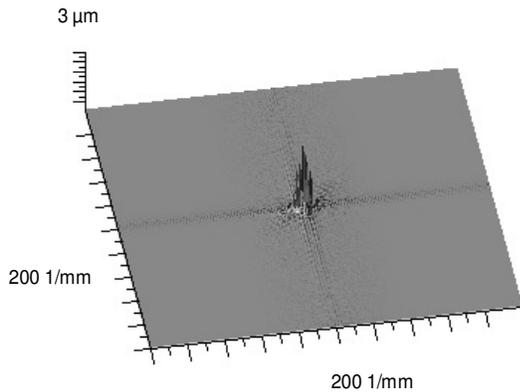
Some example of a Fourier transform of some typical profile, with or without windowing function.



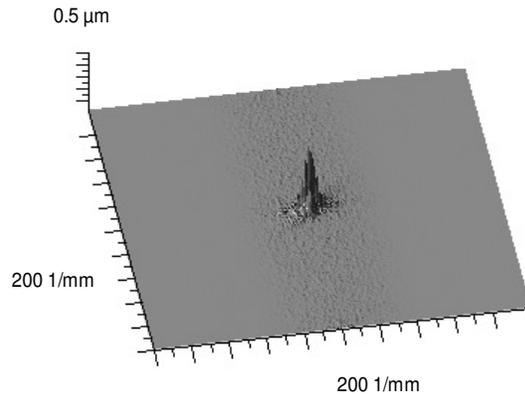
Source data, rim-levelled, DC component removed

³⁵ usually a compromise between side lobe suppression and leakage

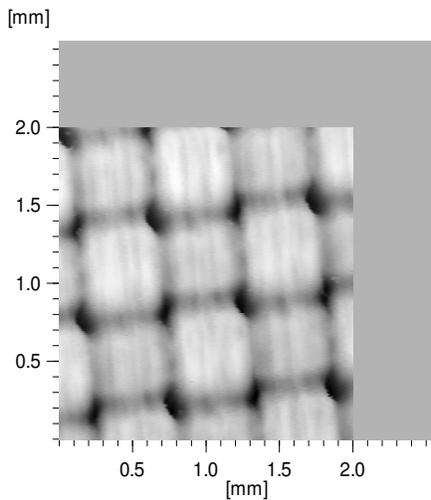
no windowing function



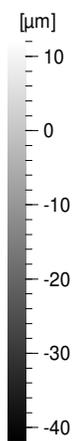
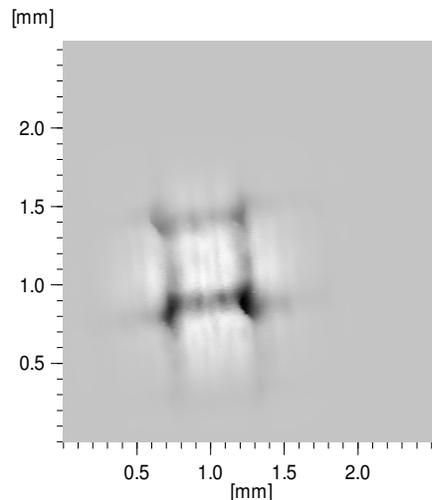
including Parzen windowing function



after transform, amplitude diagram. The horizontal and vertical lines through the centre are artificial, since the profile is not periodic modulo the measurement length.



after transform, amplitude diagram. The artificial signals are absent, but the windowing function affects the amplitudes (compare vertical scales).



reverse transformation, the source profile remains unchanged. Concerning the gray border, see the comment below.

reverse transformation. The windowing function has distorted the profile significantly.

Implemented the straight way, the Fourier transform requires extensive calculations, which are intolerable in terms of time and numerical stability. Several clever rearrangements of the basic formula have been devised, leading to a class of algorithms commonly *called fast fourier transform*, FFT in short. These algorithms exploit symmetries of the sine and cosine functions. Usually, the data is split into two or more sequences, each sequence treated recursively and afterwards combined again. For each split number (and later combination), a special algorithm is required. Many FFT algorithms are limited to a small number of manually optimised split size handlers³⁶, which allows for decomposition of a limited set of data sizes³⁷.

³⁶ e.g. handlers for 2, 3 and 5 sequences.

This process works best, if the data size can be represented as a product of numbers implemented by the algorithm. So, if the data size can not completely decomposed, a general solving algorithm is required, which is usually ineffective compared to the handlers implemented.

Some numbers, like 1009, are prime, and therefore not suitable for decomposition. A FFT algorithm trying to process prime size data sets is usually too slow and inaccurate for practical use. There are several strategies dealing with data set sizes which do not readily break up into the 'preferred' sizes of algorithm:

1. Do a Fourier transform on the data size, no matter the cost.
2. Stretch or shrink the data set size to the next number which can be conveniently handled by the algorithm. This step involves interpolation and filtering.
3. Pad the data with zeros up to the next number which can be conveniently handled by the algorithm.
4. Truncate the data to the next smaller number which can be conveniently handled by the algorithm. Data gets lost.

Inspector uses strategy number 3. The algorithm implemented at the time of writing operates on numbers of two only. Therefore, the data set is padded with zeros to the next power of two.

9.1.3.FFT operation

Menu item *Process/FFT/FFT* performs a real number³⁸ FFT. The $n = 2^M$ elements of the spatial domain get transformed into $\frac{n}{2} + 1$ elements in the frequency domain. The maximum frequency is defined by half of the sampling frequency, the resolution by the reciprocal of the measurement length. To increase resolution, the measurement length must be increased,. To increase the maximum frequency, the sampling density must be increased. This observation applies individually to the primary and secondary axis. Caused by the real valued transform there are symmetries in the frequency spectrum. The frequency spectrum is initially shown in complex form (real and imaginary part). For manual investigation it is usually convenient to convert the spectrum into amplitude and phase form.

9.1.4.Inverse Fourier transform

The inverse Fourier transform transforms a spectrum back into the spatial domain. This operation requires a complex spectrum (either as real/imaginary or amplitude/phase pair)³⁹. At the time of the inverse transformation, the absolute X/Y co-ordinates of the measurement data get lost. The operation is available using the menu item *Process/FFT/inverse FFT*, at least one complex spectrum channel is required.

³⁷ e.g. any number which can be expressed in the form $n = 2^A * 3^B * 5^C * \dots$ where A,B,C mean integer numbers greater or equal to zero. (prime factor expansion)

³⁸ complex FFT is available from script level only.

³⁹ Inspector substitutes a missing imaginary part by a zero spectrum, however the result of the inverse transformation is usually useless.

9.1.5. Spectrum conversion between real/imaginary and amplitude/phase format.

There are two ways to represent a complex spectrum. The first representation relies on coefficients a_i, b_i of the complex sinusoidal $b_i \cos(i\omega) + ja_i \sin(i\omega)$, where the a_i are assigned to the imaginary channel, and the b_i to the real channel. This representation is called real/imaginary format, and is most useful for mathematical analysis and processing.

The second representation, called amplitude/phase format, uses the representation $c_i \cos(i\omega + \varphi_i)$

with $c_i = \sqrt{a_i^2 + b_i^2}$ and $\varphi_i = \arctan(\frac{a_i}{b_i})$. The c_i are called the amplitude channel, the φ_i the phase

channel. The latter representation is the preferred format for manual evaluation⁴⁰. Inspector is able to convert between the two representations by *selecting Process/FFT/Re, Im to Amplitude and Phase* resp. *Process/FFT/Amplitude, Phase to Re, Im*. The operations are available only on complex spectra.

⁴⁰ since the amplitude c_i is some accustomed physical property.

10.Template based printing

10.1.Abstract

Template based printing is based on HTML template files, which can be modified or provided by the user. At the time the print command is issued, Inspector reads the template file, and generates a result HTML file, generating the requested items on the fly. The result file gets displayed (or printed) by the system's default HTML browser.

For each type of output (e.g. 3D, colour keyed view, line diagram), a default template is provided during installation.

The user interaction within Inspector is based on views, which show certain aspects of the data. For a printout, it is usually necessary to combine, or even generate on the fly, the contents of several views. The print template represents a page-oriented description, and the print processor has the obligation to bridge the two different models.

Note: At the time of writing, three different types of templates belong to the specification of Inspector.

- **Static templates.** The print processor gets a reference to the view which has issued the print command. The template enforces a fixed arrangement of diagrams and text. It is impossible (without modification to the template) to replace e.g. a colour keyed view with a 3D diagram, it is also not possible to show two unrelated data sets in one printout at the same time. **Advantage:** The print process does not require any user interaction, diagrams which are requested by the template may already be open and customised, or these will be generated on the fly. If a template request for example a 3D diagram, a profile section and a colour keyed view, but only a colour keyed view is present in Inspector, the print processor copies the colour keyed view, and generates the missing diagrams due to built-in rules. Views showing different data are not considered.
- **Fixed layout, interactive templates.** These templates also enforce a fixed arrangement of diagrams and text. At the time of printing, a dialogue gets displayed to select the print data and view. Drag the cross hair into the desired view to make your choice. The diagram style must match the type expected by the template⁴¹, but may be based on different data. **Advantage:** The selection of data is up to the operator, within the regulations of the template. Missing elements are generated as indicated above.
- **Interactive templates:** These templates only define several positions, which can be filled in by the operator. At the time of printing, a dialogue gets displayed to select the print data and view. Drag the cross hair into the desired view to make your choice, the style of the diagram selected does not matter. **Advantage:** The arrangement of diagrams is up to the operator. Prior to printout, open and customise all desired views, and select the views one by one. The diagrams are taken over to the printout as shown.

Concerning the use of the different template types, the following notes may provide a guide line:

- Use static templates to generate a printout which does not require any user interaction. The appearance can be influenced by opening and manually configuring the view types requested by

⁴¹ this is enforced by the selection dialogue.

the template. Missing views are generated by the print processor. Consistency (in the sense the author of the template) is enforced. This type of template is best to generate fixed reports over and over.

- Use interactive templates to put together an arrangement of diagrams. Using the 'one diagram per page' template emits markers and roughness parameters too.
- Use Fixed layout, interactive templates to produce some standardised output, e.g. there is your logo on the top, top left a 3D diagram, to the right a colour keyed view. The actual contents, this is the diagram displayed, has to be selected by the operator.

<i>Template</i>	<i>Type</i>	<i>Comments</i>
Profile.htm	static	shows logo, protocol, profile, reflection of a line diagram
Topo.htm	static	shows logo, protocol, colour keyed view, and line section
Isometric.htm	static	shows logo, protocol, two 3D views from different positions and a line section
Isometric2.htm	static	shows logo, protocol, 3D view
Topo+Profile+Roughness.htm	fixed layout	shows logo, protocol, colour keyed view, profile section and the roughness parameters of the section.
Profile+Roughness+Marker.htm	fixed layout	shows logo, protocol, profile section, roughness parameters and marker parameters.
Topo+3D+Profile+Roughness.htm	fixed layout	shows logo, protocol, 3D diagram, profile section, roughness parameters.
<i>Print/Predefined styles/One diagram per sheet</i>	interactive	shows protocol and the diagram selected by the operator, information of marker (if present), roughness parameters (if calculated).
<i>Print/Predefined styles/Two diagrams per sheet</i>	interactive	shows two diagrams including protocol selected by the operator.
<i>Print/Predefined styles/Four diagrams per sheet</i>	interactive	shows two by two diagrams including protocol selected by the operator.

10.2. The printout process

10.2.1. Outline of the print process

Selecting menu item File/Print/HTML print, Inspector opens the template associated with the view style. The template includes keywords for diagrams and text fields. Inspector analyses the keywords and generates the data requested. In case of a diagram, Inspector renders the bitmap required. If the diagram is already opened in the workspace, Inspector copies all properties (like palette, display limits, rotation, illumination), but parameters explicitly provided within the template take precedence. If the diagram is not present on the screen, Inspector generates a new one using default parameters and parameters provided in the template.

Afterwards, Inspector copies the expanded template including all diagrams generated into the temporary directory and starts up the system's default HTML browser, either for viewing the results or immediate printout).

Templates are located in the <installation path>/lib/site-packages/pymess/templates subdirectory. For each supported national language, there is a subdirectory identified by a code number (e.g. 1031 for German, 1033 for British-English, 2057 for American-English).

10.2.2. Interactive templates

Prior to printout, open and customise (e.g. palette, manual scaling, illumination) the desired views on the screen. We recommend to minimise all windows not required for the printout, and to arrange the required views side by side.

Start printout either by menu item *File/Print/Predefined Styles/One diagram per sheet* to *Four diagrams per sheet* or by one of the tool bar symbols .

Inspector opens up the dialogue Select Diagram. Depending on the print template used, the dialogue holds up to four cross hairs. Press the left mouse button on top of one of the symbols, keep the mouse button pressed, and drag the cross hair onto the window desired. Release the mouse button. Repeat the process for each diagram desired. Accept your selection by pressing the OK button of the dialogue. The figure below shows that the last cross hair does not get associated. The corresponding position in the printout will therefore be unoccupied.

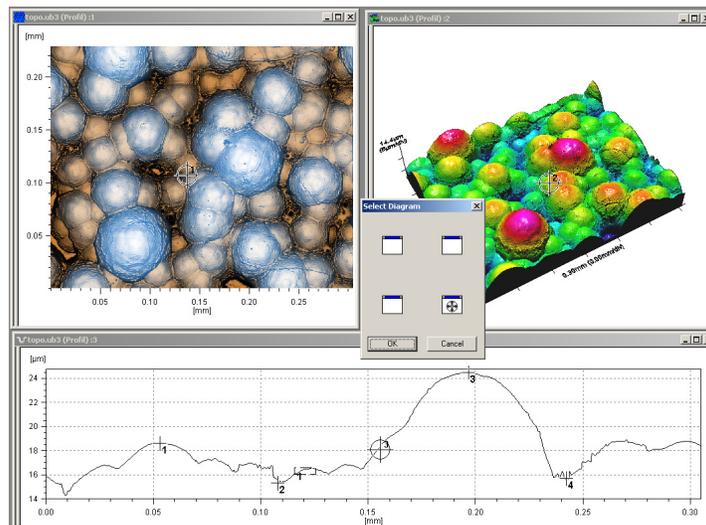
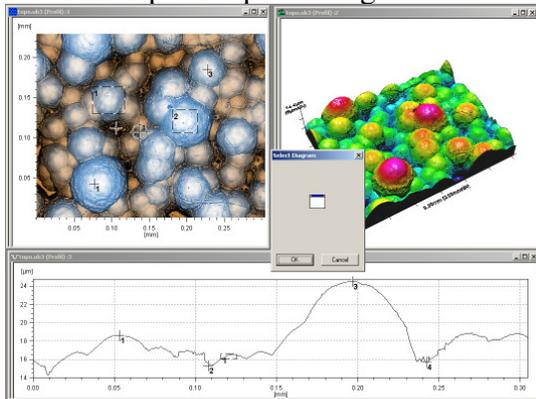


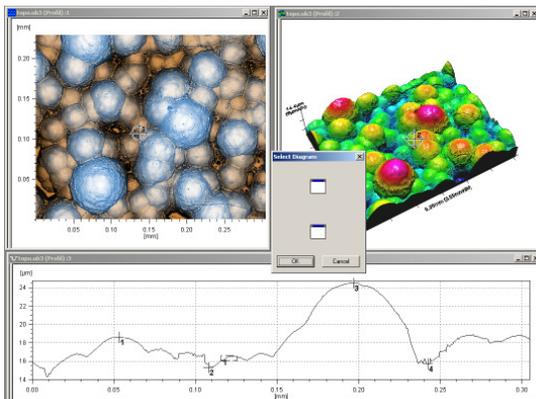
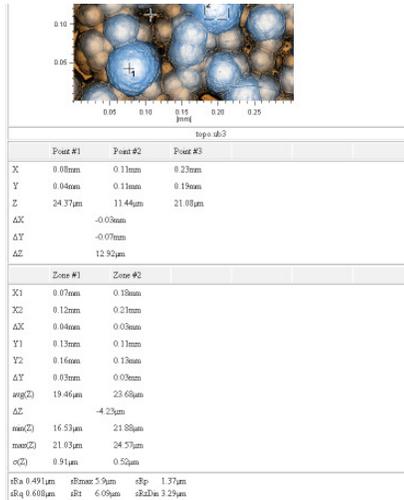
Figure 30: Interactive Diagram Association

Sample template assignment

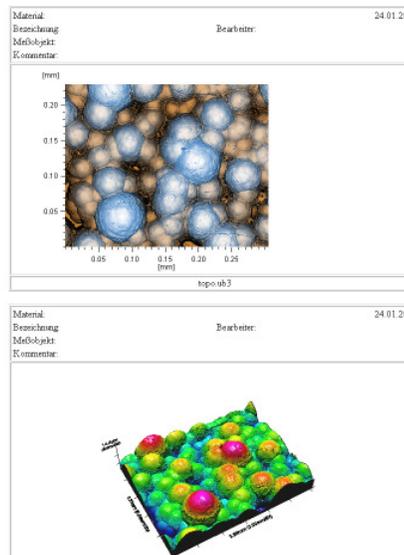


One diagram per sheet

Print results

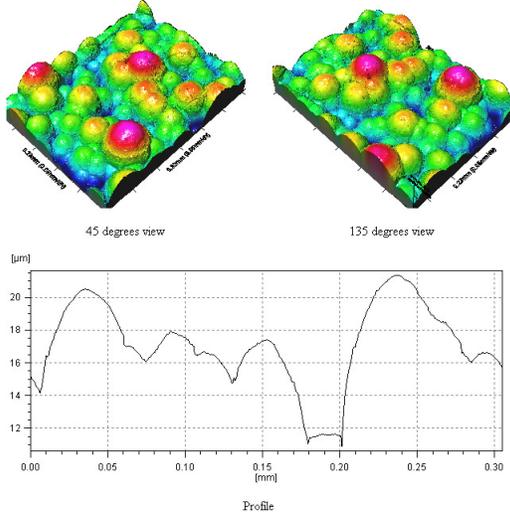


Two diagrams per sheet



Measurement Protocol

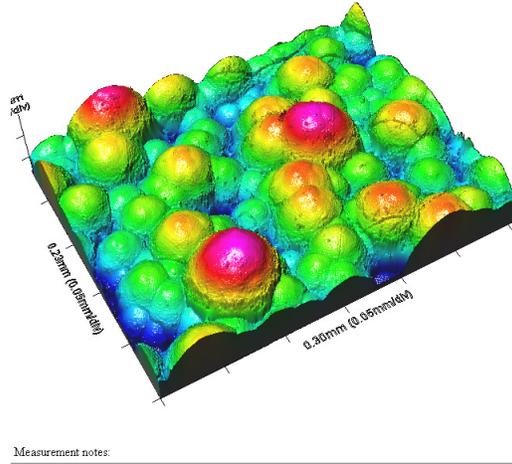
Material: Bezeichnung:
 Bearbeiter: Dimensions: 0.305 mm x 0.229 mm
 Date: 2008-14-24 13:14:04



Isometric.htm

Measurement Protocol

Material: Bezeichnung:
 Bearbeiter: Dimensions: 0.305 mm x 0.229 mm
 Date: 2008-14-24 13:14:04



Measurement notes:
 Operator:

Isometric2.htm

standard print templates

For each type of view (line diagram, colour keyed view, 3D), a print template gets associated. The default assignment is stated in the table below:

Type of view	Template
Line diagram	Profile.htm
Colour keyed view	Topo.htm
3D view	Isometric.htm

Select menu item *File/Print/HTML Print...* to request a printout. Inspector generates the dialogue *Preferences for HTML print output*⁴². Press the OK button to start printout with the dialogues settings.

The dialogue Preferences for HTML print output provides for the configurations indicated next. The settings are unique to the view style, so different configurations are allowed (and necessary).

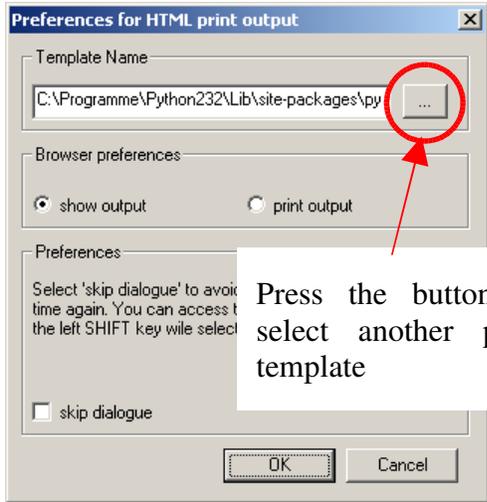
- Having generated the output file and diagrams, the result can either be displayed in the system's default browser, or rather printed immediately. Select the radio button *show output* to view the output in the browser, or *print output* to print without showing the browser. Please note that the printer settings within Inspector do not apply to the browser (this is an external application). So you may need to configure the browser ahead, or select the printer desired for output as the system's default printer.
- The controls within the pane Template Name show and select the print template to be used for printout. Press the button control *...* on the right to select the print template desired. Inspect-

⁴² If the printout starts immediately, without showing the dialogue, press the left shift key prior to selecting HTML print.

or shows a standard file open dialogue to select the new template. The print template chosen should be compatible with the view style.

- The check mark control *skip dialogue* defines whether the dialogue shall be displayed prior to printout or skipped. As you can see from the description, pressing the left shift key while issuing the print instruction shows the dialogue even if it was disabled previously.

Note: The print template should be configured independently for line diagrams, colour coded views and abbot diagram. The selection is saved for later use. Please make sure that the template chosen matches the diagram, else partial printout will result.



Type of view	Profile.htm	Topo.htm	Isometric.htm	Isometric2.htm
profile diagram	✓			
colour keyed view	✓	✓	✓	✓
3D diagram	✓	✓	✓	✓

compatibility chart

10.2.4.Fixed layout, interactive templates

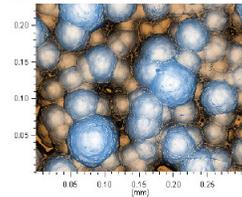
The templates illustrated in the section above rely on keyword expansion, and expose only a tiny fraction of the flexibility of the print processor. For special requirements, it is possible to use the print processor for arbitrary operations, like generation of an Excel^(R) sheet, preparation and transmission of an email, generate and update a control chart, data export to data bases etc. For this purpose, a python script has to be embedded within the template responsible for the output. Print templates Profile+Roughness+Marker.htm, Topo+3D+Profile+Roughness.htm and Topo+Profile+Roughness.htm employ this strategy.

Put your logo here

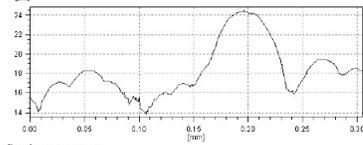
Measurement Protocol

Material:	Date:	14.04.2008
Bezeichnung:	Bearbeiter:	
Mefobjekt:	Bezeichnung:	
Measurement parameters:	0.30mm x 0.23mm, 768 x 582 = 446976 points	

Topography



Profile



Roughness parameters

Ra 0.334µm Rmax 2.23µm Rp 0.618µm Rq 0.423µm Rt 2.23µm
RzDin 1.14µm

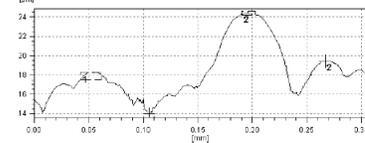
Topo+Profile+Roughness.htm

Put your logo here

Measurement Protocol

Material:	Date:	14.04.2008
Bezeichnung:	Bearbeiter:	
Mefobjekt:	Bezeichnung:	
Measurement parameters:	0.30mm, 2514.75 points/mm, 768 points	

Profile:



Roughness parameter:

Ra 0.334µm Rmax 2.23µm Rp 0.618µm Rq 0.423µm Rt 2.23µm
RzDin 1.14µm

Marker positions:

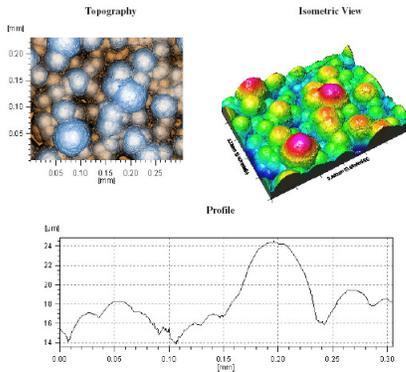
	Point #1	Point #2
X	0.11mm	0.27mm
Z	13.97µm	19.43µm
ΔX	-0.16mm	
ΔZ	-5.47µm	
	Zone #1	Zone #2
X1	0.04mm	0.19mm
X2	0.06mm	0.20mm
ΔX	0.02mm	
avg(Z)	18.11µm	24.32µm
ΔZ	-6.21µm	
min(Z)	17.52µm	24.17µm
max(Z)	18.32µm	24.56µm
σ(Z)	0.21µm	0.09µm

Profile+Roughness+Marker.htm

Put your logo here

Measurement Protocol

Material:	Date:	14.04.2008
Bezeichnung:	Bearbeiter:	
Meßobjekt:	Bezeichner:	
Measurement Parameters:	0.30mm x 0.23mm, 768 x 582 = 446976 points	



Roughness parameters

Ra	0.334µm	Rmax	2.23µm	Rp	0.618µm	Rq	0.423µm	Rt	2.23µm
RzDin	1.14µm								

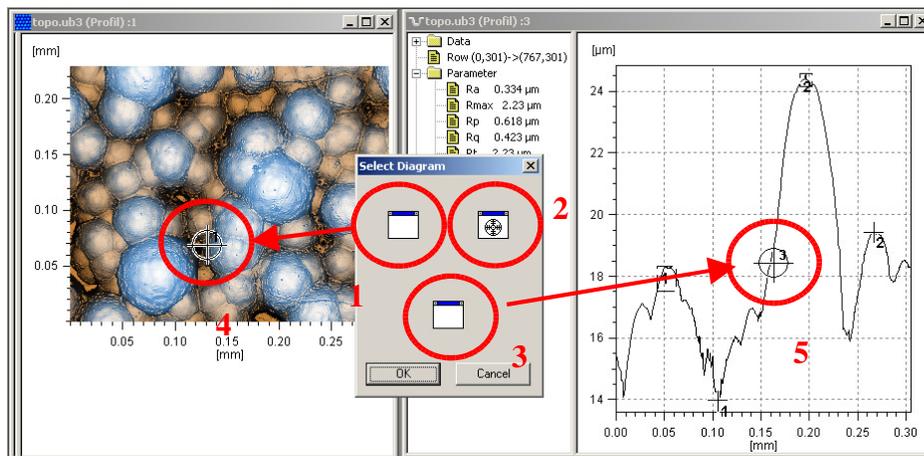
Topo+3D+Profile+Roughness.htm

The templates are situated in the folder <install path>\lib\site-packages\pymess\templates\2057, for technical reasons, the embedded code is saved externally named tpr.py, prm.py and t3dpr.py. Furthermore, the company logo *logo2.gif* is required.

Select one of the templates from within the dialogue Preferences for HTML print output as describe in the previous section.

The print processor is capable to generate all required diagrams and text data based on the view which requested print output. First, the print processor look up all diagrams matching the template, and copies attributes like markers, manual scaling, palette etc. This process shall be named 'automatic selection' further on.

Next, the operator can modify the selections:



In the figure above, the numbers 1, 2, 3 represent the diagrams of the template. The window symbols 1 and 3 do not show a cross hair, indicating that Inspector has looked up matching diagrams

in the workspace. The assignments are indicated by the cross hairs 4 and 5. Window symbol 2 shows a cross hair, therefore no automatic association took place. This diagram (3D diagram in this case) will be generated automatically.

At this point, it is possible to alter the automatic selection. Press the left mouse button for example on top of window symbol 1, keep the button pressed and drag the cross hair on top of the desired diagram. Release the mouse button. To make selection easier, it is recommended to arrange the diagrams side by side prior to printing (try Windows/Arrange horizontally). Confirm your selection by pressing OK.

The print generator generates diagrams and text data and provides the HTML page to the system's browser.

The following rules apply:

- The measurement protocol is extracted from the measurement data of view number one. The prompt strings (e.g. operator, project, company etc), together with the information, are saved within the measurement data file. Prompt strings and information are configurable by the operator, for example prior to measurement, or after loading. The strings have no dedicated meaning to Inspector.
- The information regarding width and height is taken from the first view.
- The date is part of the measurement protocol and also taken from the protocol of the first view.
- Roughness parameters and markers are taken from the last view.
- Roughness parameters are calculated automatically if not present in the last view. The settings (essentially the set of parameters and cutoff) is taken from the last interactive invocation of the roughness parameter dialogue. This may lead to surprises, if the cutoff does not match the dimension of the data of the last view. It is therefore recommended to calculate parameters explicitly.
- Markers are not generated automatically. If there are no markers present in the last view, the marker info list remains empty⁴³.

10.2.5. Generating custom templates

10.2.5.1. Abstract

This section details on static templates, which do rely on keyword substitution only. Have a look at the sample templates provided. These are generated manually, and well structured. The templates may also provide for a suitable starting point for your custom template. If you really need the flexibility of embedded code templates, you are strongly advised to have a look at the samples tpr.py, t3dpr.py and prm.py. It may prove easier to copy and modify the code there than rolling your own implementation. You can also contact Inspector's distributor and ask for a quote for your custom requirements.

In order to create and test the templates, it is best to switch Inspector into development mode. Locate and double-click the file develop.reg in the folder Extras of your installation CD. Restart Inspector. Now, in addition to the production functionality, the entire python IDE including editor, scripting engine, interactive console and python help files is available. Select *File/New* from the main menu, select Python script (this creates an empty script window, but more import-

⁴³ applies to template Profile+Roughness+Marker.htm only, others do not have the marker position list.

antly exchanges the main menu with the IDE menu) and select *View/Interactive window*. You may also select *Show at startup* and *Dockable window* from the options dialogue (View/Options in the main menu).

10.2.5.2.Keyword substitution

The specification of Inspector include some print standard templates, which can be modified to suit your requirements. Alternatively, you can create a template from scratch. You can either use a dedicated HTML editor (e.g. Frontpage[®], Composer[®], MS Word[®]), or some arbitrary text editor (syntax highlighting is recommended, e.g. Programmers Notepad available from Sourceforge)⁴⁴.

The HTML skeleton, i.e. fixed elements like text and images including logo and fancy headers are best generated and positioned by the functions provided by the HTML editor. If you have to use a plain editor, it is best to copy and customise the body of one of the standard templates. Keyword arguments have to be entered in the literal form [?? keyword ??] , outside any HTML comment.

To embed one of Inspector's diagrams, most HTML editors need some dummy bitmap file to proceed. Start up any graphics program, e.g. even Paintbrush, create an empty bitmap of size e.g. 100x100 pixels, and save this bitmap using the names *~3d.bmp*, *~profile.bmp* and *~topo.bmp* in the directory holding your custom template. Now you can use these proxy files to request Inspector's diagrams.

Embedding bitmaps with reserved names requests the diagrams indicated next:

<i>bitmap name</i>	<i>diagram style</i>
<i>~3d.bmp</i>	isometric view (3D diagram)
<i>~profile.bmp</i>	line diagram
<i>~topo.bmp</i>	colour coded view
<i>~bearing_diagram.bmp</i>	abbott (bearing area) diagram
<i>~amplitude_diagram.bmp</i>	amplitude distribution diagram

If the HTML editor permits resizing of the diagrams, you can place and size the proxies interactively. Otherwise, you can either resize the bitmap (at the same time forcing the new size in the HTML editor), or you can change the size manually using any ordinary editor. Please note that Inspector will later on generate a bitmap of the size specified in the HTML file.

Keyword expansion is requested by placing expressions within markers of the type [?? and ??] in text blocks. To avoid parsing errors, do not insert a line break within the expression (keep it within one line), and do not insert format changes (e.g. font change, bold, colour) within the brackets (you can change the attributes before and after the brackets though).

In the course of substitution the expression gets evaluated, and the result replaces the bracketed section. The term 'expression' implies that arithmetic operations and function calls are possible. Syntax and semantics are the same as python-expressions which employ pretty standard notation. For many purposes one does not need to consult more than the tables below. Please consider that

⁴⁴ An excellent reference to the HTML language is available from <http://de.selfhtml.org/>

many terms consist of composite objects, providing attributes, properties and methods. Most of the objects are able to generate textual outputs (just by requesting them for substitution, see roughness parameters for examples). Attributes, properties and methods are accessed using the dot-operator (see examples).

10.2.5.3. Global namespace

Within the global scope, the names below are defined:

<i>Name</i>	<i>Type</i>	<i>Interpretation</i>
data	object <Data>	data object (containing one or more channels, one of those is visible in the view requesting printout, see channel).
channel	object <Channel>	channel within data, which is visible in the view requesting printout.
prot	object <Protocol>	measurement protocol of the data object ⁴⁵ .
math	module	python standard module math, holds square root, arcus tangens etc. See the python documentation (e.g. help file) for a module listing.
width	string	width of channel's measurement data, including unit string ⁴⁶ .
height	string	height of channel's measurement data, including unit string ⁴⁷ .
pts	integer	number of points per line in channel ⁴⁸ .
lns	integer	number of lines in channel ⁴⁹ .
date	object <Date> ⁵⁰	measurement date taken from the measurement protocol ⁵¹
description	string	Literal description of the channel's data ⁵² .
ranges	python list holding zero or more object <Range>	list of all range markers of all views showing this data set.
Ranges	python list of lists holding zero or more objects <Range>	similar to ranges, but grouped by view. Ranges[i] is a list of object range of one view only.
points	python list holding zero or more object <Point>	list of all point markers of all views showing this data set.
Points	python list of lists holding zero or more objects <Point>	similar to points, but grouped by view. Points[i] is a list of object range of one view only.
rough	object <RoughAll>	Union of all roughness parameters already calculated of all views showing data set data.
Rough	python list holding	roughness parameter, grouped by view. Rough[i] holds all

⁴⁵ identical with the attribute protocol inside the object <Data>

⁴⁶ identical with the attribute width inside object <Channel>

⁴⁷ identical with the attribute height inside object <Channel>. Only relevant for area data.

⁴⁸ identical with the attribute points inside object <Channel>

⁴⁹ identical with attribute lines in object <Channel>, 1 for line data.

⁵⁰ this object emits has a built-in conversion to string, and emits a string in the format mm.dd.yyyy.

⁵¹ identical with the attribute date within object <Protocol>

⁵² identical with the attribute description within object <Channel>

	zero or more objects <Rough> string	roughness parameters calculated by one view. Name of the folder containing the print template ⁵³ .
--	---	--

To access one of the global names, use the expression [?? *name* ??] with *name* indicated above, e.g. [?? pts ??] or [?? pts * lns ??] or [?? points[0].z ??] or [?? "%02d.%02d.%04d" % (date.-month, date.day, date.year) ??] (all without line breaks. The latter expression outputs the date in the format dd:mm:yyyy, and is standard python % formatting similar to sprintf(format, args).).

10.2.5.4.Object <Data>

This object holds the measurement data, consisting of one or more channels, e.g. profile and reflection data. The measurement protocol is located here too.

<i>Name</i>	<i>Type</i>	<i>Interpretation</i>
protocol	object <Protocol>	Measurement protocol of the data. Identical with the global name protocol.
channels	python list holding object <Channel>	list of all channels of the data. You can process the list using standard python properties (e.g. len(channels), channels[i] etc).

Furthermore, method channel(code) is available. The method accepts a channel code argument (integer or string) and returns a object<Channel>. You can get a list of channel codes either by calling data.GetChannels() (results in a list of strings) or by using the expression [chan.Datatype for chan in channels] (including brackets, without line break, results in a list of integers). The strings are generated at the time of measurement or first import, and depend on the language settings of that time. You can also use the table below to request some specific channel⁵⁴.

channel code interpretation

- 0 unknown, or invalid channel
- 1 (primary) profile channel
- 2 (primary) reflection channel
- 3 power spectrum
- 4 auto correlation function
- 5 cross correlation function
- 6 amplitude of the sine signal (for 'thin film' measurements)
- 7 focus error signal
- 8 film thickness channel (confocal mode)
- 9 differential phase contrast
- 10 XM signal (secondary, non-linearised profile signal)
- 11 guard signal (amount of 'stray light' reaching the detector)
- 12 secondary reflection channel
- 13 laser current
- 14 coil current
- 15 diode signal

⁵³ useful for embedded code. See Topo+3D+Profile+Roughness.htm for an example.

⁵⁴ if the channel requested is not present, none is returned.

16	real part of the FFT
17	imaginary part of the FFT
18	phase of the FFT
19	film thickness channel (interferometric mode)
20	variance channel
21	encoder position (coherence radar)
22	profile 1 (coherence radar)
23	profile 2 (coherence radar)
24	amplitude 1 (coherence radar, thickness measurement)
25	amplitude 2 (coherence radar, thickness measurement)
26	coherence radar, amplitude channel
27	primary axis' co-ordinate
28	secondary axis' co-ordinate
29	amplitude distribution
30	bearing area distribution
31	histogram (of some channel)

Table 1 : Channel codes

To access properties and methods, use the dot operator. Let *x* be some object of type <Data>, then *x.protocol* yields the protocol (of type <Protocol>), and *x.channel(1)* yields the profile channel of type <Channel>.

10.2.5.5.Object <Channel>

These objects hold the data of one measurement channel. Any individual value is accessible. Some informative operators are also available.

Note: The object supports two different types of interface. Data and information is available in 'cooked' (results are represented as strings, usually of the form value + unit) or 'raw' format (results are numbers or strings, e.g. just the value, or just the unit). Cooked access is most convenient for output purposes, while raw access is suited for processing (e.g. calculating some dedicated statistical value).

Identifiers starting with a small letter indicate a raw interface, capital letters a cooked interface.

<i>Name</i>	<i>Type</i>	<i>Interpretation</i>
width	string	length of the profile, or width of the base rectangle of the channel. String includes the unit. Example: 25.4mm.
Width	double	length of the profile, or width of the base rectangle of the channel. Attribute <i>xunit</i> holds the unit associated.
height	string	height of the base area of the channel, only relevant for area measurements. String includes unit.
Height	double	height of the base area of the channel, only relevant for area measurements. Attribute <i>yunit</i> holds the unit associated.
points	integer	number of samples per line (applies to profiles and area measurements).
lines	integer	number of measurement lines (1 for line measurements, >1 for area measurements)
total	integer	total number of samples per measurement, identical width points * lines.
minimum	string	minimum value of all valid points of the channel, including unit.
Minimum	double	minimum value of all valid points of the channel. Attribute <i>unit</i> holds the

maximum	string	unit.
Maximum	double	maximum value of all valid points of the channel, including unit.
datatype	string	maximum value of all valid points of the channel. Attribute unit holds the unit.
Datatype	integer	string describing channel type, see the channel code table above.
name	string	channel code indicating type of channel, see the channel code table above.
		data contents description of the channel. This string is generated either at the time of measurement, import or production of the channel. May be different from datatype.
xunit	string	unit of the primary axis (horizontal axis)
yunit	string	unit of the secondary axis (vertical axis) for area measurements only.
unit	string	unit of the measurement values
description	string	information string of the channel data. The string is generated either at the time of measurement, import or production of the channel.
average	string	arithmetic mean value of all valid items of the channel, including unit.
Average	double	arithmetic mean value of all valid items of the channel. Attribute unit holds the unit.
sigma	string	standard deviation of all valid items of the channel, including unit.
Sigma	double	standard deviation of all valid items of the channel. Attribute unit holds the unit.
linestep	string	distance between two consecutive lines of an area measurement, including unit.
Linestep	double	distance between two consecutive lines of an area measurement, including unit. Attribute yunit holds the unit.
pointstep	string	distance between two consecutive points of a profile or area measurement (sampling distance), including unit.
Pointstep	double	distance between two consecutive points of a profile or area measurement (sampling distance). Attribute xunit holds the unit.

Furthermore, the following methods for accessing the measurement data are available:

<i>Name</i>	<i>Arguments</i>	<i>Result type</i>	<i>Interpretation</i>
at(x,y) or at(x) or at((x,y))	integer x,y x and y represent the row and column index numbers. The lower left side has the co-ordinates 0,0. Index x must be within the range 0..points-1, y within 0..lines-1.	string	return the value of data element at the position x,y, including unit. The y co-ordinate defaults to 1, and can be omitted on profile data. See Pos2idx for mapping world co-ordinates to row/column index.
At(x,y) or At (x) or At((x,y))	integer x,y Interpretation and valid range please see above.	double	return the value of data element at the position x,y. The y co-ordinate defaults to 1, and can be omitted on profile data. See Pos2idx for mapping world co-ordinates to row/column index.

			Attribute unit holds the unit.
idx2pos(x,y) or idx2pos(x)	integer x,y 0<=x<=points-1 0<=y<=lines-1	string: (x xunit, y yunit)	returns the world co-ordinates of the row/column index x,y including units. The y co-ordinate defaults to 1, and can be omitted on profile data.
Idx2pos(x,y) or idx2pos(x)	integer x,y 0<=x<=points-1 0<=y<=lines-1	tuple (x',y')	returns the world co-ordinates of the row/column index x,y. The y co-ordinate defaults to 1, and can be omitted on profile data. The primary and secondary axis' units are available from attribute xunit and yunit respectively.
pos2idx(x,y) or pos2idx(x)	double x,y	string: (idx, idy)	transforms world co-ordinates to row/column index.
Pos2idx(x,y) or Pos2idx(x)	double x,y	tuple (idx, idy)	transforms world co-ordinates to row/column index which may serve as an argument to method at.

To access properties and methods, use the dot operator. Let x be some object of type <channel>, [?? x.total ??] calculates the total number of points, [?? x.at(0,0) ??] the value of the lower left data element of the channel, including unit.

10.2.5.6.Object <Date>

This object wraps the date as indicated in the measurement protocol.

Notes: This object includes a built-in string expansion, which expands to a string of type mm.d-d.yyyy⁵⁵. Expansion can be customised using method strftime. For a detailed description see the python help file, section 6.9 *datetime -- Basic date and time types*.

Only the most important attributes are listed here, the rest can be found in the python help file:

<i>Name</i>	<i>Type</i>	<i>Interpretation</i>
year	integer	year
month	integer	month, 1..12, 1=January
day	integer	day of month, 1..31
hour	integer	hour, 0..23
minute	integer	minutes, 0..59
second	integer	seconds, 0..59

For advanced customisation and formatting use function strftime(fmt). See the python help files, 6.10 *time -- Time access and conversions* for details.

⁵⁵ more precise: in the default format defined by the locale settings of the current operator. Use method strftime to perform dedicated formatting.

To access properties and methods, use the dot operator. Let x be some object of type <Date>, expression [?? x.month ??] returns the month (in integer format, which is propagated to a string).

10.2.5.7.Object <Protocol>

This object exposes the prompt strings and responses of the measurement protocol. The protocol consists of nine prompt strings and nine text strings. The protocol is part of the measurement parameter dialogue, and shall be entered prior to measurement.

<i>Name</i>	<i>Type</i>	<i>Interpretation</i>
Key0	string	prompt string of the first protocol line
Txt0	string	response string of the first protocol line
...		
Key7	string	prompt string of protocol line number eight
Txt7	string	response string of protocol line number eight
Key8	string	prompt string 'Comment' (fixed)
Txt8	string	response string of the comment line
date	Object <Date>	time and date of the measurement, or import.

Attributes Key0 to Key8 and Txt0 to Txt7 have a maximum length of 80 characters. The maximum length of Txt8 is 2000 characters.

To access properties and methods, use the dot operator. Let x be some object of type <Protocol>, the expression [?? x.Txt2 ??] retrieves the third user response string.

10.2.5.8.Object <Rough>

This object holds all roughness parameters of a single view. These parameters are visible in the information pane of the view.

Attributes of this object are generated dynamically, depending on the set of roughness parameters of the view. Some or all of the following attributes are available:

profile parameters	Rt, Rp, Rq, Pt, Lo, Mr1, Mr2, R3zm, Lr, Ra, NrS, Rk, Pavg, Wt, RzIso, D, Rmax, K, Sk, SM, Rvk, SST, RzDin, R3z, Rpk, Rpm
surface parameters	sR3zm, sRzIso, sMr2, sWt, sMr1, sRvk, sRmax, sSk, sRa, sR3z, sRk, sLr, sK, sRp, sLo, sRt, sRpm, sRpk, sPt, sRq, sPavg, sRzDin

Accessing one of the attributes yields an object of (or the string '####', if the attribute does not exist). Object <RoughItem> includes a built-in string expansion and can therefore be used in place of a string. The default expansion generates a string of the type "parameter=value unit" (e.g. sRa=3.45 µm). To emit some roughness parameter, expressions like [?? rough[0].Ra ??] are usually sufficient.

The standard dictionary helpers are implemented too:

<i>Name</i>	<i>Argument type</i>	<i>Result Type</i>	<i>Interpretation</i>
keys()	n.a.	list of strings	names of all roughness parameters available.
values()	n.a.	list holding objects<RoughItem>	values of all roughness parameters available, represented as object <RoughItem>.
items()	n.a.	list of pairs (key, value), key is a string, value an object<RoughItem>	key indicates the name of the roughness parameter, value the parameter's value represented as an object <RoughItem>.
len()	n.a.	integer	number of roughness parameters available
[key]	string	object<RoughItem>	retrieves roughness parameter <key> as indicated above, returns the parameter's value represented as an object <RoughItem> (or the string '#####' if it does not exist).

To access properties and methods, use the dot operator. Let x be some object of type <Rough>, access the individual parameters either by [?? x.Ra ??] or [?? x['Ra'] ??].

10.2.5.9.Object <RoughAll>

This object has the same methods, attributes and properties as object <Rough>. <RoughAll> is a union of all roughness parameters of all views based on the very same data set. It is possible to calculate different parameter sets in different views, even with different cutoffs etc. In case of multiple calculated parameters, the value is represented by the string '++++'.

This object is provided for convenience to cover the most widespread situation. Be careful, however, the parameters may result from different calculations.

10.2.5.10.Object <RoughItem>

This object represents the name, value, unit and description of a roughness parameter.

The following properties are available:

<i>Name</i>	<i>Type</i>	<i>Interpretation</i>
name	String	name of the parameter, e.g. sRa.
value	string	value plus unit of the parameter, or '#####' if invalid or '++++' if calculated more than once (only in object <RoughAll>).
unit	string	unit of the parameter, e.g. μm .
description	string	description of the parameter.
Value	double	numerical value of the parameter, 0.0 if invalid.
Valid	bool	valid-flag, false if parameter invalid, true if valid.

The object has integrated string formatting, if a conversion to string is requested, the string "parameter=value unit" (e.g. sRa=3.45 μm) will be generated.

10.2.5.11.Object <Point>

This object represents a cross hair position, displayed in the information pane of a view. The object hosts the attributes indicated next:

<i>Name</i>	<i>Type</i>	<i>Interpretation</i>
No	integer	number of the marker.
no	String	identifier of the marker, e.g. Point #1. No will be 1 in this case.
X	double	X (primary axis) position of the marker, in world co-ordinates. The unit of the primary axis can be retrieved from attribute XUnit.
x	String	X (primary axis) position of the marker, in world co-ordinates, including unit.
Y	double	Y (secondary axis, area data only) position of the marker, in world co-ordinates. The unit of the secondary axis can be retrieved from attribute YUnit.
y	String	Y (secondary axis, area data only) position of the marker, in world co-ordinates, including unit
Z	double	profile value of the marker in world co-ordinates. The unit can be found in attribute Unit.
z	String	profile value of the marker in world co-ordinates, including units.
XUnit	String	unit of the X (primary, horizontal) axis
YUnit	String	unit of the Y (secondary, vertical) axis, for area data only.
Unit	String	unit of the profile values (Z axis).

To access properties and methods, use the dot operator. Let x be some object of type <Point>, [?? x.no ??] returns the identifier of the marker (e.g. Point #3).

The object has integrated string formatting, if a conversion to string is requested, the string "Name=(x, y, z)" is generated.

10.2.5.12.Object <Range>

This object represents a rectangular area, displayed in the information pane of a view. The object hosts the attributes indicated next:

<i>Name</i>	<i>Type</i>	<i>Interpretation</i>
No	integer	region number.
no	string	identifier for the region, e.g. Range #3, No will be 3 in this case
X1	double	left side limit of the range, the unit can be found in attribute XUnit
x1	string	left side limit of the range, including unit.
X2	double	right side limit of the range, the unit can be found in attribute XUnit
x2	string	left side limit of the range, including unit.
Y1	double	<i>area data only</i> : bottom side limit of the range, the unit can be found in attribute YUnit.
y1	string	<i>area data only</i> : bottom side limit of the range, including unit
Y2	double	<i>area data only</i> : upper side limit of the range, the unit can be found in attribute YUnit.
y2	string	<i>area data only</i> : upper side limit of the range, including unit
Avg	double	arithmetic mean value of the data elements within the range. Attribute Unit holds the unit.

avg	string	arithmetic mean value of the data elements within the range, including unit.
Min	double	minimum value of the data elements within the range. Attribute Unit holds the unit.
min	String	minimum value of the data elements within the range, including unit.
Max	double	maximum value of the data elements within the range. Attribute Unit holds the unit.
max	string	maximum value of the data elements within the range, including unit.
Sigma	double	standard deviation of the data elements within the range. Attribute Unit holds the unit.
sigma	String	standard deviation of the data elements within the range, including unit.
Width	double	width of the area, i.e. X2-X1 , the unit can be found in attribute XUnit.
width	String	width of the area, i.e. X2-X1 including unit.
Height	double	<i>area data only</i> : vertical height of the area, i.e. Y2-Y1 , the unit can be found in attribute YUnit.
height	string	<i>area data</i> : vertical height of the area, i.e. Y2-Y1 , including unit. <i>profile data</i> : '####'
pos	string	position of the area. <i>area data</i> : (X1-X2, Y1-Y2) <i>profile data</i> : (X1-X2) numbers include co-ordinate units.
XUnit	String	unit of the X (primary, horizontal) axis
YUnit	String	unit of the Y (secondary, vertical) axis, for area data only.
Unit	String	unit of the profile values (Z axis).

To access properties and methods, use the dot operator. Let *x* be some object of type <Range>, then [?? *x*.width ??] generates the width of the range (including units), [?? *x*.Width * *x*.Height ??] calculates the area enclosed (in XUnit*YUnit). Unit conversions are possible, but should be performed within the <script> sections.

10.2.6. Configuration of diagrams

The diagram properties can also be configured. This usually has to be done in text mode, so save your file, and open it again in a text editor.

Diagram configuration has to be done within the tag. The style of the image is defined by the file name, listed here again for convenience:

<i>bitmap name</i>	<i>diagram style</i>
~3d.bmp	isometric view (3D diagram)
~profile.bmp	line diagram
~topo.bmp	colour coded view
~bearing_diagram.bmp	abbott (bearing area) diagram
~amplitude_diagram.bmp	amplitude distribution diagram

Look up the file name with the editor⁵⁶. The name should be located within an tag, which has as structure like that (the order of the attributes does not matter):

```
<IMG SRC="~/topo.bmp" WIDTH=579 HEIGHT=363 alt="">
```

Attributes width and height define the size of the bitmap generated. Inspector's print processor generates a bitmap of the requested size⁵⁷, therefore these attributes are **required**. In case your HTML WYSIWYG editor did not allow for resizing the proxy images, enter the desired size here now.

Apart from the required attributes src, width, height and alt⁵⁸, special attributes can be specified. These attributes take precedence over the configurations on screen. These special attributes are not recognised by the HTML standard, and get removed by the print processor. The attributes have to be specified with the syntax *attribute="value"*.

The following attributes are recognised:

10.2.6.1.Attributes of profile diagrams

<i>Attribute name</i>	<i>Argument type</i>	<i>Interpretation</i>
m_bGridTicks	integer 0 or 1	enables (1) or disables (0) scale text and the background scale grid.
m_bBackGrid	integer 0 or 1	enables or disables the background scale grid.
m_cGridColor	string rrggbb, rr,gg,bb represents a hexadecimal number (two digits)	colour of the background scale grid
m_cLineColor	string rrggbb, rr,gg,bb represents a hexadecimal number (two digits)	colour of the profile line
m_dZmin	double	lower limit of the vertical scale
m_dZmax	double	upper limit of the vertical scale

10.2.6.2.Attributes of a colour keyed diagram

<i>Attribute name</i>	<i>Argument type</i>	<i>Interpretation</i>
m_cMinColor	string rrggbb, rr,gg,bb represents a hexadecimal number (two digits)	colour used for any elements below m_dZmin
m_cMaxColor	string rrggbb, rr,gg,bb represents a hexadecimal number (two digits)	colour used for any elements beyond m_dZmax
m_iPaletteNum	integer 0..5 • 0: gray staircase	palette used. See also m_bPhoto

⁵⁶ in case the HTML editor inserted any (absolute or relative) path name, you have to remove the path name. Only the file name should remain. Keep the extension .bmp.

⁵⁷ Usually, browsers do not employ filtering resize, so image quality degrades significantly on resize. This is especially visible on line and text elements.

⁵⁸ attribute alt is required by the HTML standard. It should provide for a textual description of the image and is useful in the absence of the bitmap, and for handicapped persons.

	<ul style="list-style-type: none"> • 1: inverse gray staircase • 2: red staircase • 3: green staircase • 4: blue staircase • 5: rainbow palette 	
m_bGridTicks	integer 0 or 1	<ul style="list-style-type: none"> • 0: hide XY scale • 1: show XY scale
m_bScaleBar	integer 0 or 1	<ul style="list-style-type: none"> • 0: hide profile value bar on the right • 1: show profile value bar on the right <p>Note: using the photo palette, there is no unique mapping between colour and profile value, the profile bar must be disabled.</p>
m_bIsotropic	integer 0 or 1	<ul style="list-style-type: none"> • 0: scale X and Y axis independently • 1: scale X and Y axis simultaneously <p>this item enables or disables isotropic XY scaling</p>
m_bPhoto	integer 0 or 1	<ul style="list-style-type: none"> • 0: do not use photo palette • 1: use photo palette. <p>Note: Using the photo palette, disable the vertical scale bar. The photo palette uses its own colours, so the selection of m_iPaletteNum does not matter.</p>
m_dZmin	double	lower limit of the vertical scale
m_dZmax	double	upper limit of the vertical scale

10.2.6.3.Attributes of the 3D view

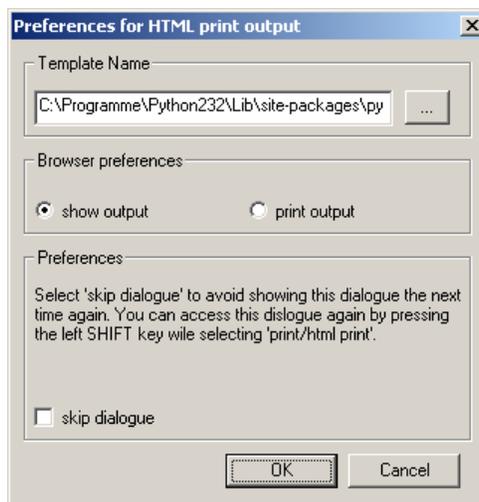
<i>Attribute name</i>	<i>Argument type</i>	<i>Interpretation</i>
m_cMinColor	string rrggbb, rr,gg,bb represents a hexadecimal number (two digits)	colour used for any elements below m_dZmin. These elements are also clipped in the diagram.
m_cMaxColor	string rrggbb, rr,gg,bb represents a hexadecimal number (two digits)	colour used for any elements beyond m_dZmax. These elements are also clipped in the diagram.
m_cAxColor	string rrggbb, rr,gg,bb represents a hexadecimal number (two digits)	colour of the XY axis
m_cBackGnd	string rrggbb, rr,gg,bb represents a hexadecimal number (two digits)	Background colour of the diagram (border colour)
m_cBorder	string rrggbb, rr,gg,bb represents a hexadecimal number (two digits)	Colour of the 'curtains' closing the diagram to the front.
m_iPaletteNum	integer 0..6 <ul style="list-style-type: none"> • 0: gray staircase • 1: inverse gray staircase • 2: red staircase 	palette of the diagram. For comparison: <ul style="list-style-type: none"> • False colour: m_iPaletteNum=0..5, m_bPhoto=0

	<ul style="list-style-type: none"> • 3: green staircase • 4: blue staircase • 5: rainbow palette • 6: photo gray staircase⁵⁹ 	<ul style="list-style-type: none"> • Photo (I): m:iPaletteNum= 0..5, m_bPhoto=1 • Photo (II): m_iPaletteNum=6, m_bPhoto=1
m_bGridTicks	integer 0 or 1	<ul style="list-style-type: none"> • 0: do not show XYZ scale and text • 1: XYZ show XYZ scale and text
m_bIsotropic	integer 0 or 1	<ul style="list-style-type: none"> • 0: scale XY axis independently. • 1: scale XY axis simultaneously
m_bPhoto	integer 0 or 1	<ul style="list-style-type: none"> • 0: disable lighting calculations • 1: enable lighting calculations
m_dAlpha	double	rotation of the diagram along the vertical Z axis in degrees.
m_dTheta	double	tilt angle, and scaling of the profile along the vertical Z axis. 0=view from top, 90=view from the side..
m_dAmbient	double 0..1	ambient illumination intensity, relevant for m_bPhoto=1 only.
m_dZmin	double	lower limit of the vertical scale
m_dZmax	double	upper limit of the vertical scale

10.2.7.Using custom templates

Having created your template, it is ready to use for the next print job. Inspector remembers the template configuration for each type of view (line diagram, colour keyed view, 3D, abbot and amplitude distribution) separately.

Select a view matching your template, and select menu item File/Print/HTML print from the main menu. Inspector creates the dialogue Preferences for HTML print output:



Press the button ..., navigate and select to your custom template, and confirm your selection with the OK button.

⁵⁹ reduced gray depth compared to 0, useful only in conjunction with m_bPhoto=1

11.Important

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12.Declaration of Conformity

According to the EG-standard Maschinen 98/37/EG, Annex IIA
EG-standard "Electromagnetic compatibility" 89/336/EWG
EG-standard „Low Voltage“ 73/23/EWG

The following harmonised standards are applied:

DIN EN 292

DIN EN 60204-1

DIN EN 31252

DIN EN 50081-2 1993

DIN EN 50081-1995

DIN EN 60825-1