High-precision wear resistance tester

kaloMAX NT II

Manual

BAQ

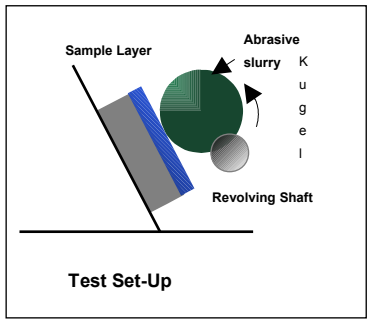
1 General information about measuring wear resistance on thin layers

1.1 Overview

In tribological orientated development of layers and in quality assurance of wear-protective layers, the determination of wear resistance of layers is an essential demand.

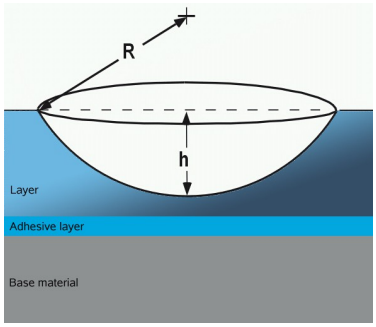
In a collaboration between the Fraunhofer Institute for Surface Engineering and thin films (IST) and the company BAQ GmbH, the method of ball cratering tests according to DIN EN 1071-2 has been adapted to tests of thin layers. A method for testing the wear resistance of thin layers (µm range) has been developed.

The high-precision wear resistance tester kaloMAX NT is useful for abrasive wear characterization of materials and layers. By means of an automatic dosage apparatus, an abrasive slurry is applied onto a 100Cr6 steel ball with a diameter of 30mm. This ball is rotating against a specimen (see Figure).



Test Set-Up

The wear crater should be ground into the layer without breaking through to the base material. The width and depth of the wear crater has to be measured by means of a surface profiler or a microscope.



The wear coefficient specific to the abrasion slurry can be calculated from the volume of the wear crater, the bearing load and the grinding path. The volume of the wear crater can be calculated from the diameter of the grinding ball and the depth or the diameter of the wear crater.

Bearing strength, grinding speed and grinding path must be constant to obtain comparable wear resistance coefficients.

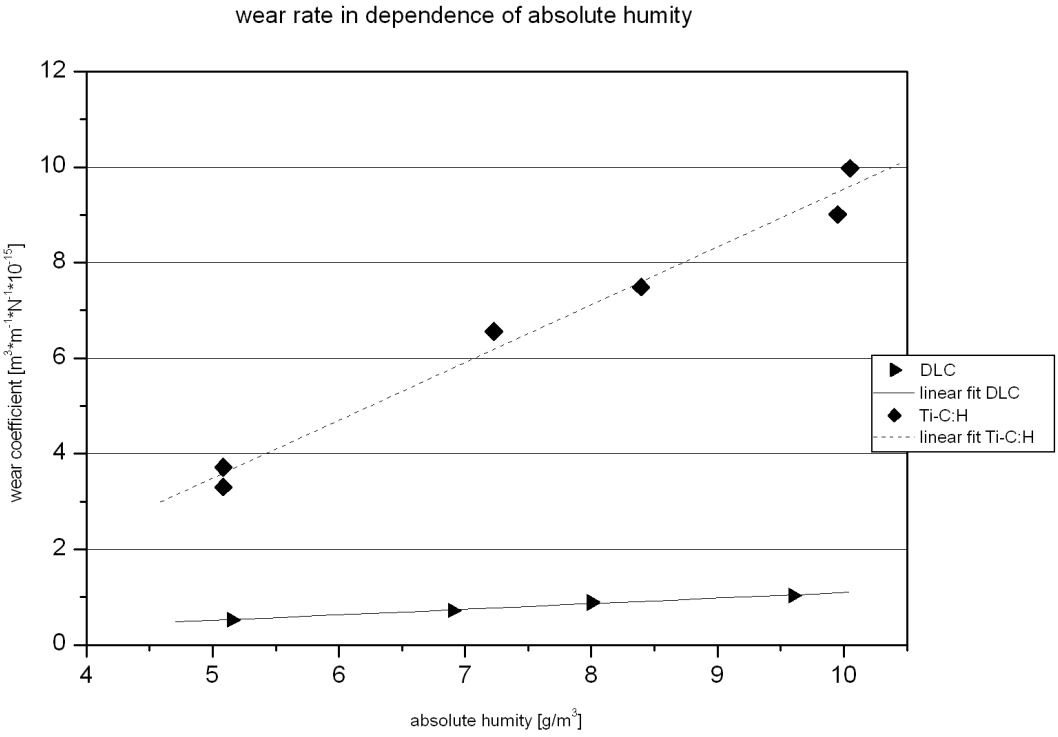
The minimum thickness of the layer which can be reliably measured is about 1 µm for hard coatings. This is primarily determined by the shortness of measurement time.

Furthermore the device can be used for tests according to the cap grinding method (DIN EN 1071-2).

1.2 Climatic influences on tribological processes

As in every other tribological process, the ambient temperature and humidity affects the abrasion process. Naturally, this applies also to the determination of wear resistance by means of a high-precision wear resistance tester.

Extensive measurements have been done at the FhG-IST to characterize the influence of different climatic conditions (temperature and humidity) on wear resistance of layers.



The chart shows that the influence of the humidity on the wear coefficient depends on the material of the layer system.

1.3 Abrasive slurry

The abrasive slurry has been developed especially for the determination of wear resistance of thin layers. Due to characteristic properties of this abrasive slurry, very

homogeneous wear craters (free from deep furrows) are obtained on thin layers. This is a basic condition for the quantification of the wear volume (Vv). Furthermore, the low abrasiveness of the slurry allows measurements in the range of μm. Because of the viscosity, the slurry does not spread out on the ball during the grinding process, but adheres on the grinding trace around the ball. Moreover, it ensures a well-balanced proportion between lubrication and wear process.

To obtain reproducible and comparable results, it is essential to use a slurry of constant characteristics. Therefore, it is recommended to use the abrasive slurry wich is available as consumable supply. This slurry is made by the IST and the quality of every 50ml-cartridge is tested. A reference layer is provided, so you can check the quality at any time.

1.4 Place of installation

It would be best to place the device in an air-conditioned room. If this is not possible, the place of installation should be choosen considering the following aspects:

- The climatical conditions should be as constant as possible.
- A separate room is advisable.
- The device should not be placed close to heat sources (e.g. radiator) or windows (solar radiation, draught).
- The place of installation should not be draughty (e.g. near by a door).

1.5 Handling the abrasive slurry

To preserve the above-named (1.3) properties (viscosity) of the abrasive slurry, the following should be observed:

- Open the cartridge only for short periods of time to fill the pipette with abrasive slurry (protection against humidity absorption).
- Stir up the abrasive slurry with a clean and dry stirring rod.

- Do not keep the abrasive slurry near by heat sources (e.g. radiators, solar heat). Most suitable would be a drawer near by the tester.
- It is recommendable to use a reference sample (e.g. standard layer) to check the „state“ of the abrasive slurry in regular intervals. A change in viscosity of the abrasive slurry causes mostly higher wear coefficients.

2 Test preparations

The wear coefficient is calculated from the volume of the wear crater, the bearing strength (perpendicular to the surface of the specimen) and the grinding path.

2.1 Selection of the test parameter (grinding path / number of revolutions)

The appropriate grinding path (or the number of ball or shaft revolutions) and hence the measurement duration, has to be determined experimentally according to the requirements. The suitable value depends basically on the thickness and wear resistance of the layer to test. It is important, that the depth of the resultant wear crater is not greater than the thickness of the functional layer.

The experiences of the Fraunhofer Institute for Surface Engineering and Thin Films can give a rough guide for the determination of the measurement duration. These values are only valid for this special developed layer systems. For several layer systems, the following wear crater depth have been determined (20°C, 50 % relative humidity equivalent to 7,3 [g/kg dry air] at 1013mbar).

Layer system	Revolutiuons of the ball	Measurement duration [min]	Wear crater depth [μm]	Wear volume [$m^3*m^{-1}*N^{-1}*10^{-15}$]
Carbon films (DLC)	540	9	0,7	0,8
Metal carbon films: Ti-C:H	180	3	1,1	6,2
Metal carbon films: W-C:H	180	3	0,8	3,3

Table 1: Layer systems/crater depth

The direct input of the grinding path has practical advantages over the input of the number of ball or shaft revolutions. The calculation of number of ball revolutions ⇒

grinding path will be done automatically. The ball diameter must be entered. The geometrical values of the device (distance between the supporting points, diameter of the shaft at the supporting points) will automatically be taken into the calculation.

2.2 Grinding speed / ball or shaft revolutions per minute

The grinding speed (ball or shaft revolutions per minute) corresponds to the distance which the surface of the ball covers. This also has a great influence on the resulting wear coefficient.

For all tests on hard coatings, 60 revolutions of the ball per minute has been used by the IST. This is equivalent to a grinding speed of 5.6 m/min.

2.3 Bearing strength

The bearing strength cannot be measured directly. It depends on the weight and diameter of the ball, the blade angle of the specimen and the distance between specimen and shaft.

Therefore it is recommended, to keep this values constant for a series of tests. The surface of the specimen should parallel the top side of the vice so that the blade angle is 60 °.

The distance between specimen and shaft can be adjusted by means of a gauge. Set the gauge onto the ground plate and push it against the shaft. Then push the whole vice with the clamped specimen against the inclined surface of the gauge from behind. The gauge must contact the shaft at both sides. The surface of the specimen should contact the inclined surface of the gauge. Thus, the blade angle can be controlled.

Given a ball diameter of 30mm, the bearing strength is 0.54N in this position. The adjustment has to be executed very carefully, because even small variations can lead to different wear coefficients.

2.4 Cleaning the shaft

The contact surfaces of the rubber rings on the shaft must be cleaned with ethyl alcohol before the test. If the contact surfaces of the rubber rings are contaminated with abrasive slurry, this will decrease the friction. Furthermore, the rubber rings may not be damaged. If the rubber rings are damaged, the whole shaft has to be replaced, because the rings must be adjusted to the shaft.

Accurate (round) wear craters can be obtained only if the rubber rings are in a proper state.

2.5 Specimen

The specimen has to be clamped to the vice. Clean the measuring area with ethyl alcohol to remove pollutions (e.g. grease, oil, fingerprints etc.).

2.6 Ball

The ball must be cleaned with ethyl alcohol. The ball has to be free from abrasive slurry. A thorough cleaning of the ball is recommended to avoid slipping at the contact surface of the rubber rings. Put the ball onto the V-shaped notch on the driving shaft.

Of course, the balls may not be rusted. They must be stored dry. A container with silica gel is recommended.

2.7 Automatic dosage apparatus

The automatic dosage apparatus facilitates the application of the abrasive slurry. A single drop will be released when the START-button is pressed. The drops have a constant mass (preferably 35 mg). The amount depends on the viscosity of the slurry, dosage time and dosage pressure (see below).

Required accessories

Cartridge:	5 ccm, Polypropylene
Plug:	5ccm, Polyethylene, double seals (white)
Hollow needle:	olive (1,54mm), stainless steel

2.8 Filling the cartige with abrasive slurry

Take care that the slurry has as few air bubbles as possible, when filling the cartidge. Close the cartidge with a blind plug and then fill it maximum half-full.

Push the plunger down the cartridge until it touches the abrasive slurry. The air in the cartridge can escape at the side of the plunger . Take care, that there is no air between the plunger and the abrasive slurry! Be careful, that the abrasive slurry is not pressed between the plunger and the cartridge wall. Now the cartridge adapter and the needle are fastened.

2.9 Dosing parameters

Before the dosing process can start, pressure and duration must be set.

Parameters for a drop with a mass of about 35 mg :

Pressure:	0.45 bar
Duration:	150 ms

The pressure is adjusted by a fine setting valve at the rear side of the device. The duration can be programmed in the menu.

When the cartridge has just been filled, the slurry must first be pressed into the needle. Therefore, no drop will be build the first few times the START-button is pressed. It is not recommended to use the first 5-6 drops for measurements.

The drop size is constant with a tolerance of about $\pm$ 1 mg.

A single drop can be released by pressing the STOP-button when the main screen is displayed unless a grinding is in progress.

2.10 Manual dosage with a pipette

A rubber bulb is attached to a clean pipette. Only clean pipettes should be filled with abrasive slurry (draw up). The abrasive slurry should be stirred up with the provided

stirring rod. The slurry should not be drawn up from the bottom of the bottle but from the middle of the filling quantity. Clean the outside of the pipette. Then place the pipette into the holder.

Abrasion slurry once taken from the bottle should not be put back.

3 Test execution

Be sure that you have followed all test preparation instructions.

3.1 Adjusting the specimen

The vice with the clamped specimen can be moved in x-y-direction. The optional laser pointer facilitates the positioning of the specimen.

If a ball with a diameter of 30 mm is used and the surface of the probe has been adjusted by means of the gauge, the laser pointer points to the spot on the surface of the specimen where the ball will grind the spherical cap.

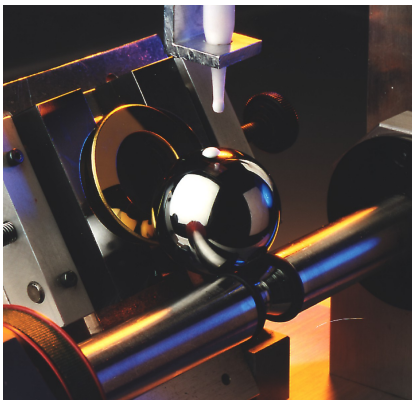
The laser pointer will be switched on automatically, when it has reached its final position.

3.2 Application of the abrasive slurry (only manual application)

If the automatic dosage apparatus is not used, the abrasive slurry must be applied manually before doing a test.

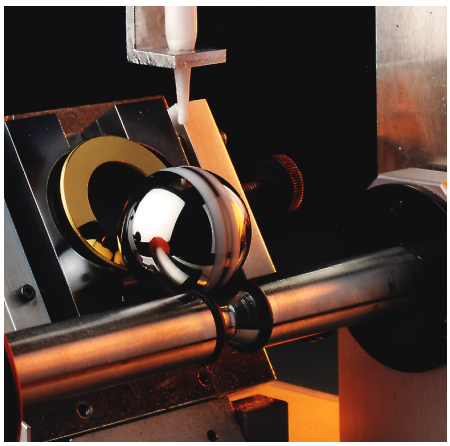
Each test requires only **1 drop** (see figure) of abrasive slurry. This applies to all indicated test durations.

Exert slight pressure on the rubber bulb until a drop of slurry is formed. The drop should come off the pipette by self-weight. This should ensure that the drops have a constant mass. Take heed that there are no air bubbles in the drop, otherwise the ball must be cleaned and a new drop must be applied.



Picture 1: Drop of abrasive slurry applied to the ball

After a running-in period of about 0.5 min, the abrasive slurry should be evenly spread around the ball (see figure).



Picture 2: Evenly spread abrasive slurry

3.3 Further tests

Remove the ball from the shaft and clean it with ethyl alcohol. Also clean the specimen. The probe can be moved and further tests can be made. The grinding craters should have a minimal distance of 1-2mm.

3.4 Aborting a test

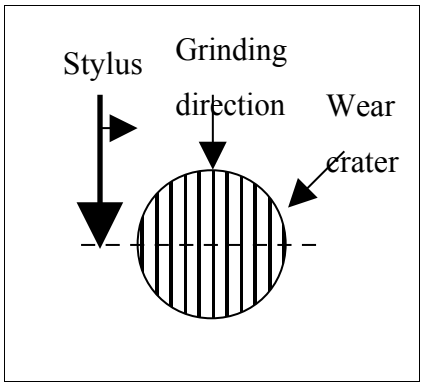
A test should be aborted when the ball begins to tumble. Probably a bit of the abrasive slurry has spread on to the rubber rings or the ball or the specimen has not been cleaned sufficiently.

4 Analysis of the wear craters

The wear craters can be measured by means of a surface profiler (depth of the crater) or a microscope (diameter of the crater).

4.1 Analysis by surface profiler

For an analysis by a surface profiler (determination of the depth of the wear crater), the scan should be taken at right angle to the grinding direction and along the centre line (deepest point of the wear crater). See figure.



Drawing 1: Analysis of a wear crater by a surface profiler

4.2 Calculation of the wear coefficient

For the calculation of the wear volume, an ideal spherical cap is assumed. The crater i.e. wear volume (Vv) can be calculated as follows:

(1) $$V_V = \frac{\pi}{3} \bullet h^2 \bullet (3r - h)$$

where: V_v = Wear volume [m^3]

h = Crater depth [m]

r = Ball radius [m]

Then the wear coefficient (**Vr)** can be determined:

(2) $$V_r = \frac{\text{Wear volume}}{\text{Sliding distance} * \text{Bearing strength}}$$

The grinding path (s) can be calculated from the periphery of the ball and the number of ball revolutions n.

(3) $$s = 2\pi r \bullet n$$

The formula for the wear coefficient is:

(4)

$$V_r = \frac{V_v}{s \bullet F_K}$$

V_r = Wear coefficient [$m^3*m^{-1}*N^{-1}$]

V_v = Wear volume [m^3]

s = grinding path [m]

F_K = Bearing strength [N]

A bearing strength (F_k) of 0.54 N can be adjusted by means of the provided gauge.

The unit of the wear coefficient should be given as $m^3*m^{-1}*N^{-1}$. It is not recommended to reduce the units, because the source units should be kept recognizable.

4.3 Analysis by microscope

For an analysis by microscope, the diameter of the wear crater has to be measured.

4.4 Calculation of the wear coefficient

The depth of the wear crater is calculated from the diameter. An ideal spherical cap is assumed.

The formula for the depth of the wear crater is:

$$h = r - \sqrt{r^2 - r_1^2}$$

h = Depth of the wear crater [m]

r = Ball radius [m]

r_1 = Crater radius [m]

The wear coefficient can be calculated with formula (1) and formula (4) (see chapter 4.2 Calculation of the wear coefficient).

5 Handling

5.1 General operating instructions

5.1.1 Key functions

By pressing this key the user exits the current function and enters the superordinate menu item. Changed settings are not imported.

Using this key completes the editing in one field or selects a subordinate menu item.

Function key

Function key

Function key

Function key

Pressing this key starts the grinding process (see chapter 5.3 Start / Stop).

Pressing this key during grinding stops the grinding process (see chapter 5.3 Start / Stop). Otherwise, the valve is cleaned (see chapter 5.7 Clean valve).

Cursor keys

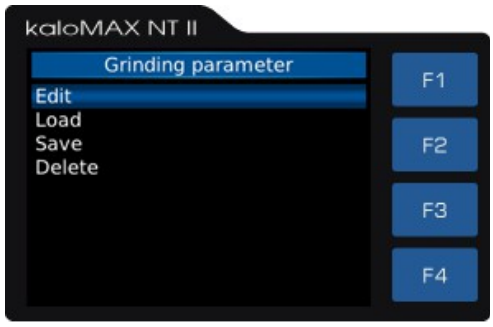
These keys are used to select menu items and to move the cursor within the input fields.

In certain situations, function keys F1 to F4 are used to simplify handling, e.g. to quickly change the major grinding parameters in the main screen without having to enter the menu.

The number keys are used to enter numerical values.

5.1.2 The menus

A menu consists of a list of available menu items the highlighted one of which is the active menu item. With the ▲ and ▼ cursor keys you select the active menu item. ENTER selects the active menu item and either opens a screen or sub menu.

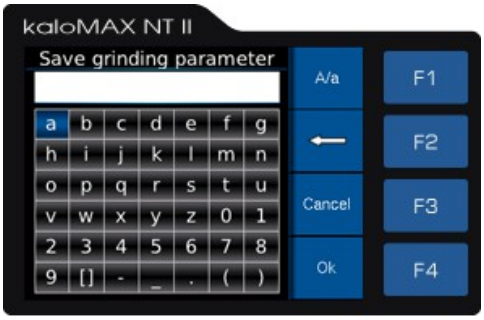


Picture 1: Menu

ESC brings the user back to the previous menu.

5.1.3 Text input

Saving the grinding parameters requires input in plain text. In this case, a text input field opens.



Picture 2 : Text input

In the upper field highlighted in white (called text field hereafter), the entered text is shown. The previous lines show the characters that can be selected. A space is represented by [ ].

The cursor keys move the cursor through the character fields and select a character by pressing ENTER. The selected character appears in the text field.

F1 switches between upper and lower case, F2 deletes the last character in the text field.

F4 (OK) exits text input and the entered text is now available.

ESC and F3 (Cancel) exits text input without saving.

5.1.4 Input of numerical values

Open the number input screen to enter numerical values. In the field highlighted in white the entered number is displayed. The ◄ and ► cursor keys are used to shift the cursor in the field. F2 (←) deletes the character left of the cursor. Numerical values and the decimal separator are entered by using the appropriate keys.

F4 (OK) or ENTER key completes the input and saves the value.

F3 (Cancel) or ESC aborts the input.

5.2 Grinding parameters

The following parameters have to be defined for the grinding process:

- Grinding speed (m/min), ball RPM or shaft RPM
- Grinding path (m), number of ball revolutions or number of shaft revolutions
- Dosage time of the abrasive slurry (ms)
- Diameter of the grinding ball

Furthermore, the following basic settings can be made:

- Unit in which speed has to be entered (grinding speed, ball revolutions per minute or shaft revolutions per minute)
- Unit in which the grinding path has to be entered (meter, number of ball revolutions or number of shaft revolutions)

These parameters (with basic settings) can be saved and retrieved at a later point of time. The current parameters can be changed in the main screen (see chapter5.4) or via the menu (see chapter 5.6.1); stored parameters have to be loaded first, before they can be altered and stored again.

The configuration serves to define the basic settings (see chapter 5.8.1).

The pre-pressure for pneumatic dosage can be adjusted by using the rotary knob on the back of the device. The setting is shown on the upper left part of the main screen.

5.2.1 Input range

		Minimum	Maximum
Speed	Ball revolutions	15 /1/min	590 /1/min
	Grinding speed	1.4 /m/min	55.8 /m/min
	Shaft revolutions	30 /1/min	1000 /1/min
Distance	Number of ball revolutions	13 /U_B	9200 /U_B
	Grinding path	1.2 /m	870 /m
	Number of shaft revolutions	20 /U_S	15000 /U_S
Grinding ball diameter		12 /mm	40 /mm

5.3 Start / Stop

Press START on the main screen to start the grinding process.

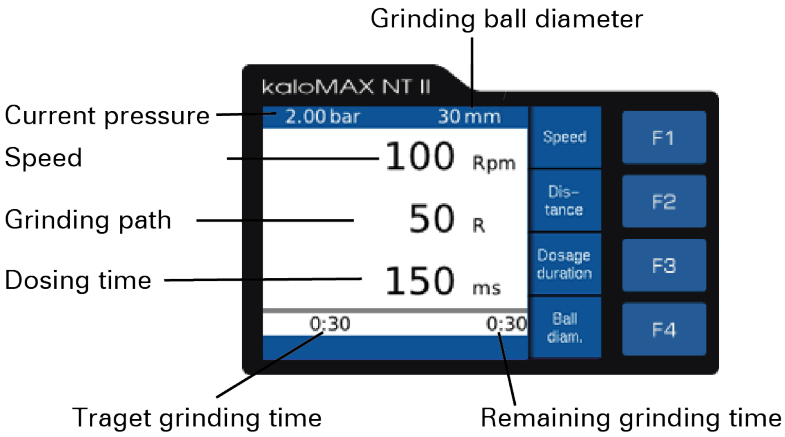
A small amount of grinding suspension is put on the grinding ball, i.e. the valve opens for the defined dosage time.

After a pause of 1.5 seconds, the motor starts.

The grinding process can be aborted anytime by pressing the STOP button. The grinding process ends after the grinding path has been covered or the number of revolutions has been completed.

5.4 Main screen

Press the START button on the main screen to start the grinding process.



The current parameters are displayed and can be changed after pressing the corresponding function key. If a set of parameters is loaded, the data record name is indicated in lower left corner of the screen. Changing the parameters in the main screen has no effect on the stored parameters.

If no grinding operation is in progress, the valve can be cleaned by pressing the STOP key.

5.5 Menu

Press ESC when the main screen is visible to enter the menu. In the menu, you can choose the following items:

- Grinding – the main screen is shown.
- Grinding parameters – display of the sub-menu for grinding parameter setting and managing.
- Clean valve – opens the valve for the dosage time.
- System – display of sub-menus for system settings.

5.6 Manage grinding parameters

5.6.1 Change parameters

Grinding speed, grinding path, dosage time and ball diameter can be changed

- in the main screen by pressing the corresponding function key or
- by selecting the appropriate menu item in the sub-menu **Grinding parameter** / **Edit**.

The unit in which the grinding speed and the grinding path have to be entered are determined in the system configuration (see chapter 5.8.1).

In any case, an input screen appears, where the value of the parameter can be changed.

5.6.2 Save parameter

Under the menu item **Grinding parameter** / **Save**, the current grinding parameters can be saved with a chosen name.

After selection of the menu item, a text input screen comes up where the user can enter the new data record name.

5.6.3 Load parameter

Under menu item **Grinding parameter** / **Load**, it is possible to retrieve the stored grinding parameters.

Use the ▲ and ▼ cursor keys to select the required data record from the list of available grinding parameters and load it by pressing ENTER.

5.6.4 Delete parameter

If a stored grinding parameter record is not required any more, it can be deleted under menu item **Grinding parameter** / **Delete**.

Use the ▲ and ▼ cursor keys to select the required data record from the list of available grinding parameters and delete it by pressing ENTER.

5.7 Clean valve

For valve cleaning, the valve has to be open for the duration of dosage. There are two options:

1. Select menu item **Clean valve**.
2. If no measurement is in progress, press the STOP button on the main screen (in case a measurement is in progress when the STOP button is pressed, this causes the measurement to abort).

5.8 System settings

Selecting **System** on the menu opens a sub-menu with the following sub-items:

- Configuration – Setting the input units for speed and path.
- Language – Selection of the language.
- Factory settings – Reset to default.
- Information – Display of system information.

5.8.1 Configuration

The unit of grinding speed and grinding path can be selected in the system configuration.

5.8.1.1 Speed

The following units can be selected for speed:

- Ball revolutions / 1/min
- Grinding speed / m/min
- Shaft revolutions / 1/min

5.8.1.2 Grinding path

The following units can be selected for grinding path:

- Number of ball revolutions
- grinding path / m/min
- Number of shaft revolutions

5.8.2 Language

Select your language under menu item **System** / **Language**. Use the cursor keys to select the required language. Exiting the screen via ENTER or F4 (OK) activates the new language.

5.8.3 Factory settings

Under the menu item **System** / **Factory defaults**, current grinding parameters can be reset to default values.

5.8.4 Information

Under the menu item **System** / **Information** the system information is displayed. This information comprises the device serial number, software version number, kernel version and file system version number and software and hardware revision.

Appendix 1: License information

This product contains Free Software which is licensed under the GNU General Public License (GPL) or under the GNU Lesser General Public License (LGPL). The free software source code can at least for a period of 3 years be requested from BAQ GmbH. However, please be noted that we cannot provide guarantee with the source code, and there is also no technical support for the source code from us.

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