# Test&Motion

# Application Module:

# ME 10, 13, 14
# Precrack, da/dN, KIC, CTOD, JIC

## DOLI Elektronik GmbH


| | | |
|---|---|---|
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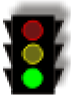
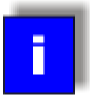
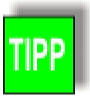
# Table of Contents

Introduction

Dear customer, thank you for choosing a product of **DOLI Elektronik GmbH**. This manual will help you to get familiar with your new testing software **Test&Motion** fast. The manual shall answer questions and help you to solve problems, which might appear.

## 1.1 Symbols

The different symbols in this manual will allow you to find your way easier.

| Symbol | Meaning |
|---|---|
|  | **Safety Instructions:**<br>**In order to avoid interruptions in the work flow as well as damages to man and machine, follow the safety instructions at all cost.** |
|  | **Job/work instructions:**<br>**Instructive part of the document with precise work instructions.**<br>**Here you are asked to do something.** |
|  | **Information:**<br>**General information and descriptions of working procedures, etc.** |
|  | **Note:**<br>**Important note for the operation, the function or for the working procedures.** |
|  | **Tip:**<br>**Gives tips for easy handling of the Test&Motion Software, the EDCs or the testing instrument.** |

**Test&Motion** has been developed for testing instruments, which can be controlled by the measurement electronics of **DOLI Elektronik GmbH** – the External Digital Controller **EDC**. This ‘intelligent’ electronics has its own processor with a separate program, which is able to exchange data with the PC software. This way, it is possible to detect data from the tester, process them in real-time and send commands from the PC to the tester.

It is possible that, besides the EDC, further measuring cards or measuring instruments are served by the software. These cards and instruments have to be defined with different test configurations before the start of the test. Since the handling of different machines having different test configurations differs in some points, the most important differentiating factors are named at the corresponding place. The relevant places of the help system refer to the different measuring technology systems.

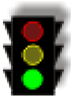
The EDC (External Digital Controller) is located either in a separate housing beside or as a build-in unit inside the testing instrument. EDC and PC do communicate via a serial cable. For simple test tasks, the EDC is even able to control the instrument without a PC; this is called "stand alone" mode.

# 1 Application Modules ME10, ME13, ME14

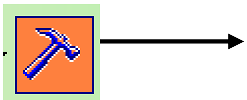
This manual does notdeal with the **Test&Motion software** in general but with the application modules **ME_10**, **ME_13** and **ME_14 Precracking, da/dN, KIC, JIC, CTOD** in particular. Hence it is recommended to read the **Test&Motion** in order to get familiar with the software. Please follow the demands and safety hints listed in the manual!

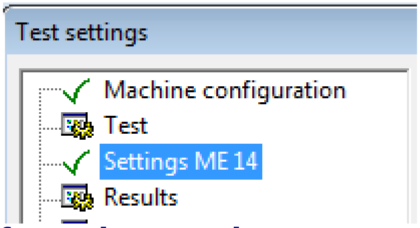
Please Note: ME14 includes ME10 and ME13. In this manual we refer only to ME14!

# 2 Crack growth measurement and Sample shape

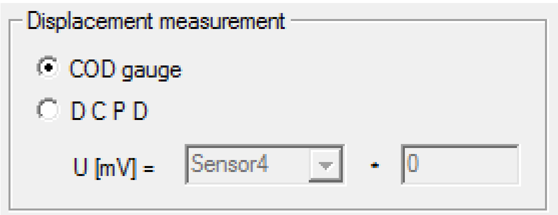


**Test settings -> Settings ME 14**






## 2.1 Methods of crack growth measurement

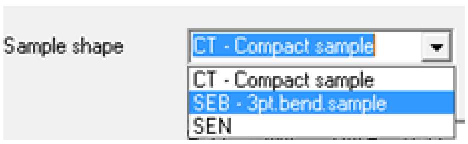



1. Crack opening displacement (**COD**)
   The crack opening displacement is measured with a mechanical device (like an extensometer).
   The crack length ai is calculated using this COD.
2. **DCPD, or potential measurement**, a constant current is applied to the specimen. The voltage drop over the specimen is used to calculate ai. This small voltage can be measured directly by a measuring channel of an EDC. The conversion factor from measured voltage to [mV], as well as the logical measuring EDC channels (Sensor 4... Sensor 15) are adjustable here.

## 2.2 Sample shape.

The test sample can be one of the several types

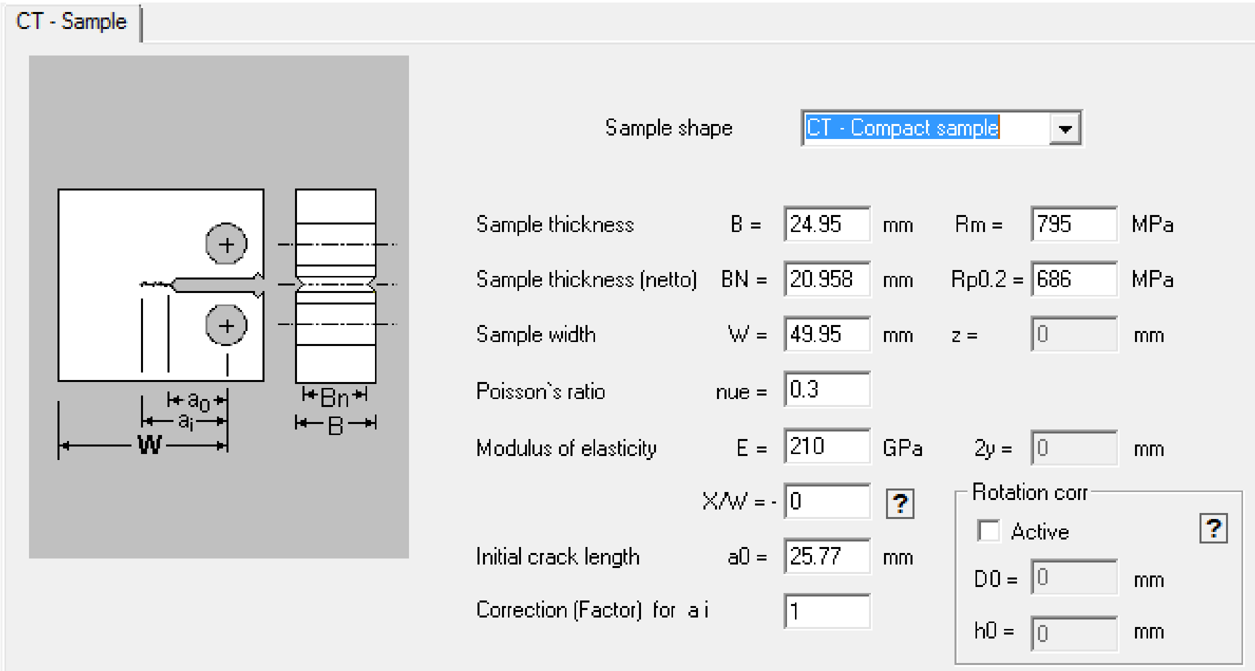
1. CT – Compact sample
2. SEB –3pt.bend sample
3. SEN




The selection is done by combo-box ‘Sample shape’,
Depending from that the load direction is automatically defined.

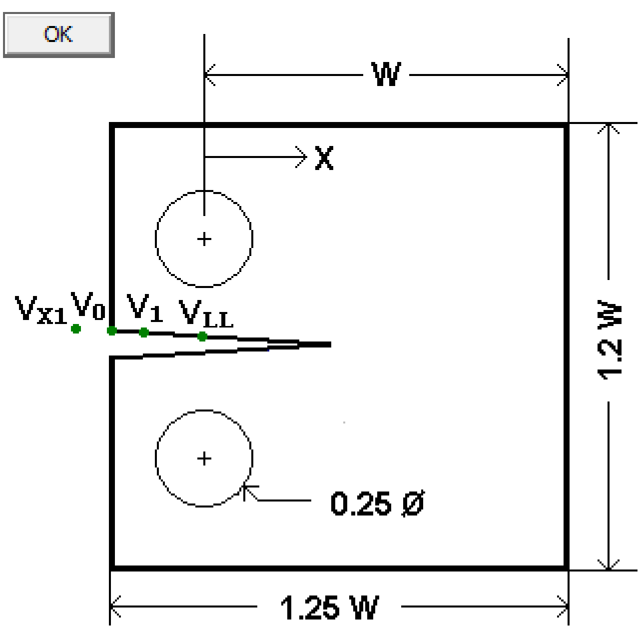
CT – Tension test
SEN – Tension test
SEB – Compression test

## 2.2.1 Sample shape CT (Compact sample)



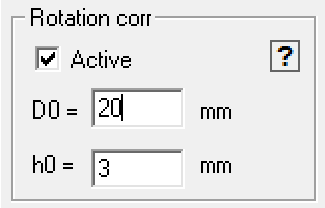

### 2.2.1.1 Input value X / W

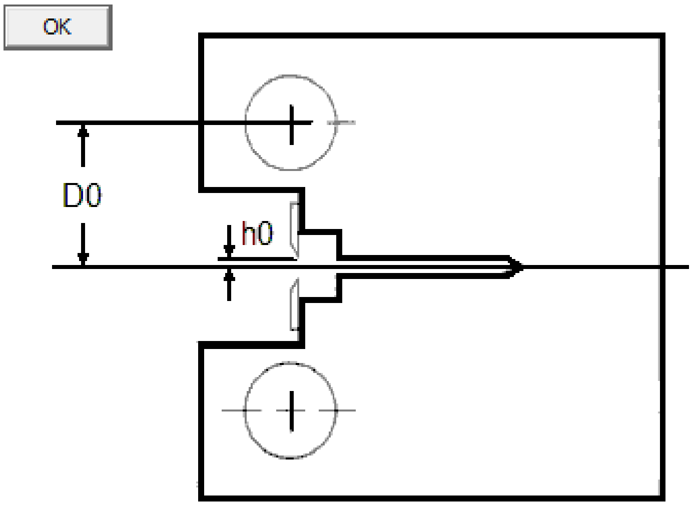
The input value X / W defines the measurement location for the COD extensometer. The extensometer may be in the front line, in the power-line or otherwise mounted. This has consequences for the calculation of crack length ai to be considered by the input value X / W.




| Meas. Location | X/W |
|---|---|
| $V_{X1}$ | - 0.345 |
| $V_0$ | - 0.250 |
| $V_1$ | - 0.1576 |
| $V_{LL}$ | 0 |

### 2.2.1.2 Rotation correction

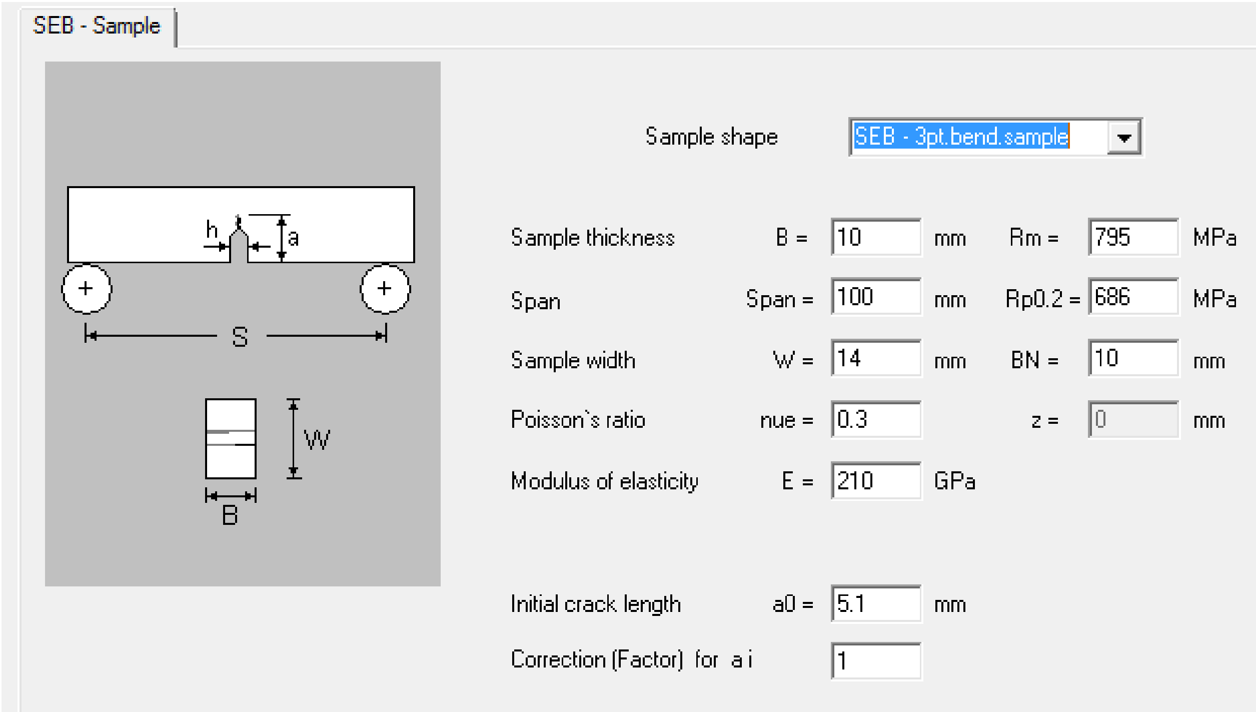


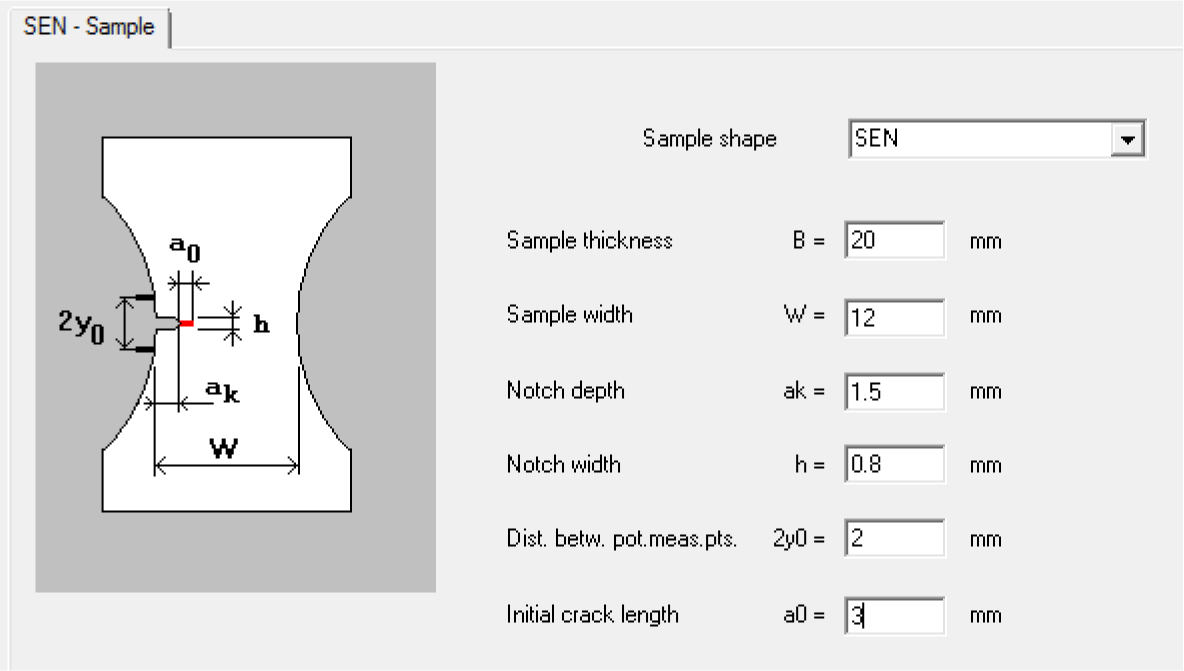

Enter these two values in case of a rotation-Correction is needed.

In most cases the rotation error can be neglected.
Note: for DCPD there is no rotation correction!

## 2.2.2 Sample shape SEB



### 2.2.3 Sample shape SEN

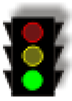



This sample form was only measured with potential method, so you have to enter here an input value for the distance of measurement points for potential (2y0).

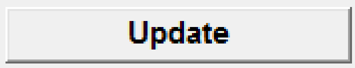
# 3 Test regulation Precracking, da/dN, KIC, CTOD, JIC

## 3.1 Field of application

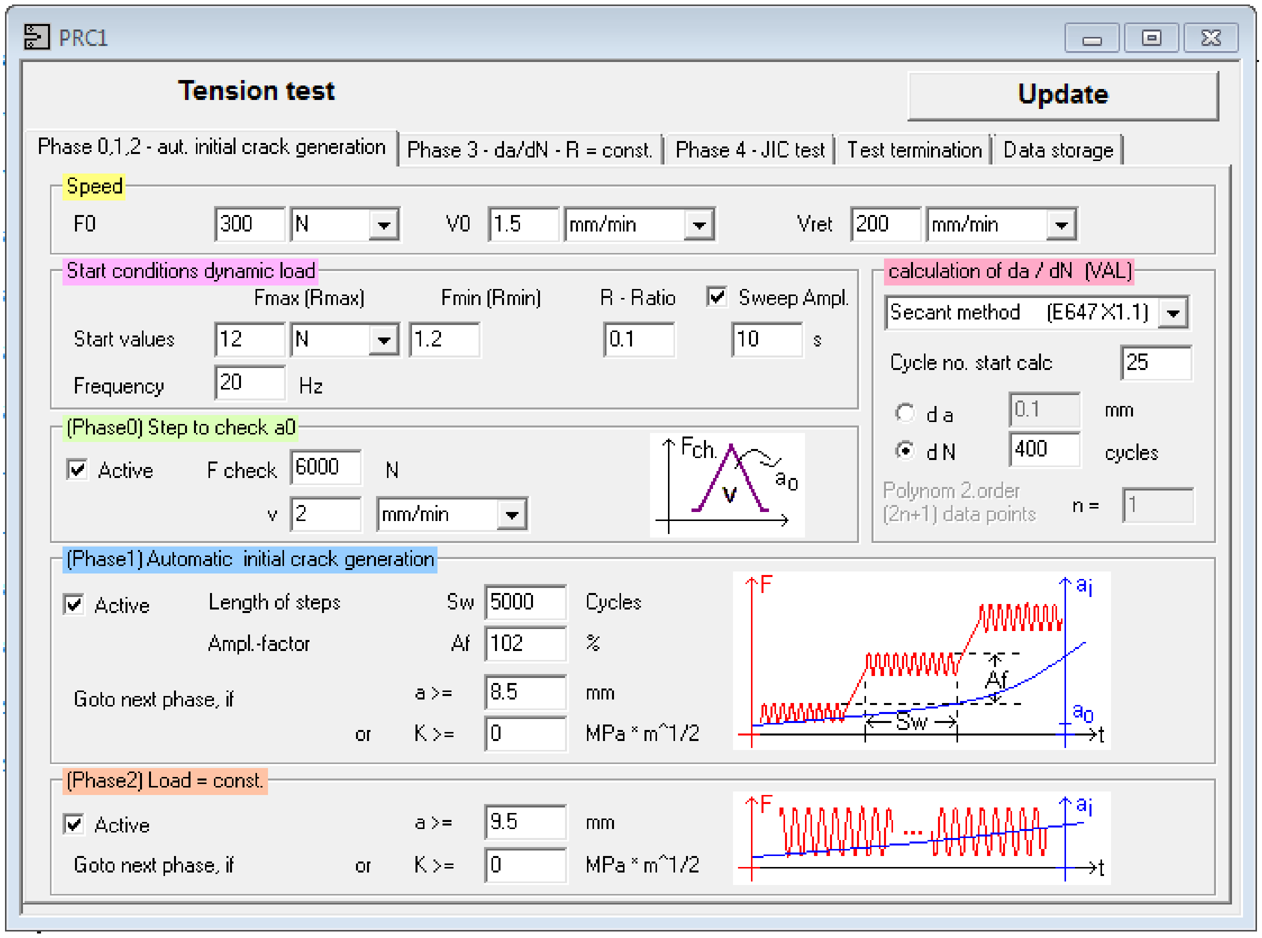
During the last years the investigation of crack propagation and fracture toughness attained a bigger and bigger meaning. The test procedure **ME_14** performs fatigue crack propagation testing and crack growth studies on homogenous materials. **ME_14** manages the creation of an initial crack (**Precracking**), provide cyclic loading of notched specimen that have been precracked in fatigue. The crack length is measured as a function of cycles, the **rate of crack growth (da/dN)** is calculated. At last **KIC, CTOD or JIC** test can be performed to determine fracture toughness.


Click on Menu window → PRC.

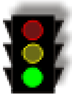
Here you define the settings for all phases.
The PRC window offers five tabs for entering parameter and an **Update** button.




You may change parameter during a running test.
With the update button the modified parameter will become active.



# 4 Phase 0, 1, 2 – automatic Initial crack generation

 Click on Menu window → PRC → Tab → “Phase 0, 1, 2 aut. initial crack generation”.

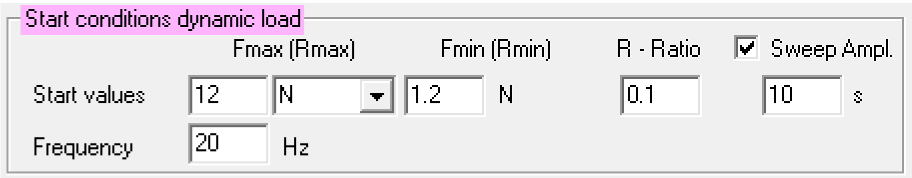
Here you define settings for the phases of initial crack generation. These include the peak values of the sinusoidal load, optionally before Phase 1 and 2 a check should be made (Phase 0). You can specify whether phase 1 or phase 2 will be executed sequentially or both.

## 4.1 Preload, Vret

This parameter is valid for all phases!

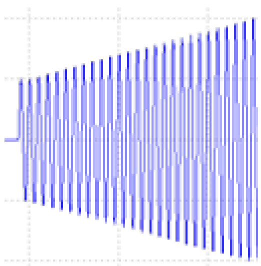

| | |
|---|---|
| F0 | Preload; after test is started, the machine will go to this load |
| V0 | Speed up to preload F0 |
| Vret | Return speed on test end<br>the automatic return on end of test is deactivated for ME14! |

## 4.2 Start conditions dynamic load




These values are used to start the cyclic (sinusoidal) loading. The ratio R = Fmin / Fmax can also be entered. Depending on the last entered value (Fmin or ratio) the other input value is calculated.

| | |
|---|---|
| Fmax | Maximal load of sinus command |
| Fmin | Minimal load |
| Ratio | Fmax * Ratio = Fmin |
| Frequency | Frequency of sinus command |
| Sweep amplitude | Program starts with amplitude (Fmax-Fmin)/10,<br>The amplitude increases in xx seconds to (Fmax-Fmin). |



## 4.3 Phase 0 check a0

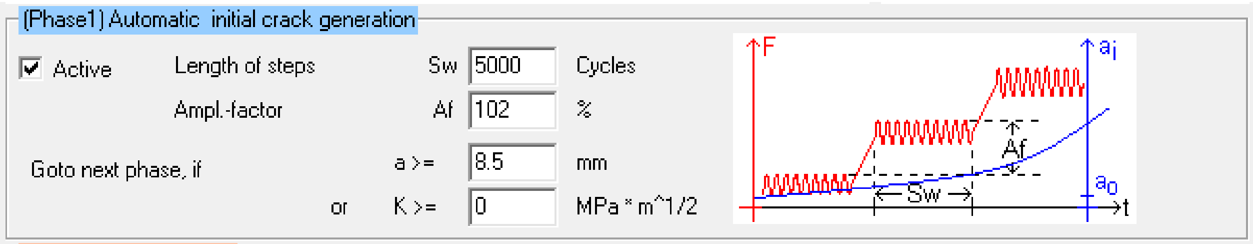

In order to generate an initial crack as quickly as possible, the sample is loaded with the highest possible frequency and power. If you have made an error in the test setup, you'll pay it quickly with the death of the sample, without having generated any results.

To exclude errors in the test equipment or to minimize them, you can call up a single measurement cycle before starting Phase 1 and 2. In this step, we drive Xhead-controlled with low speed to a small load.

The Xhead is moving slowly with speed **v0** to preload **F0**.
After reaching **F0**, the Xhead is moving with **v** to load **F check** and back to **F0** with the same speed

Now a temporarily **a0** and module will be calculated. If this is ok the test will be continued. Otherwise, the operator can terminate the test

## 4.4 Phase 1 automatic initial crack generation

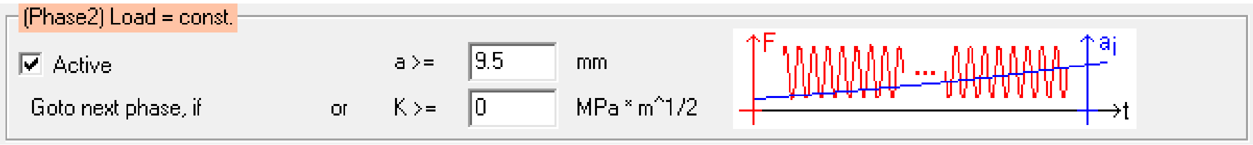



**Method:** The specimen is loaded with a predefined force in a cyclic (sinusoidal) manner. During this procedure, the crack length (blue curve) **ai** and the **stress-intensity factor Ki** are calculated. In case ai exceeds the input value **a>=** or if the calculated **stress intensity factor Ki** is bigger than **K>=** phase 0 will be finished, and if active phase 2 or phase 3 is started.

After the predefined number of cycles (input value **Length of steps Sw**) is reached (and the final values for **ai (max crack length)** or for **Kmax are not exceeded)**, the force values for the upper and lower peak are multiplied with the **Amplitude factor AF** (in dialog 102%). Now, the test will be continued with higher load peaks and the next **"Length of steps Sw"** cycles are performed. However, if the final values for **ai** or **Kmax** cannot be reached again, the load will be increased again.

| | |
|---|---|
| Sw | Number of cycles with constant amplitude, use values defined at start conditions above |
| Ampl.-factor | Increase Fmax by e.g. 102% |
| a>= | Limit for ai |
| A>= | Limit for K |

## 4.5 Phase 2 Load = constant

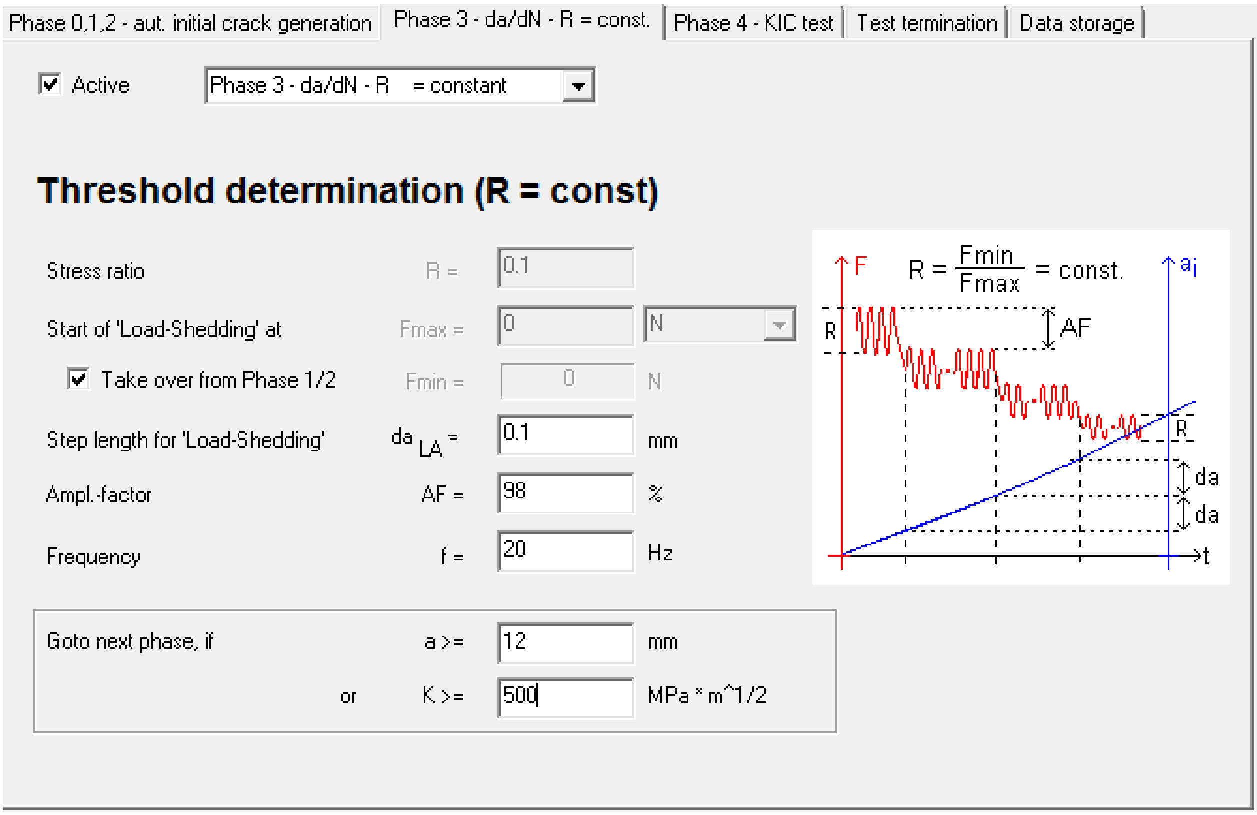



**Method:** The specimen is loaded with a predefined force in a cyclic (sinusoidal) manner. During this procedure, the crack length (blue curve) **ai** and the **stress-intensity factor Ki** are calculated. In case ai exceeds the input value **a>=** or if the calculated **stress intensity factor Ki** is bigger than **K>=** phase 0 will be finished, and if active phase 3 is started.

| | |
|---|---|
| a>= | Limit for ai |
| A>= | Limit for K |

## 4.6 Phase 3: da/dN – R=const

The initial crack **ai** now progresses rapidly. In the following step (Phase 3) the load will be reduced step by step. The ratio (R – Ratio = Fmin / Fmax) will be constant during this phase, that means both peaks (**Fmax** and **Fmin**) are multiplied with the same **Ampl.factor** (here 0.98).

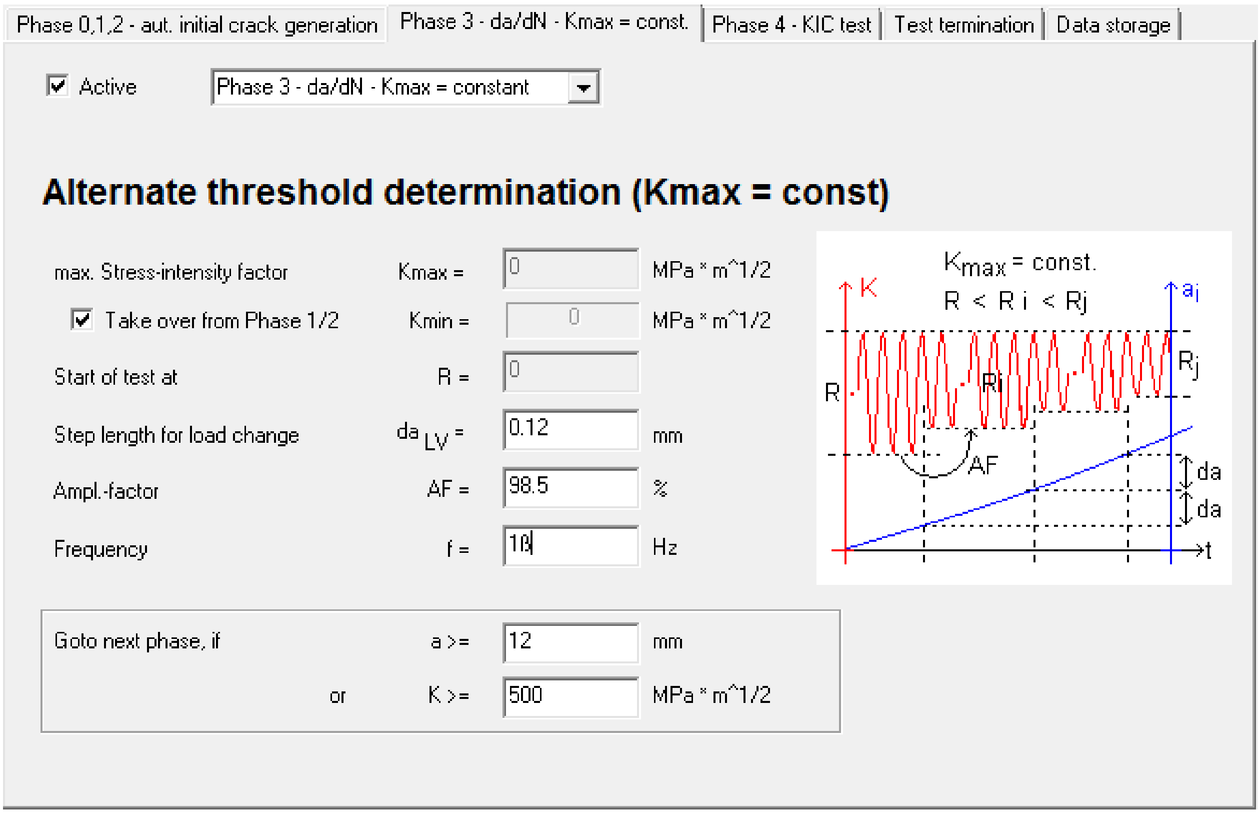



At start of phase 3 the values for load **Fmax** and **Fmin** can either be transferred automatically from the preceding phases 1 or 2, or entered manually. The Ratio and the frequency have to be entered here, too.

<u>**Method:**</u> The specimen is loaded with a predefined force in a cyclic manner. During this process, the crack length (blue curve) **ai** is calculated. If the crack length **ai** increases more than input value **"da LA"**, then the load **Fmax** and **Fmin** will be decreased. This is done by multiplying the upper and lower force value with the amplitude factor **AF** (98% in the dialogue). Now, the test is continued with lower peak values. If **ai** is increasing again with the value **"da LA"** compared to the time of the last load reduction, the next load reduction will be calculated. This procedure is repeated in a cyclic manner until the user stops the process or a test end criterion is reached.

## 4.7 Phase 3: da/dN – KMax=const

The initial crack **ai** progresses now rapidly. In the following step (Phase 3) the load will be reduced step by step, while the load intensity at the upper peak (**Fmax**) will be kept constant. Hence, **Kmax** stays constant, also. The ratio (R – Ratio = Fmin / Fmax) increases during this phase.

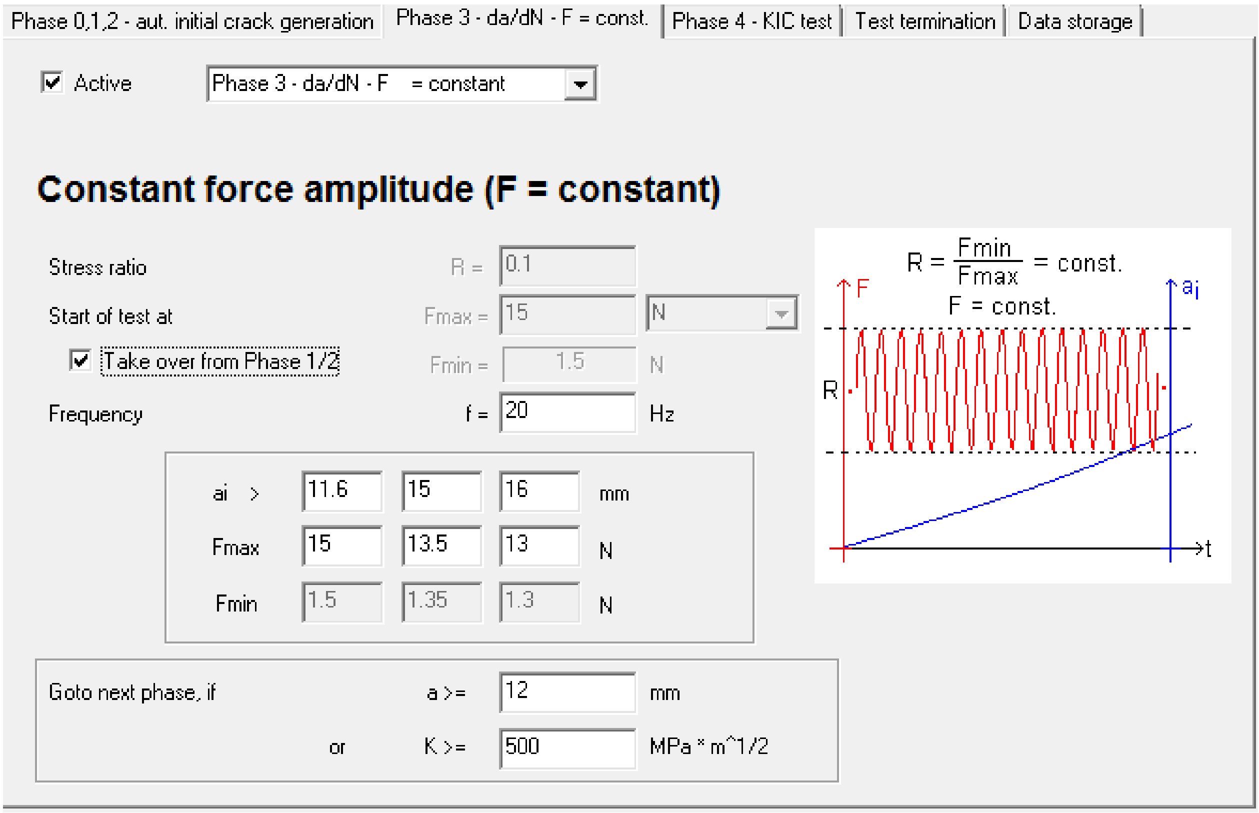



At start of phase 3 the values for load **Fmax** and **Fmin** can either be transferred automatically from the preceding phases 1 or 2, or entered manually. The Ratio and the frequency have to be entered here, too.

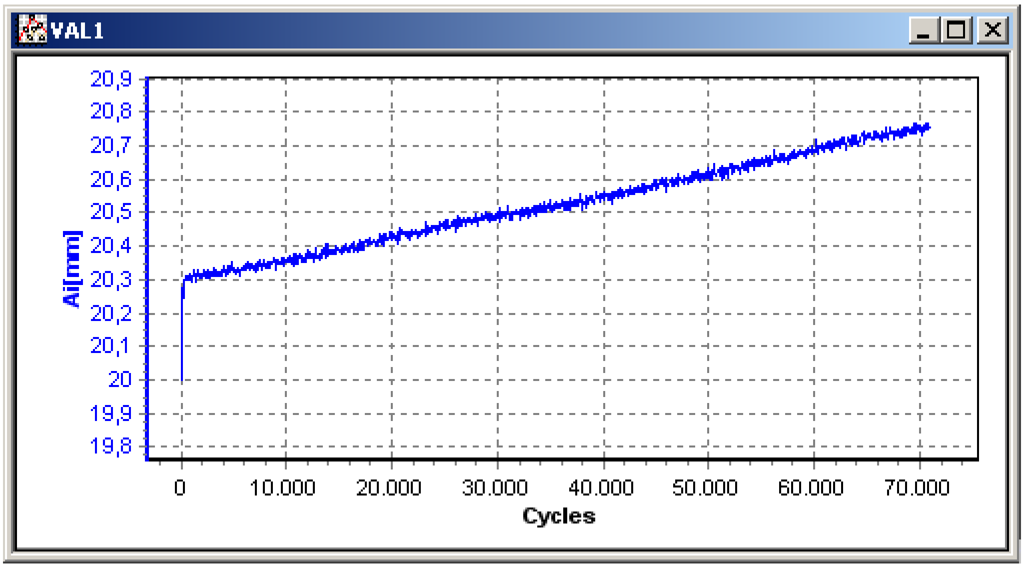
**Method:** The specimen is loaded in a cyclic manner with a predefined force. During this process, the crack length (blue curve) **ai** is being calculated. If the crack length **ai** increases more than input value **"da LV"**, the load **Fmin** will be decreased. This is done by multiplying the amplitude with the amplitude factor **AF** (98.5% in the dialogue). The upper load peak **Fmax** stays constant; hence **Kmax** stays constant, also. The lower load peak **Fmin** results out of **Fmax** minus the lower amplitude (reduced by the amplitude factor **AF**). This way, the value for **Fmin** approaches the one for **Fmax**. Now the test is continued with new peak values, i.e. the lower load. If **ai** increases again by value **"da LV"** compared to the time of the last load reduction, the next load reduction will be calculated. This will be repeated in a cyclic manner until the user stops the process or until a test end criterion is reached.

## 4.8 Phase 3: da/dN – F=const

The initial crack **ai** progresses now rapidly. In the following step (Phase 3) the load is kept constant during the complete step. The operator is able to change the load up to 3 times, depending on the calculated crack length **ai**. The limit for **ai** and the new peak values can be changed during the test. If the operator changes this value, he must press button <Update> to activate the changes.




### 4.8.1 Phase 3 da/dN – Graphic display for crack growth.



## 4.9 Phase 4: KIC Determination of fracture toughness

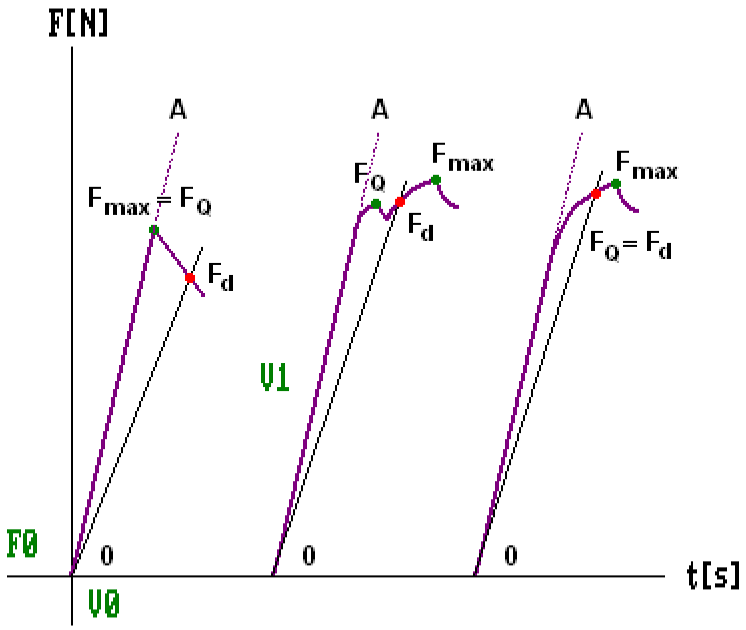
Prior to determine **KIC**, we have to find the intermediate result **KQ**. (Fracture toughness at point **FQ**).

**The procedure is as follows (see sketch):**

First of all, we have to determine the ascending slope of the tangent of the 'load / crack expansion' curve (i.e. the slope in the starting range of the curve). The next step is to construct a secant (see picture), having an ascending slope of 95% of the slope of the tangent. The cross section point of this secant with the graph of the 'load / crack expansion" curve is **Fd**.

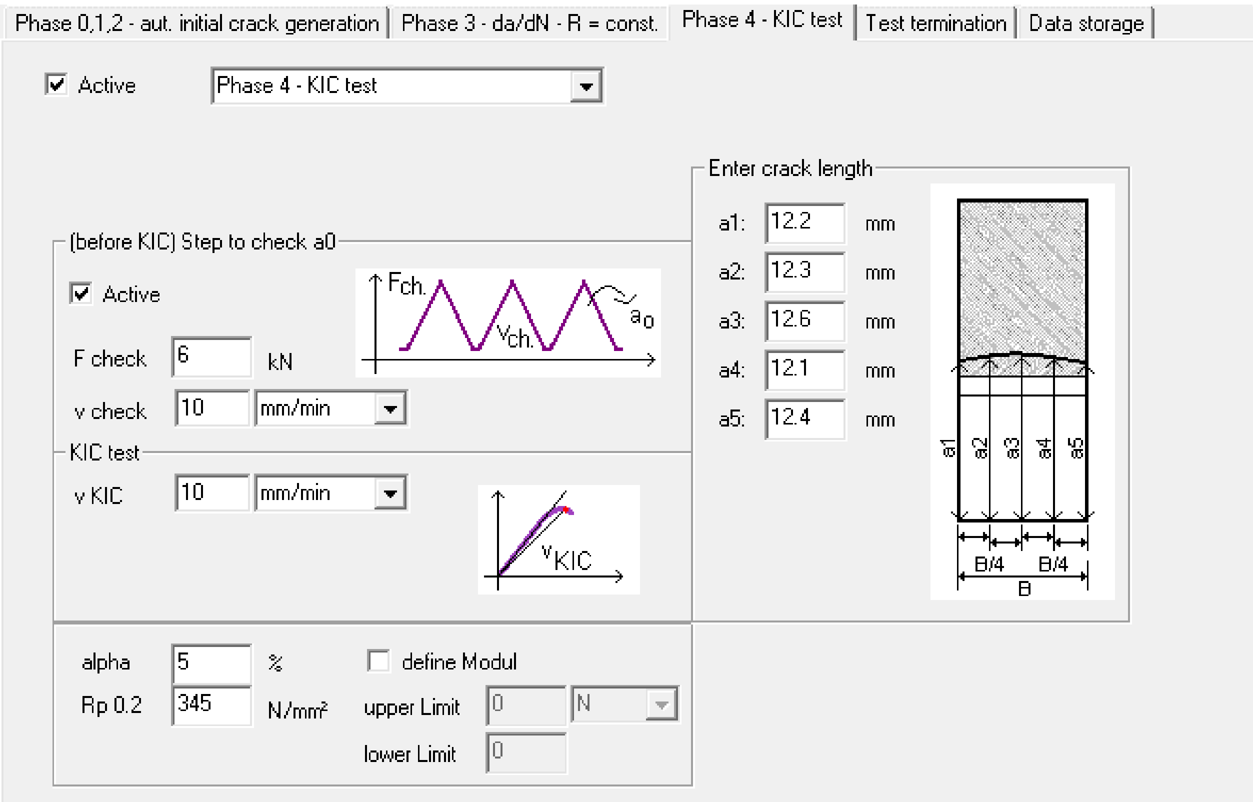
**PQ** now is the maximum load before or in **Fd**. Therefore, we have three possibilities:
First curve: **Fmax** lies in front of **Fd** and is bigger than **Fd**. Then, **Fmax** is **FQ**
Second curve: **Fmax** lies behind **Fd** and is bigger than **Fd**, but there is another load peak in front of **Fd**, which is bigger that **Fd**. This load peak is **FQ**
Third curve: **Fmax** lies behind **Fd** and is bigger than **Fd** and there is no load in front of **Fd** being bigger than **Fd**. Then, **Fd** is **FQ**.

For **KQ** will be calculated out of **FQ**. Now, special qualification requirements are checked in order to verify the test and to identify **KQ** as **KIC**.




The ascending slope of the tangent is determined in an automatically manner; it is the maximum rise of the regression line with a length of 20% of the maximum load **Fmax**. However, if the tangent may not have been place as wanted, it is possible to define the limits manually with command 'Define module'.

Before starting **KIC**, you can exclude or minimize errors by calling up a step to check the testing equipment. In this step, 3 cycles are done, in which we drive from **F0** to a small load "**F check**" in a Xhead-controlled manner and with low speed ("**V check KIC**"). Then, the mean value **a0** will be calculated out of these three cycles and shown in a dialog. If **a0** is ok, the user can now continue the **KIC**-test (or abort it if **a0** is not ok). In the first case, the test will be continued with speed "**v KIC**" in tensile direction until break of the sample.




After the sample is broken, the following results are calculated:

| **Fmax** | **Maximum load** | **[N]** |
|---|---|---|
| | | |
| A | Module line, determined over a range of Fmax / 5.<br>Regression line  y = A x + n | [N/mm] |
| n | See above | [mm] |
| dLh | Elongation at max. load | [mm] |
| Fd | Intersection point of secant with the graph, whereas the secant was constructed as line through zero point with a rise of 5% less than tangent line 0 – A | [N] |
| FQ | Maximal load between zero point and intersection point Fd | [N] |
| KQ | Stress-Intensity in point FQ, calculated from FQ acc. 6.2.3. | [Mpa m^0.5] |

The normalized crack length is:

a/W = c0 + c1*u + c2 * u^2 + c3 * u^3 + c4 * u^4 + c5 * u^5

Whereas: c0, c1, c2, c3, c4, c5 are compliance-coefficients

The u-value in the polynomial is:

u = 1 /  [ sqrt ( B * E * V / P) + 1 ]

Whereas:

| | | |
|---|---|---|
| B | = | Sample thickness |
| E | = | Young's Modulus |
| V | = | crack opening displacement |
| P | | Load |
| V/P | = | Rise of (Crack opening displacement/Load) data during test |

If the crack length is known, the **stress intensity K** can be calculated. The calibration-coefficients are used to calculate f (a/W).
The calculations are done according to ASTM E399-90.

$$K = \frac{P}{BW^{\frac{1}{2}}}\left[f\left(\frac{a}{W}\right)\right]$$

]
where

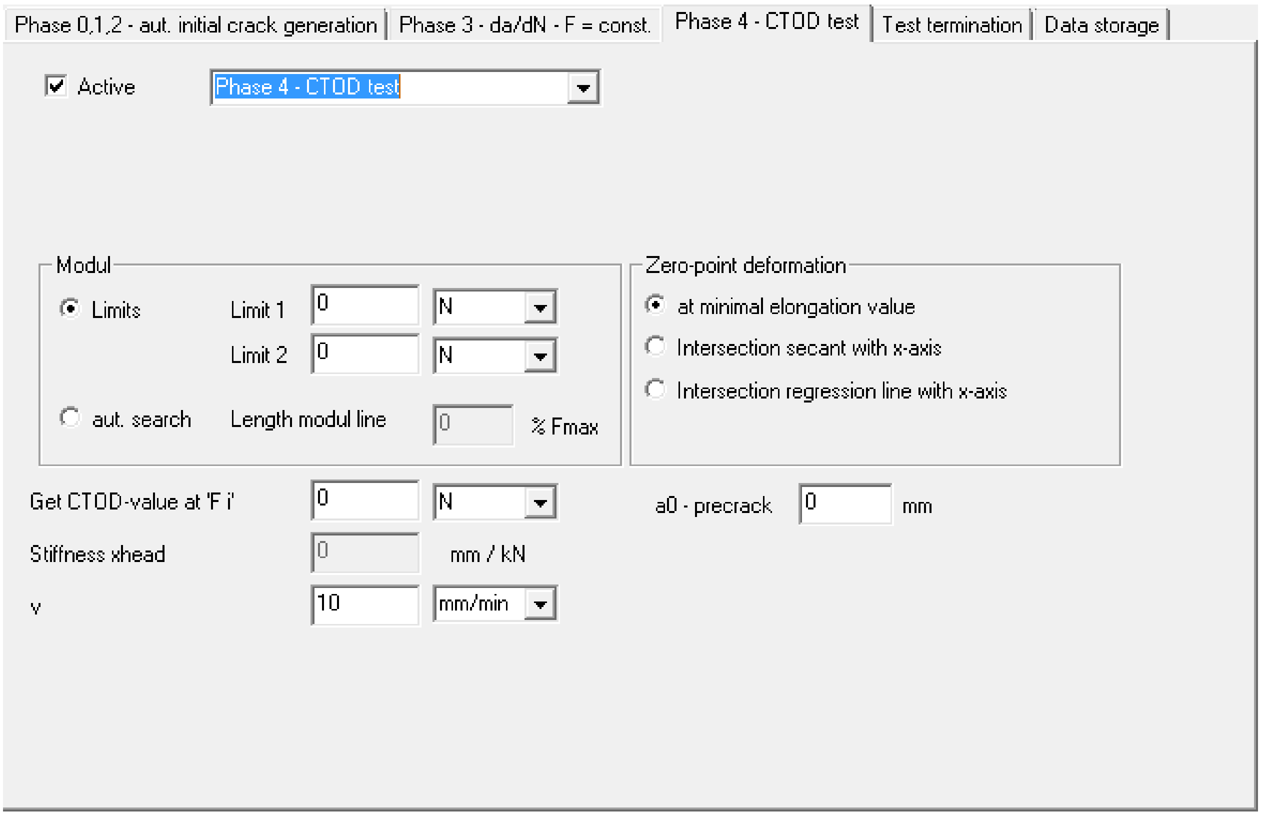
$$f\left(\frac{a}{W}\right) = \left[\frac{2+\frac{a}{W}}{\left(1-\frac{a}{W}\right)^{\frac{3}{2}}}\right]\left[\mathrm{c0} + \mathrm{c1}\left(\frac{\mathrm{a}}{\mathrm{W}}\right) + \mathrm{c2}\left(\frac{\mathrm{a}}{\mathrm{W}}\right)^2 + \mathrm{c3}\left(\frac{\mathrm{a}}{\mathrm{W}}\right)^3 + \mathrm{c4}\left(\frac{\mathrm{a}}{\mathrm{W}}\right)^4\right]$$

For **KQ** to be qualified as a **KIC** value it must meet special qualification requirements.
Requirements acc. ASTM E 399-90:
‚a' is the average of manual measured **ai**:

- Max Diff. (a2, a3, a4) <= 0,1 * a
- Min (a1, a5-a) / a <= 0,15 * a
- a1 – a5 <= 0,1 * a
- min ( ai – Notchlength ) >= 0.025 * W, i=1..5
- min (ai – Notchlength ) >= 1.3, i=1..5
- 0.45 * W <= a <= 0.55 * W
- Pmax / PQ <= 1.10
- $B > 2.5\left(\frac{K_Q}{R_{p02}}\right)^2$
- $a > 2.5\left(\frac{K_Q}{R_{p02}}\right)^2$

$$2.5 * \left(\frac{K_Q}{R_{p02}}\right) \leq \mathrm{B}^{2.5} * \left(\frac{K_Q}{R_{p02}}\right)^2 \leq a$$

## 4.10 Phase 4: CTOD Test

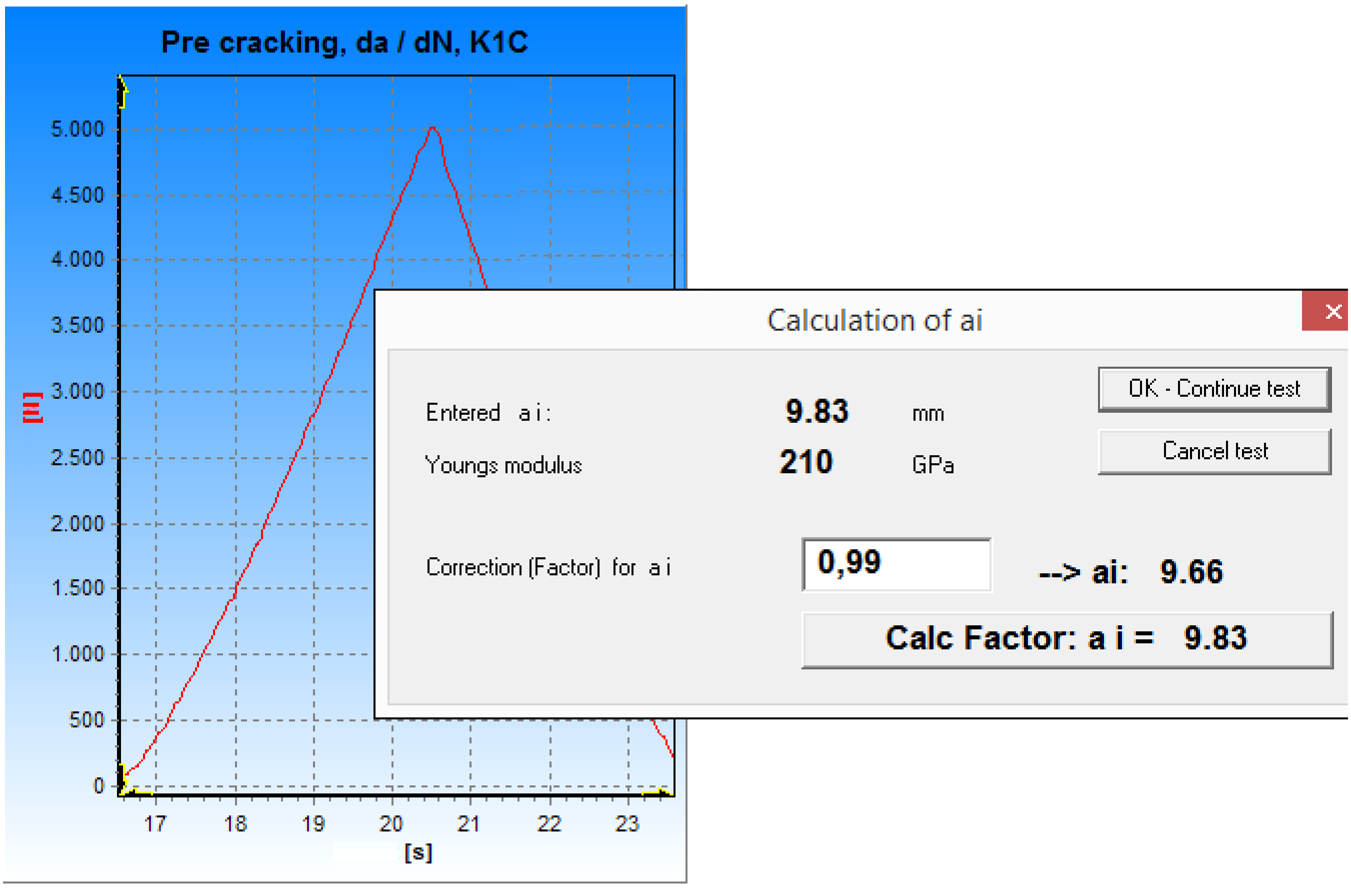



## 4.11 Phase 4: JIC Test

## 4.12 (Phase 0) Step to check a0

To generate an initial crack the sample is loaded with the highest possible frequency and high power to generate the initial crack as quickly as possible. If you have made an error in test equipment, you pay them quickly with the death of the sample, without having generated any results. To exclude errors in the test equipment (or minimize them), you can call before Phase 1 + 2 a single measurement cycle. In this step we go with low speed xhead controlled to a small load.

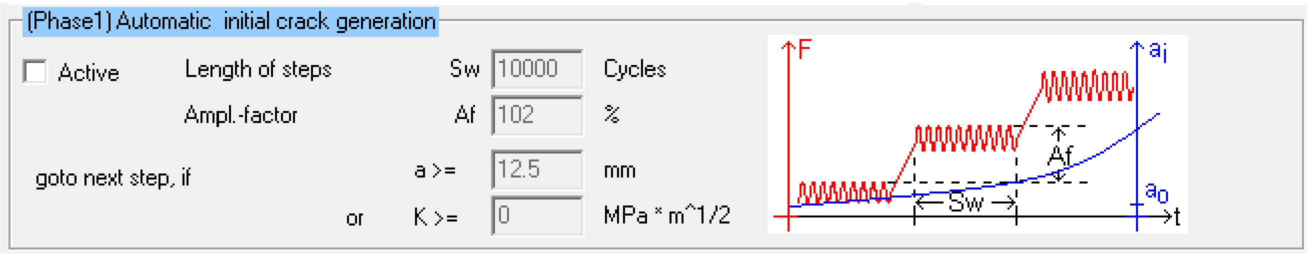

The Xhead is moving slowly with speed V0 (dialog „Test settings | Speeds) to preload F0. After that the Xhead is moving with „v“ to load „F check“ and back to F0 with the same speed.
Now a temporarily „ai“ is calculated, if this is ok the test will be continued. If not the operator can terminate the test.




The user is now free to terminate the test with button <Cancel test>. Or he can enter a factor to correct the calculated "ai". If the operator confirm the result with button <OK – Continue test> the test will continue to generate initial crack, phase 1 + 2 will start.

## 4.13 (Phase 1) Aut. Initial crack generation

This step is optional, so it can be skipped.

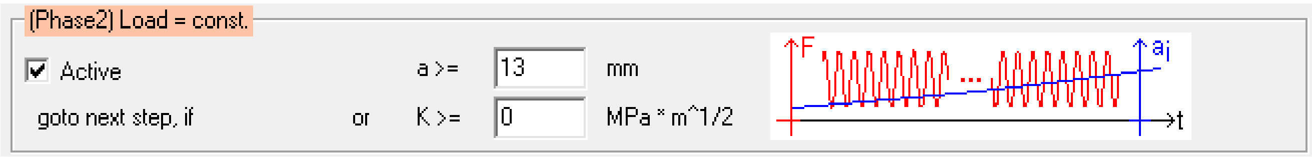



**Method:** The specimen is loaded with a predefined force cyclic (sinusoidal). During this the crack length (blue curve) **ai** and the **stress-intensity factor Ki** are calculated. If **ai** will be greater than the input value **a** or calculated **stress intensity factor Ki** greater than **K** (maximum stress intensity factor), then we branch to the next phase (Phase 2 or Phase 3 or Phase 4, if active).

After the predefined number of cycles (input value **Length of steps Sw**) is reached and still not been reached final value for **ai (max crack length)** or **Kmax** the force values for the upper and lower peak are multiplied with the **Amplitude factor AF** (in dialog 102%). Now with higher load peaks the test will be continued and the next **"Length of steps Sw"** cycles are performed. If the final values for **ai** or **Kmax** again not reached, the load is increased again.

### 4.14 (Phase 2) F = const.

This step is optional, so it can be skipped.




**Method:** The specimen is loaded with a predefined force cyclic (sinusoidal). During this the crack length (blue curve) **ai** and the **stress-intensity factor Ki** are calculated. If **ai** will be greater than the input value **a** or calculated **stress intensity factor Ki** greater than **K** (maximum stress intensity factor), then we branch to the next phase (Phase 3 or Phase 4, if active).

## 5 Activation of test phase 3 - da/dN

After creation of initial crack (Phase 1 / 2) the test can be continued with phase 3. It is also possible to start directly with phase 3, if the sample already has an initial crack.

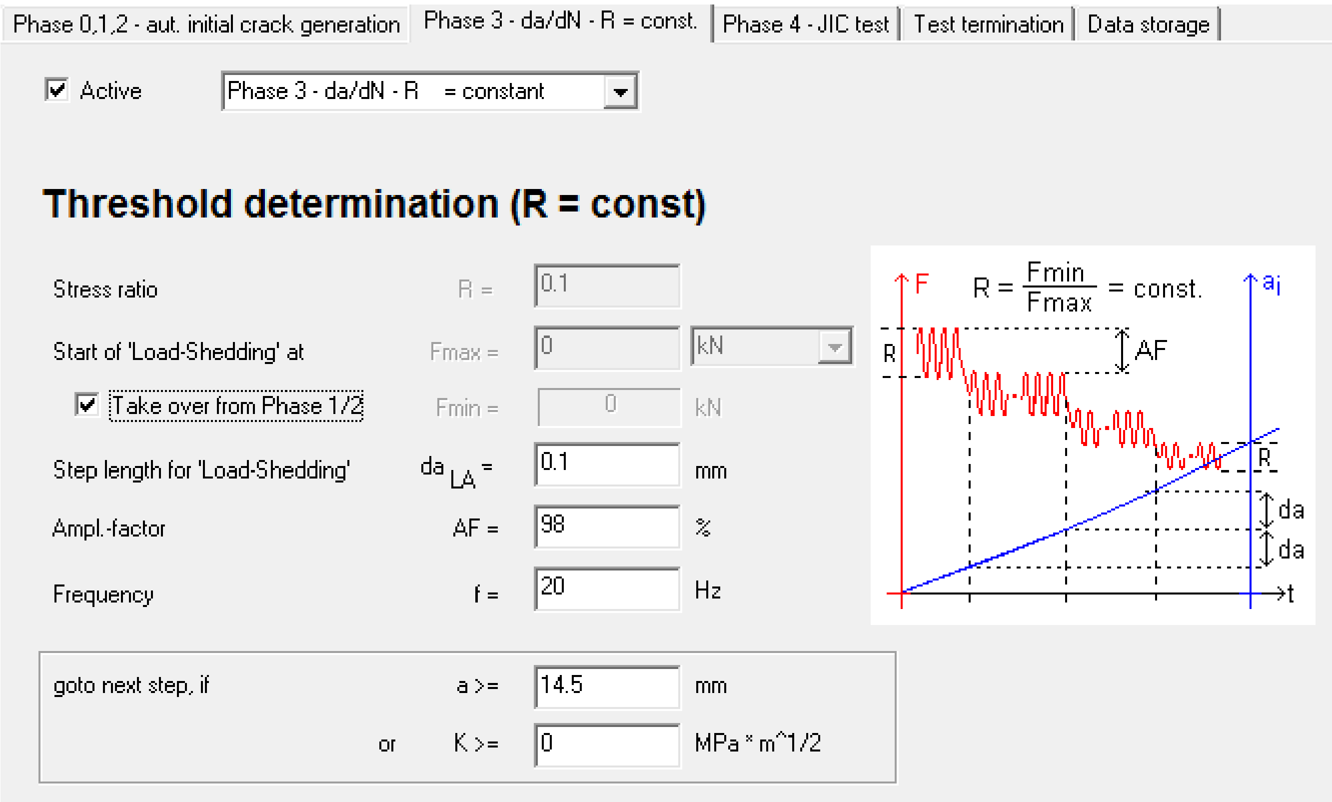
In phase 3 you can select between these tests:

1. da / dN – R = constant (Threshold determination)
2. da / dN – Kmax = constant (alternate Threshold determination)
3. da / dN – F = constant (Load is constant)

This decision is caused by activating checkbox „Test (Phase3)“ and selecting a choice in combo box.

### 5.1 Phase 3 da / dN – R = const. Threshold determination

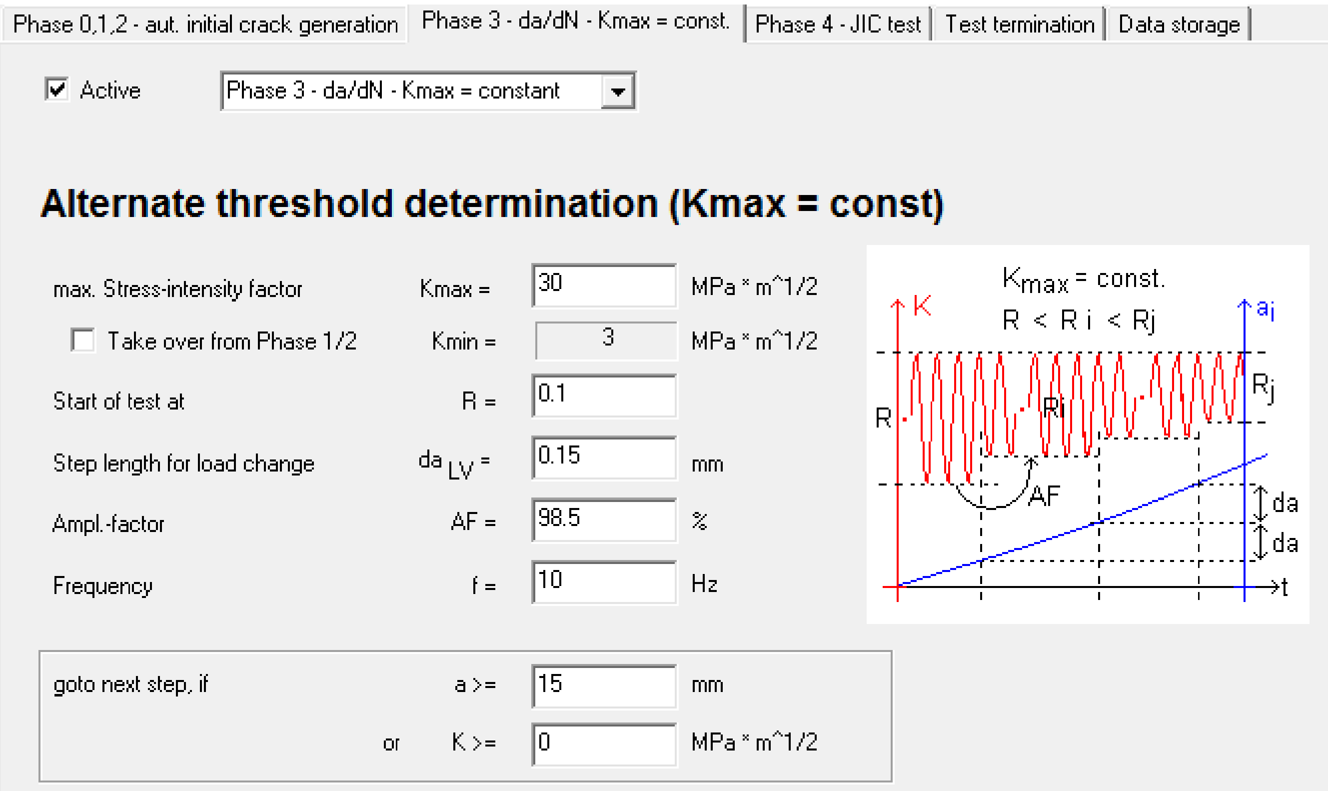
The initial crack ai progresses now rapidly. In the following step (Phase 3) the load will be reduced step by step. The ratio (R – Ratio = Fmin / Fmax) will be constant during this phase, that means both peaks (Fmax and Fmin) are multiplied with the same Ampl.factor (here 0.98).




At start of phase 3 the load Fmax and Fmin of the preceding phase 1 or 2 may be accepted as start values (Take over from Phase 1 / 2), or you can enter new peak values Fmax and Fmin (or Ratio).
**Method:** The specimen is loaded cyclic with a predefined force. During this process, the crack length (blue curve) ai is calculated. If the crack length **ai** increases more than input value **"da LA"**, then the load Fmax and Fmin will be decreased. This is done by multiplying the upper and lower force value with the amplitude factor AF (98% in the dialogue). Now the test is continued with lower peak values. If ai is increasing again by value **"da LA"** compared to the time of the last load reduction, the next load reduction will be calculated. This is repeated cyclically until the user stops the process or test end criterion is reached.

## 5.2 Phase 3 da / dN – Kmax = const. Alternate Threshold determination

The initial crack ai progresses now rapidly. In the following step (Phase 3) the load will be reduced step by step. The ratio (R – Ratio = Fmin / Fmax) increases during this phase. For that peak Fmax will be const., that why Kmax is also const, Fmin increases, the amplitude decreases from step to step.

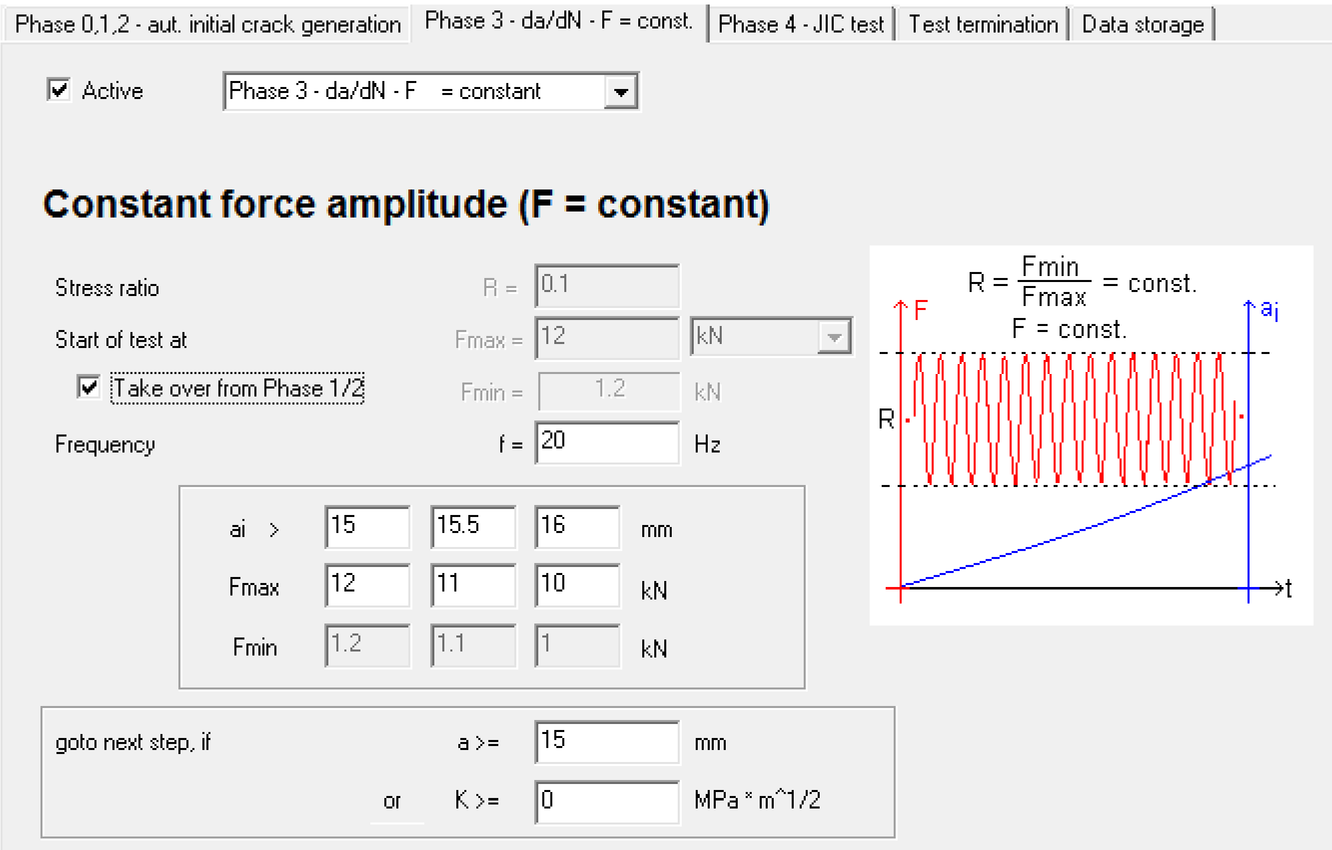



At start of phase 3 the load Fmax and Fmin of the preceding phase 1 or 2 may be accepted as start values (Take over from Phase 1 / 2), or you can enter new peak values Fmax and Fmin (or Ratio).

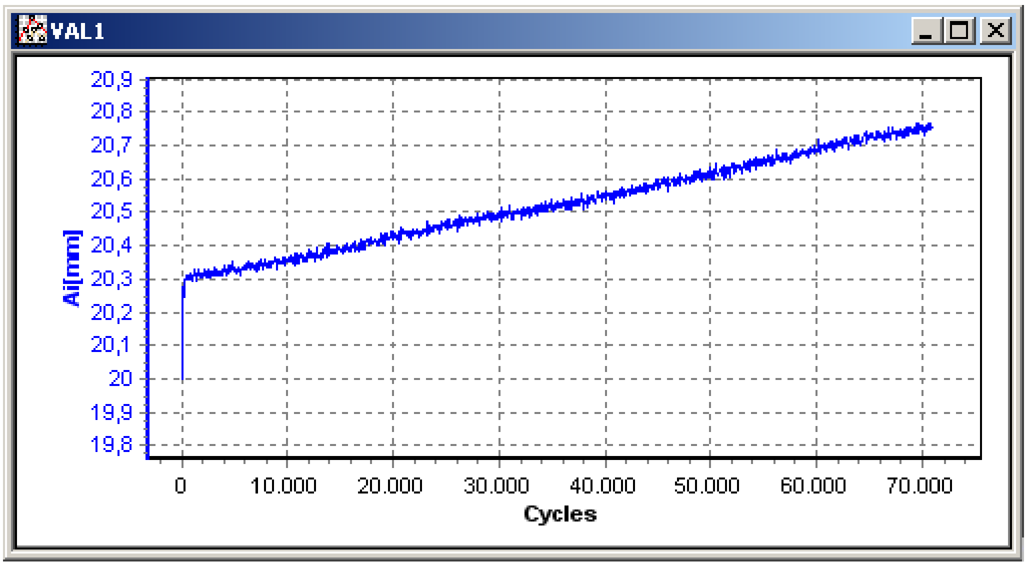
**Method:** The specimen is loaded cyclic with a predefined force. During this process, the crack length (blue curve) ai is calculated. If the crack length **ai** increases more than input value **"da LV"**, then the load Fmin will be increased, Fmax is const, → Kmax also const. This is done by multiplying the amplitude with the amplitude factor AF (98% in the dialogue), and calculate Fmin as Difference from old Fmax and new amplitude. Now the test is continued with new peak values. If ai is increasing again by value **"da LV"** compared to the time of the last load reduction, the next load reduction will be calculated. This is repeated cyclically until the user stops the process or test end criterion is reached

## 5.3 Phase 3 da / dN – F = const.

The initial crack ai progresses now rapidly. In the following step (Phase 3) the load is const. During the complete step the operator is able to change the load up to 3 times, depending from a calculated crack length ai. The limit for ai and the new peak values are changeable during the test. If the operator changes this value, he must press button ‘Update’ to activate the changes.




### 5.3.1 Phase 3 da / dN – Graphic display for crack growth.



# 6 Activation of test phase 4

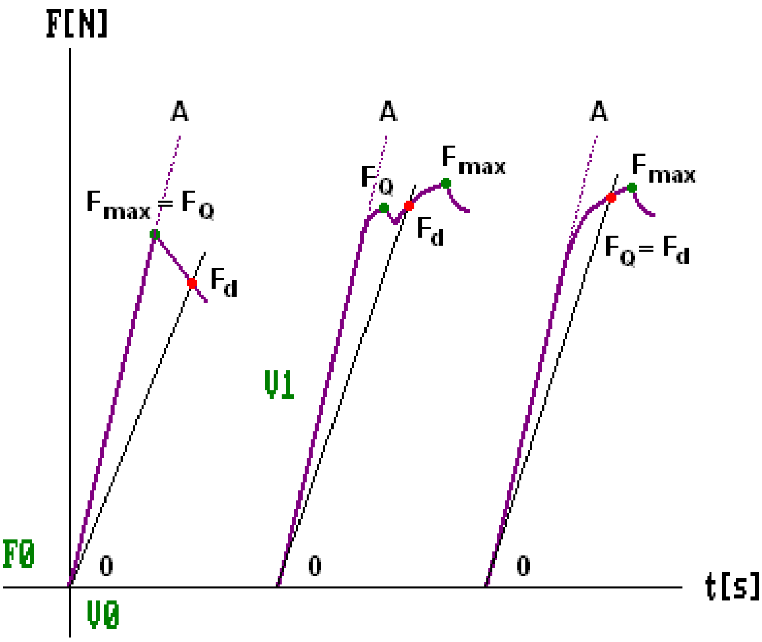
After creation of crack (Phase 1 / 2 / 3) the test can be continued with phase 4. It is also possible to start directly with phase 4, if the sample already has an initial crack.
In phase 4 you can select between these tests:

1. KIC test (Fracture toughness KIC)
2. CTOD test
3. JIC test (Compliance method)

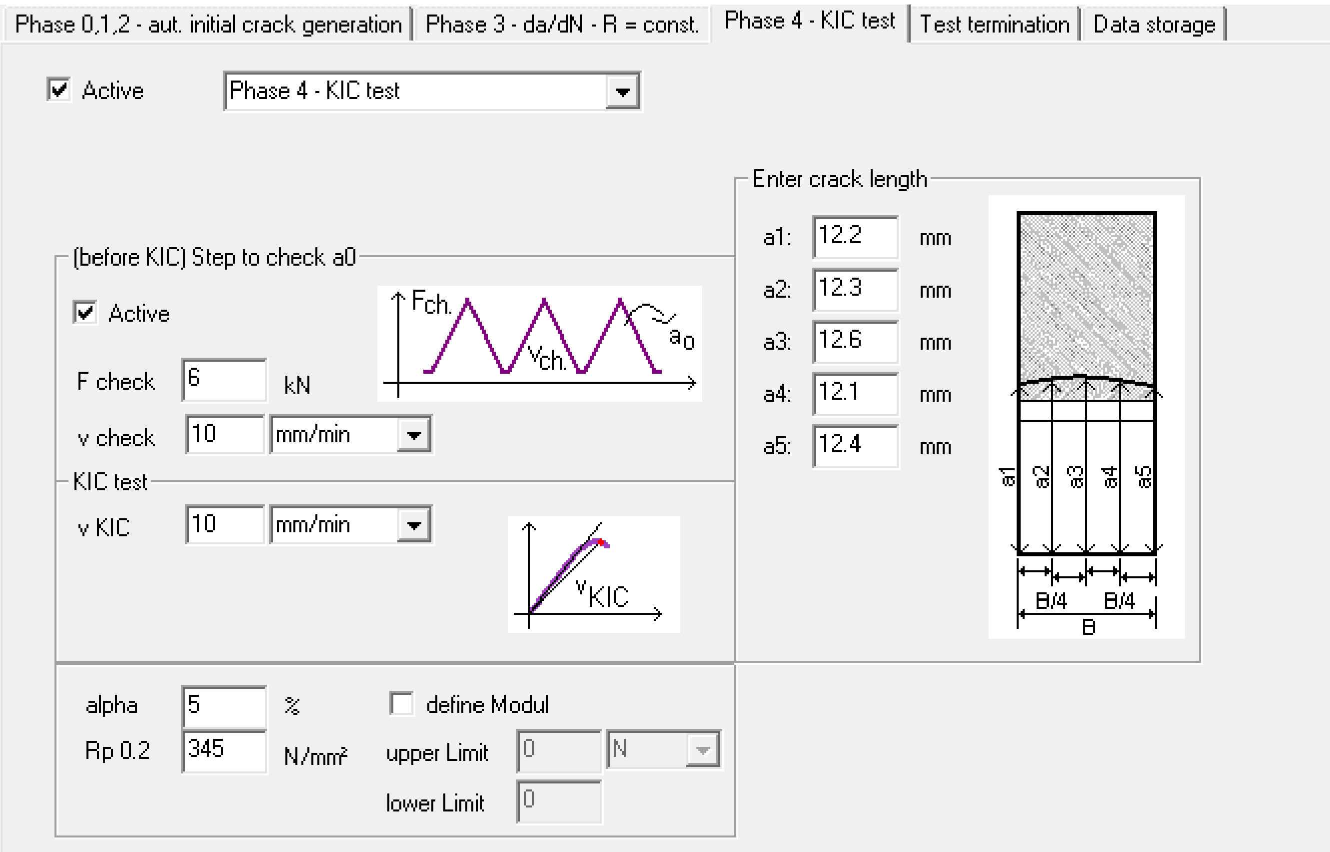
## 6.1 Phase 3 KIC Determination of fracture toughness

To determine $K_{IC}$, in first step we have to find temporarily result $K_Q$ . (Fracture toughness at point $F_Q$).
In order to determine $K_{IC}$ in accordance with this test method, it is necessary first to calculate a conditional result, KQ, which involves a construction on the test record, and then to determine whether this result is consistent with size and yield strength requirements.
The procedure is as follows:
Construct a secant line as shown in picture below with a slope (P/v)5 = 0.95(P/v)o where (P/v)o is the slope of the tangent OA to the initial portion of the data record. This slope can be obtained from a slope calculation using digital data or fit to an autographic record as desired.
The load $P_Q$ is then defined as follows:
If the load at every point on the record that precedes Fd is lower than Fd, then Fd is $P_Q$ (Type I).
If, however, there is a maximum load preceding Fd that exceeds it, then this maximum load is $P_Q$ (Types II and III).

For $K_Q$ to be qualified as a $K_{IC}$ value it must meet special qualification requirements.



The rise of the module is determined automatically. It is the maximal rise of the regression line with length 20 % of max. load Fmax between preload F0 and max. force Fmax. If this result not acceptable the operator can define the tangent line manually, by activating checkbox '"define Module". Than he can define the module limits with input values.
To exclude errors in the test equipment (or minimize them), before starting KIC you can call a step to check the measurement equipment. For that 3 cycles are done. In these cycles we are going with low speed xhead controlled to a small load "F check". The Xhead is moving slowly with speed V0 (dialog „Test settings | Speeds) to preload F0. After that the Xhead is moving with „v check KIC" to load „F check" and back to F0, this 3 times, with the same speed.
Now a temporarily „ai" and modul is calculated, is this ok the test will be continued. If the value for "ai" is confirmed, the xhead is moving with speed "v KIC" in tensile direction, until the sample breaks.




After the sample is broken, the following results are calculated:

| | | |
|---|---|---|
| Fmax | Maximal load | [N] |
| A | Module line, determined over a range of Fmax / 5.<br>Regression line y = A x + n | [N/mm] |
| n | See above | [mm] |
| dLh | Elongation at max. load | [mm] |
| Fd | Intersection point of secant with the graph, secant was constructed as line through zero point with rise 5% less than tangent line 0 – A | [N] |
| FQ | Maximal load between zero point and intersection point Fd | [N] |
| KQ | Stress-Intensity in point FQ, calculated from FQ acc. 6.2.3. | [Mpa m^0.5] |

The normalized crack length is:

$$\frac{a}{W} = c0 + c1 * u + c2 * u^2 + c3 * u^3 + c4 * u^4 + c5 * u^5$$

Where: c0, c1, c2, c3, c4, c5 are compliance coefficients
The u-value in polynom is:

$$u = \frac{1}{\sqrt{\left(B * E * \frac{V}{P}\right) + 1}}$$

u = 1 / [sqrt (B * E * V / P) + 1]

Where:

| | | |
|---|---|---|
| B | = | Sample thickness |
| E | = | E-modul |
| V | = | crack opening displacement |
| P | | Load |
| V/P | = | Rise of (Crack opening displacement/Load) data during test |

If the crack length is known, so the stress intensity K can be calculated. The calibration-coefficients are used to calculate f (a / W).
The calculations are done according ASTM E399-90.

$$K = \frac{P}{BW^{\frac{1}{2}}}\left[f\left(\frac{a}{W}\right)\right]$$

]
where

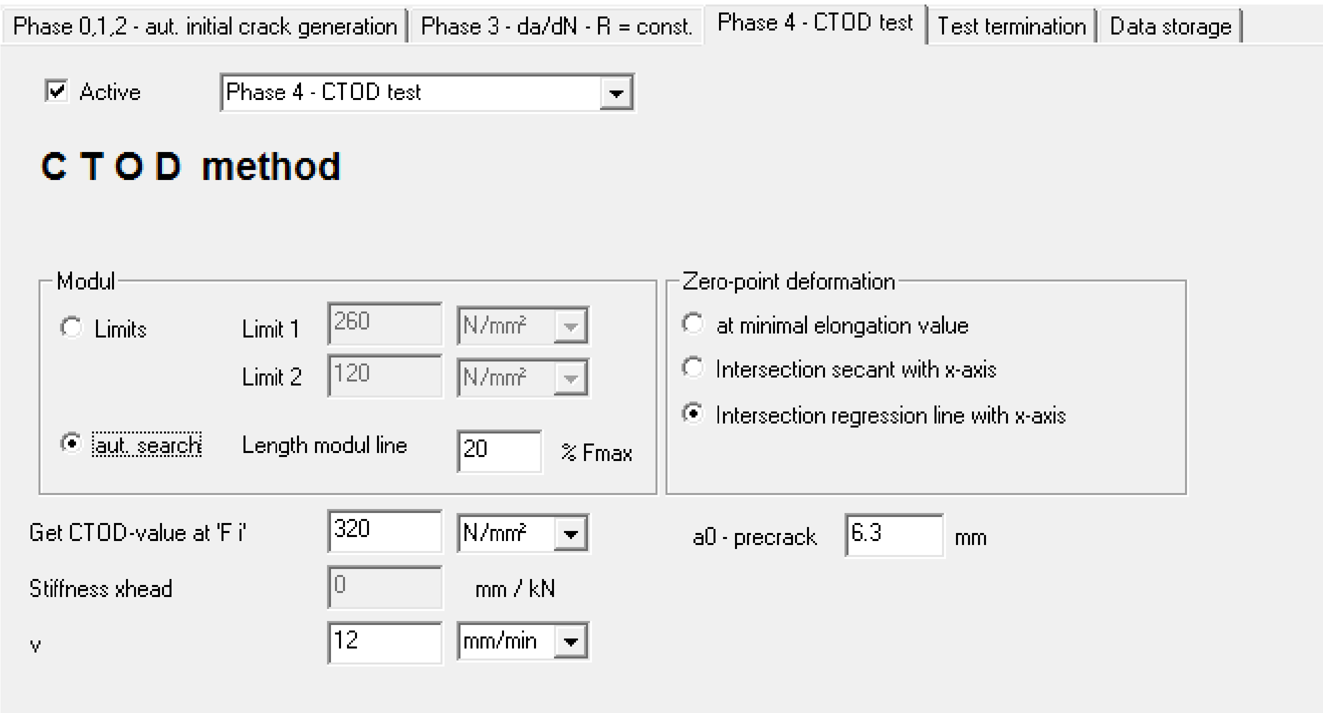
$$f\left(\frac{a}{W}\right) = \left[\frac{2 + \frac{a}{W}}{\left(1 - \frac{a}{W}\right)^{\frac{3}{2}}}\right]\left[c0 + c1\left(\frac{a}{W}\right) + c2\left(\frac{a}{W}\right)^2 + c3\left(\frac{a}{W}\right)^3 + c4\left(\frac{a}{W}\right)^4\right]$$

For $K_Q$ to be qualified as a $K_{IC}$ value it must meet special qualification requirements.
Requirements acc. ASTM E 399-90:
‚a' is the average of manual measured ai:

- Max Diff. (a2, a3, a4) <= 0,1 * a
- Min (a1, a5-a) / a <= 0,15 * a
- a1 – a5 <= 0,1 * a
- min ( ai – Notch length ) >= 0.025 * W, i=1..5
- min (ai – Notch length) >= 1.3, i=1..5
- 0.45 * W <= a <= 0.55 * W
- Pmax / PQ <= 1.10
- B > 2.5 (KQ / Rp0.2) ^ 2
- a > 2.5 (KQ / Rp0.2) ^ 2

- $2.5*\left(\frac{K_Q}{R_{p0.2}}\right)^2 \le B \wedge 2.5*\left(\frac{K_Q}{R_{p0.2}}\right)^2 \le a$

## 6.2 Phase 3 CTOD test (Crack-tip opening displacement)




In this test rnethod, CTOD is the displacement of the crack surfaces normal to the original (unloaded) crack plane at the tip of the fatigue precrack, a0 . In this
test method, CTOD is calculated at the original crack size, a0, from measurements made from the force versus displacement record.

CTOD delta is calculated acc:

- ISO 12135
- ASTM E1290 (in RPT window)
- BS 7448T1 (in RPT window)

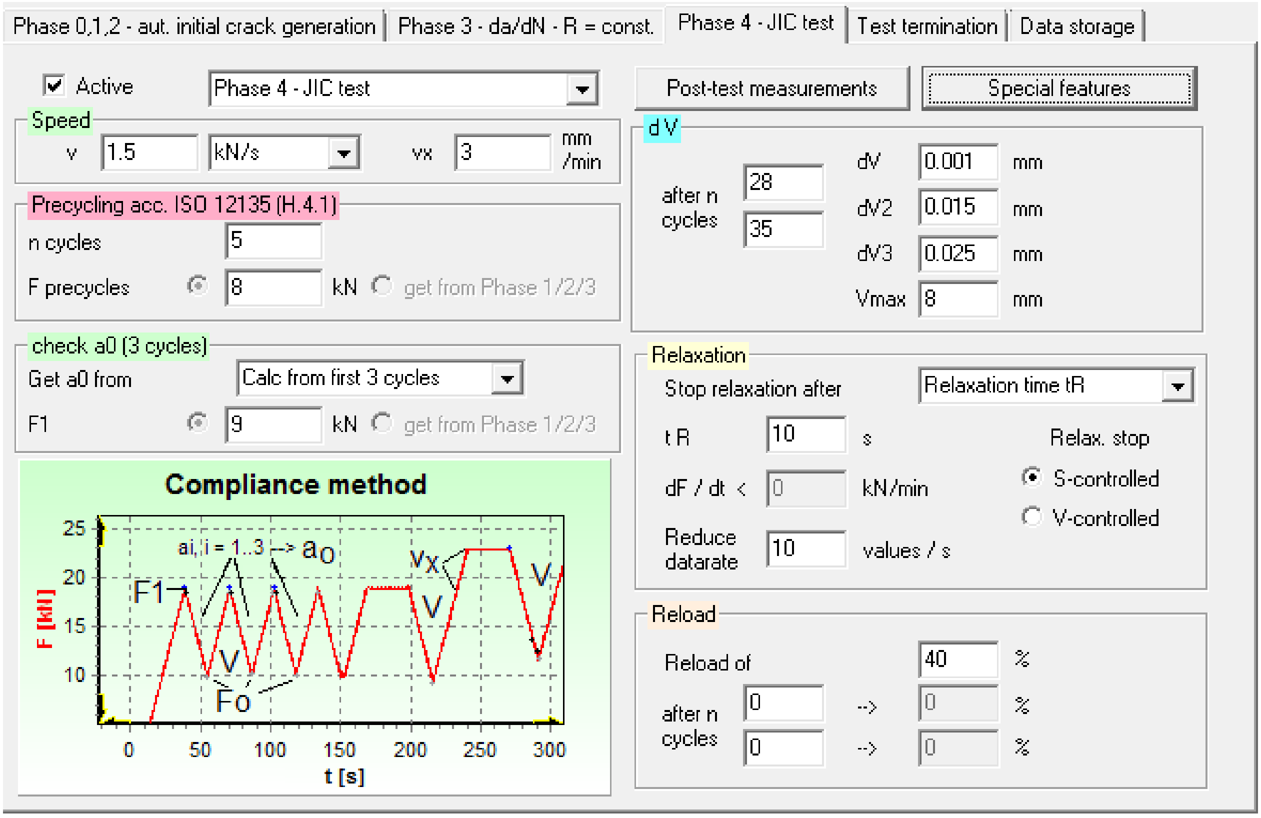
After the sample is broken, the following results are calculated:

| | | |
|---|---|---|
| F i | Input value Fi, or defined by mouse | [N] |
| Cmod i | Extensometer value at Fi | [mm] |
| LLD i | Load line displacement at Fi (XHead path) | [mm] |
| Delta i | CTOD δ at F I (acc. ISO 12135) | [mm] |
| J i | J at F I (acc. ISO 12135) | [kJ/m²] |

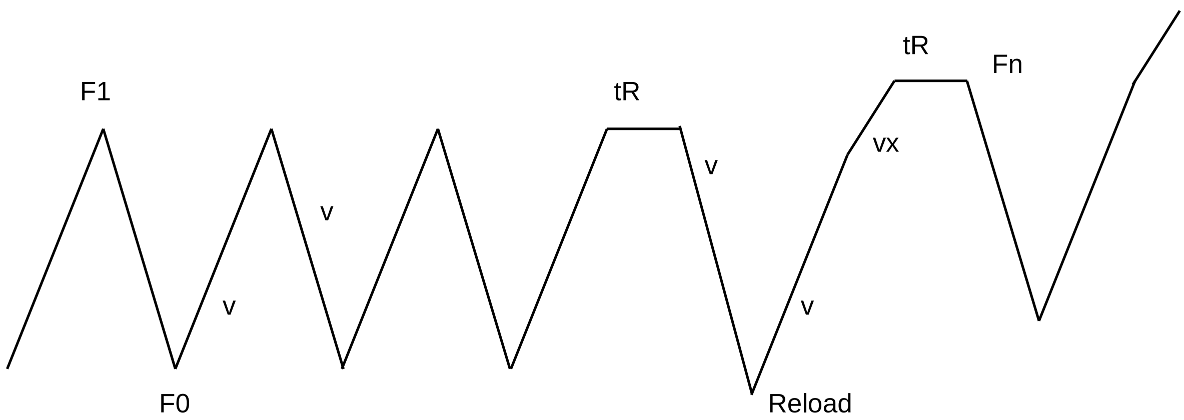
| | | |
|---|---|---|
| F max | Maximal load | [N] |
| Cmod max | Extensometer value at F max | [mm] |
| LLD max | Load line displacement at F max | [mm] |
| Delta max | CTOD δ at F max (acc. ISO 12135) | [mm] |
| J max | J at F max (acc. ISO 12135) | [kJ/m²] |
| | | |
| F end | Load at end of test | [N] |
| Cmod end | Extensometer value at F end | [mm] |
| LLD end | Load line displacement at F end | [mm] |
| Delta end | CTOD δ at F end (acc. ISO 12135) | [mm] |
| J end | J at F end (acc. ISO 12135) | [kJ/m²] |
| | | |
| a0 calc. | Calculated a0 | [mm] |

## 6.3 Phase 4 JIC test (Compliance method)

Determination of J integral at metal tests following the compliance method.




Before commencing the test, it is recommended that the specimen be cycled several times in the elastic regime at test temperature to allow the specimen to “bed-in”. Precycling acc. ISO 12135 (H.4.1)




Check a0 (3 cycles)

These cycles perform between preload F0 and F1 define precrack value a0. We can use this value or a entered value for a0 for the following calculations.

The test speed is „v“.

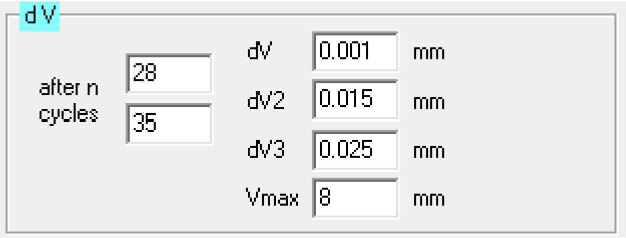
At least three unloading compliance measurements shall be made at a force less than the maximum permissible final fatigue force defined in 5.4.2.4.3. No value of the estimated crack length shall differ from the mean by more than 0,002 *W*. The maximum range of the unload/reload cycles shall not exceed 50 % of the actual maximum force used to measure the three initial unloading.

To determine the first crack length a0 we have to do 3 load/reload cycles (until load **F1**).
The calculation is using load and deflection values in the rising and falling part of the curve.
The reload value is either a certain percentage of Fn, or 50% of Pf calculated when checking a0!

After determination of a0, the first cycle starts:

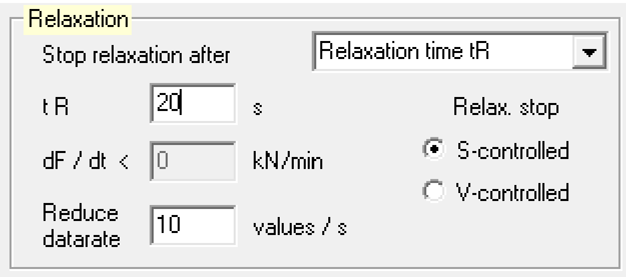
1. Wait at Fn until relaxation time is over
2. Go with speed v to the reload value
3. Go with speed v to Fn
4. Go with speed vx to Vn + dV (Vn is the last crack opening)

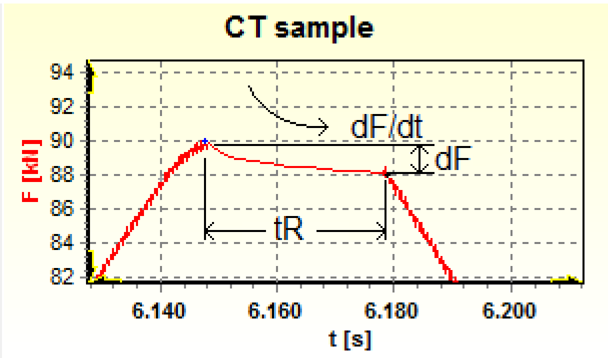
### 6.3.1 Definition of Crack Opening




The crack opening can be automatically increased by three steps after reaching n cycles.
JIC-Test is finished when the maximum crack opening Vmax in exceeded.

### 6.3.2 Definition of Relaxation

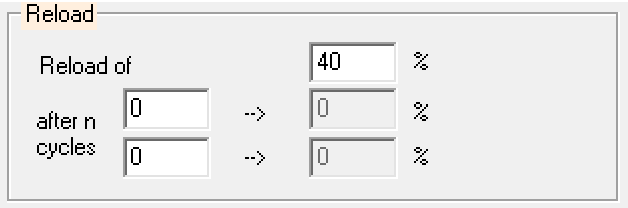



**tR** is the relaxation time, here in graphic 20 sec. The relaxation can be finished after the end of relaxation time, after falling below the relaxation rate **dF/dt** or both criteria simultaneously. You can activate this behaviour in dialog Input-Select, input selection **Relaxation after**.

During relaxation, we can measure with reduced data rate, only. The input value **pAbspRelax** defines, which n-th measurement value is stored (e.g. pAbspRelax=5, if we have a data rate of 50Hz → we have 10 measured values / sec).

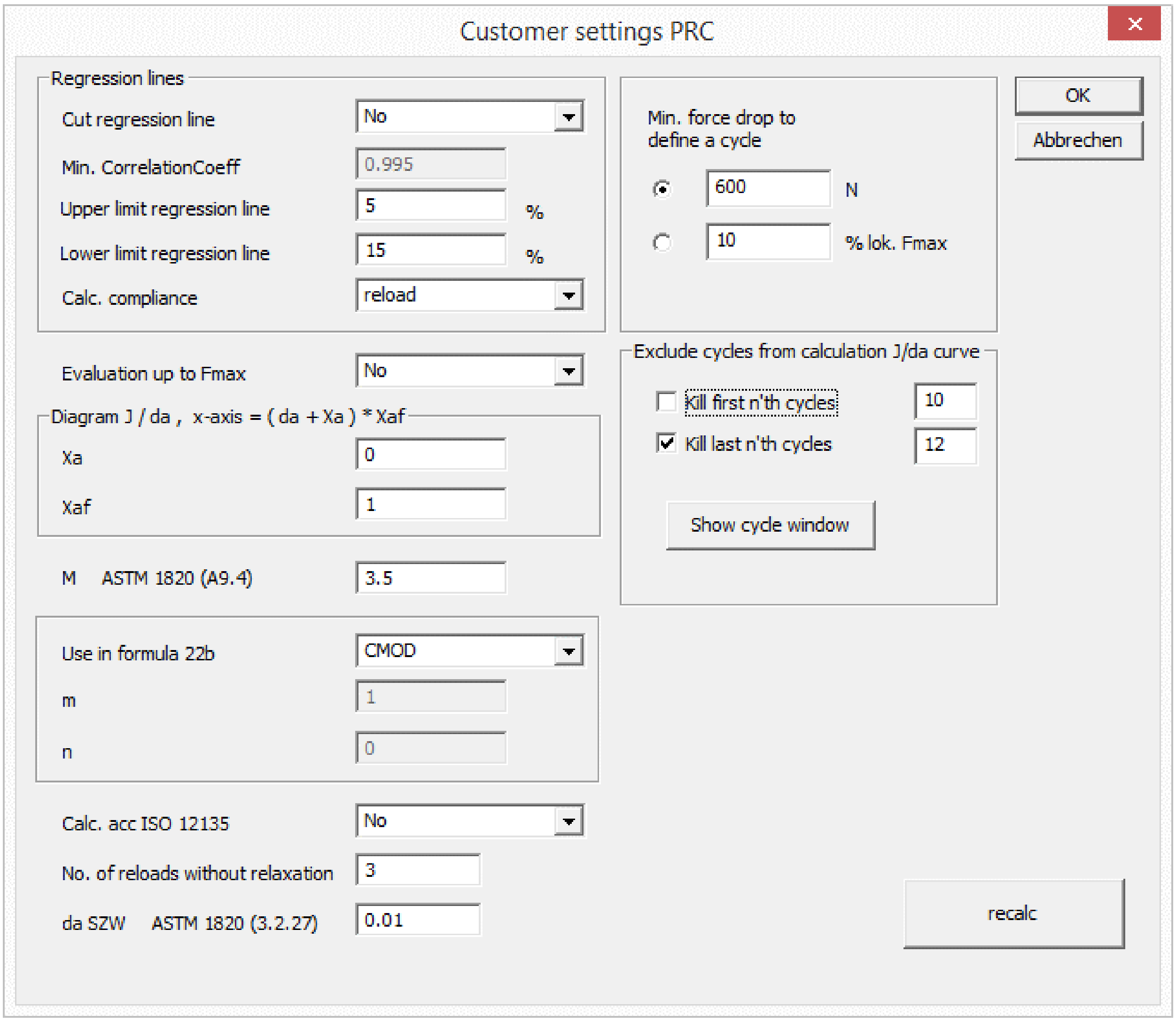
### 6.3.3 Definition of Reload



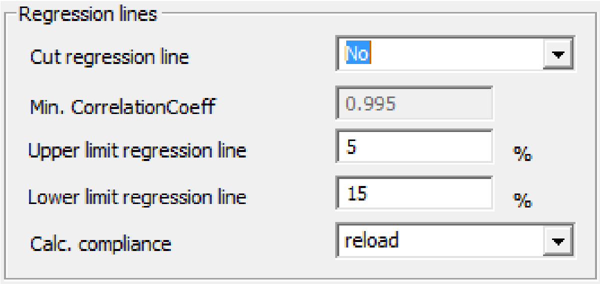

It is recommended that the unloading range be as small as practicable but not exceed (ISO 12135) 25 % of the force $F_L$ evaluated from 5.6.2, (ASTM 1820 50% of calculated Pf) or 50 % of the current force value, whichever is smaller.

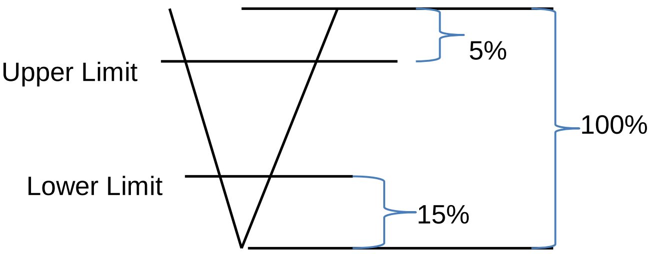
### 6.3.4 Button Special features

The values entered her will influence the calculation of results.



#### 6.3.4.1 Regression Lines



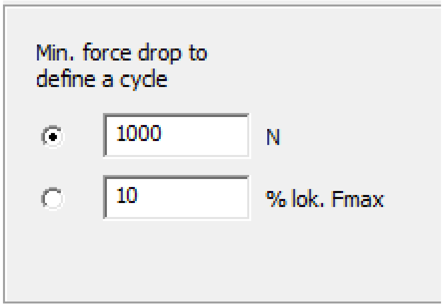




To calculate the crack propagation “ai” a linear regression F / dV is calculated. The regression factor should be nearly 1, that means, the force/dV values should lie on a straight line. If the regression factor is too small, the reload cycle is invalid. In that case we can automatically (Cut regression line = Yes) reduce the length of regression curve to find a straight portion of the cycle, to get a valid reload cycle. We can enter here the minimum regression coefficient for a valid reload cycle.

You can define the upper and lower limits for the linear regression.

The compliance can be calculated using the reload, load or both sections.

#### 6.3.4.2 Minimum force drop



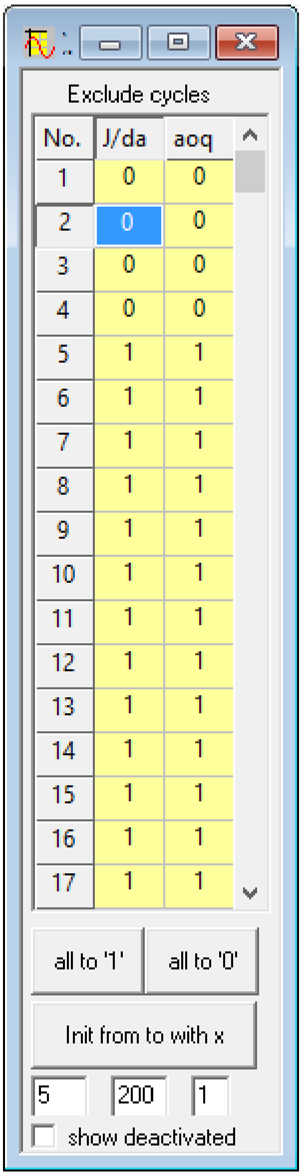

A cycle is determined by an minimum drop of force.

Here you can either choose an absolute value or percentage of the local Fmax.

At start of test this value is initialized with F1 / 10 (absolute value).

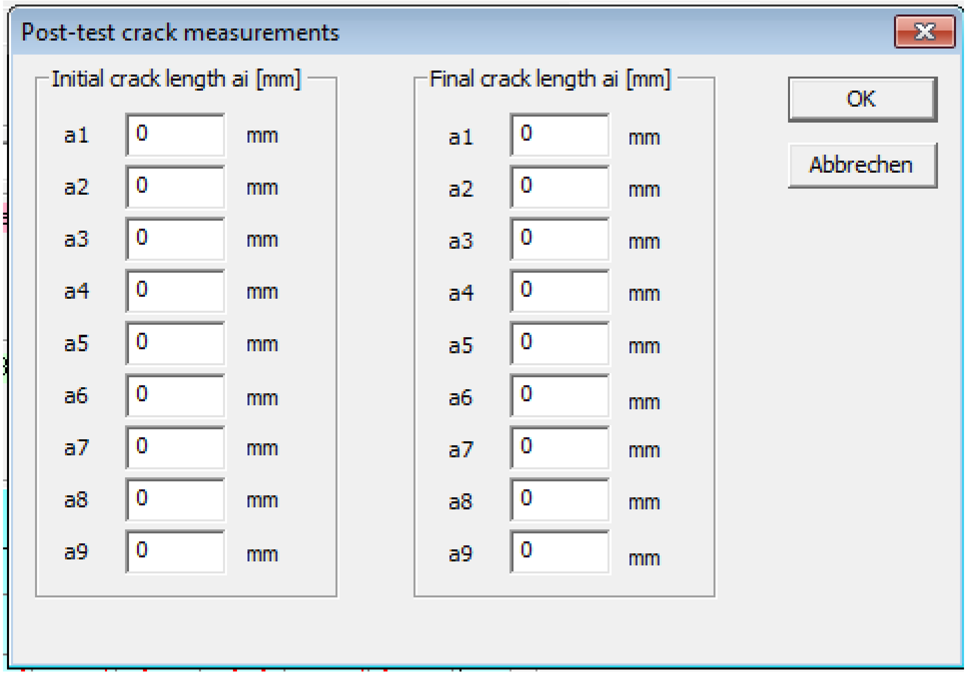
### 6.3.4.3 Exclude cycles from calculation of J / da

You may want to exclude certain reload cycles to calculate J / da curve. Usually the first or last cycles are to be removed. For this just activate checkboxes “Kill first/last n’th cycles” and enter the number of cycles. In addition you can enable / disable each cycle in the dialog “Exclude cycles”




The calculation of J / da curve is done twice. First time with value “a0” (from input dialog or from the first 3 cycles), second time with value “aoq” from the calculation of the equation system. For both calculations you can specify separately, which cycles should be used.

### 6.3.5 Post-Test Crack Measurements




The specimen shall be broken open after testing and its fracture surface examined in order to determine the original crack length $a_0$, and any stable crack extension delta $a$ that may have occurred during the test.

**Initial crack length**
Initial crack length $a_0$ is measured to the tip of the fatigue crack. Nine measurements shall be made as indicated in ISO 12135 Figures 13 and 14.

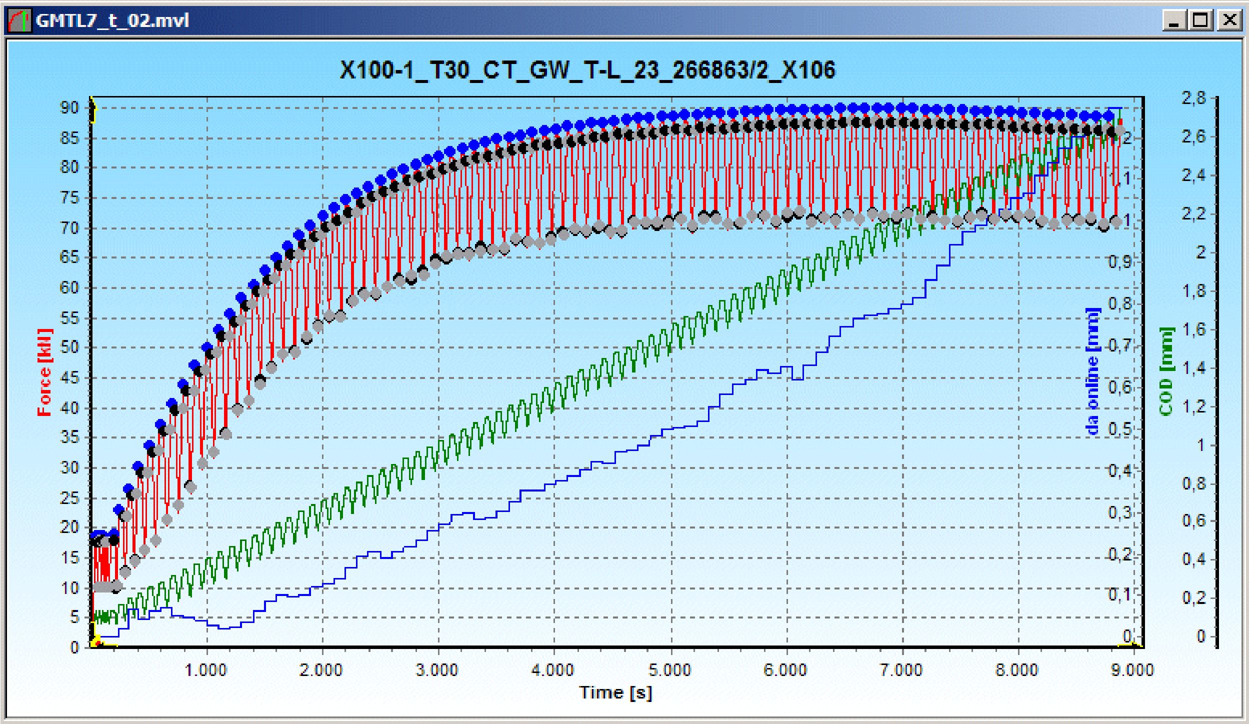
From that points calculate the average:

$$a_0 = \frac{1}{8}\left[\left(\frac{a_1 + a_9}{2}\right) + \sum_{j=2}^{j=8} a_j\right]$$

and check than the following requirements:

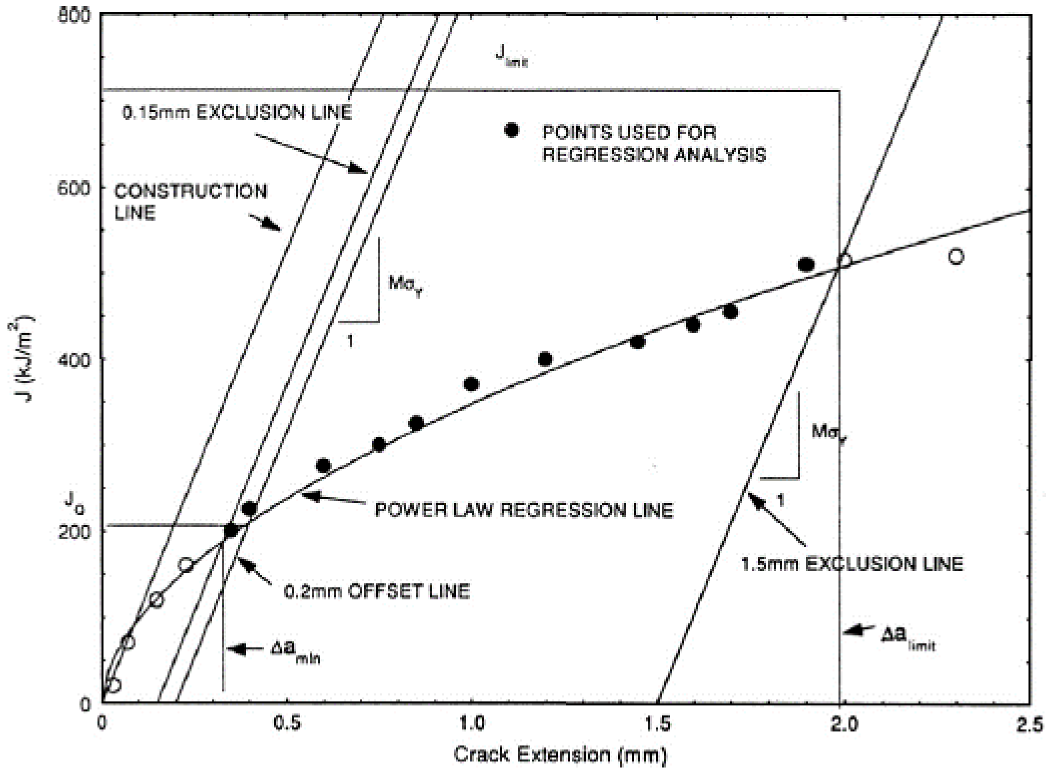
- ratio ao / W shall be within the range (0,45 to 0,7)
- The difference between any one of the central seven points and the average shall not exceed 0,1 $a_0$.

## 6.3.6 Sample of a JIC curve of a steel specimen



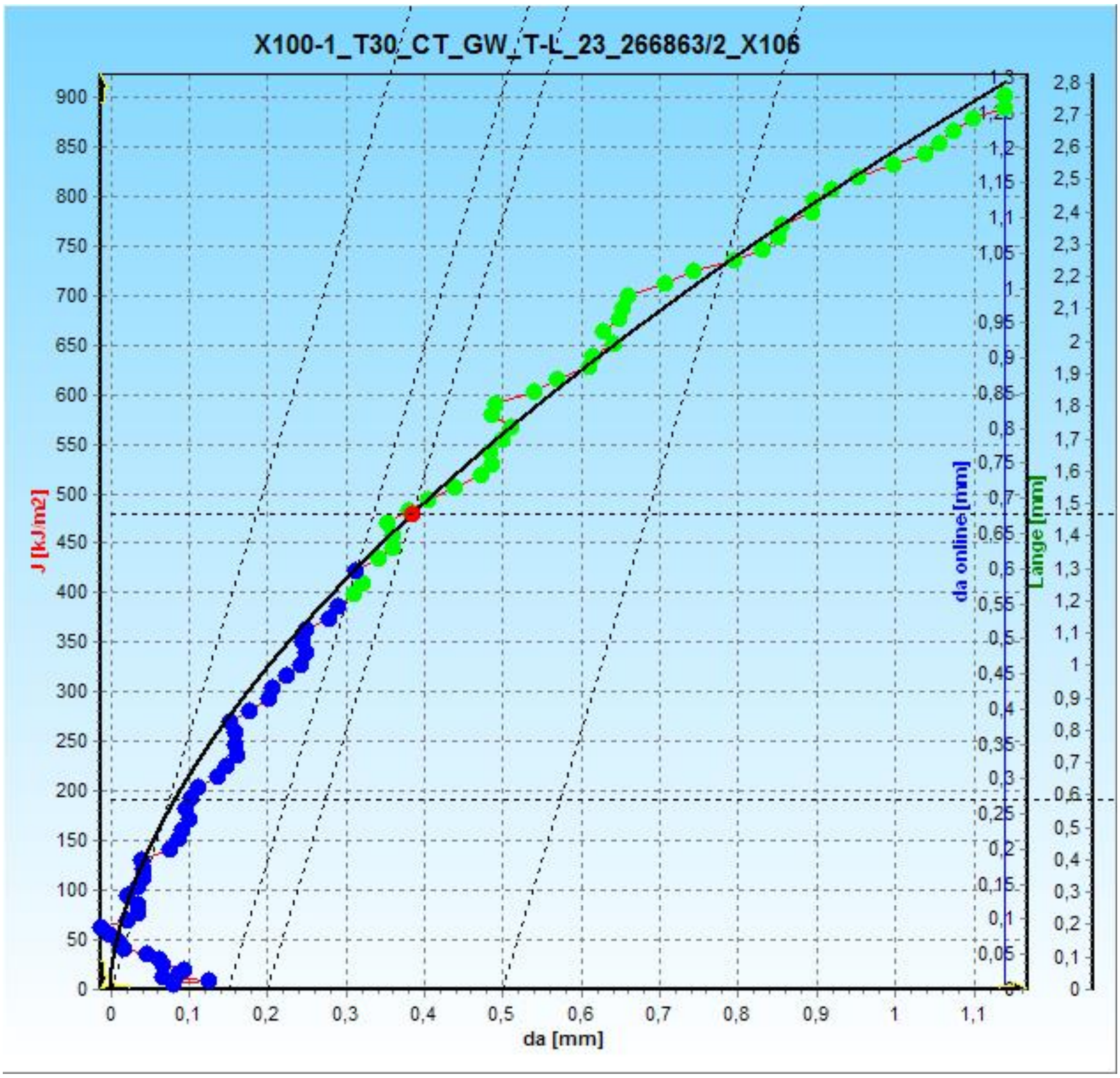

| | Fmax[kN] | vmax[mm] | J0.2[kJ/m²] | aoq[mm] | Jq[kJ/m²] | JIc[kJ/m²] | Kq[MPa*m^1/2] | KIc[MPa*m^1/2] | J max[kJ/m²] |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 90.109 | 2.75 | 312.13 | 25.35 | 458.84 | 459 | 325.40 | 325.40 | 894.09 |

A typical J-R curve with test data points, construction lines and limitation bounds by ASTM 1820

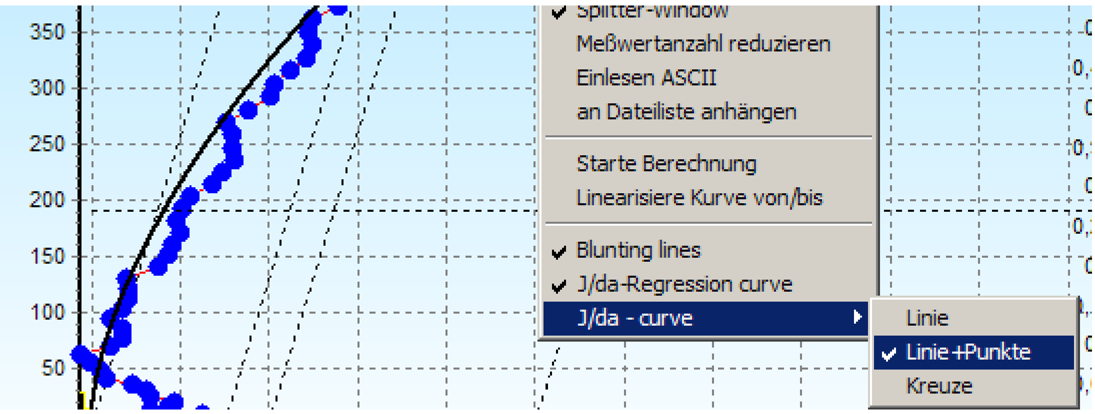


### 6.3.7 J / da curve

On end of test you can select in dialog “Diagram settings” J / da. The J/da – curve looks like that:



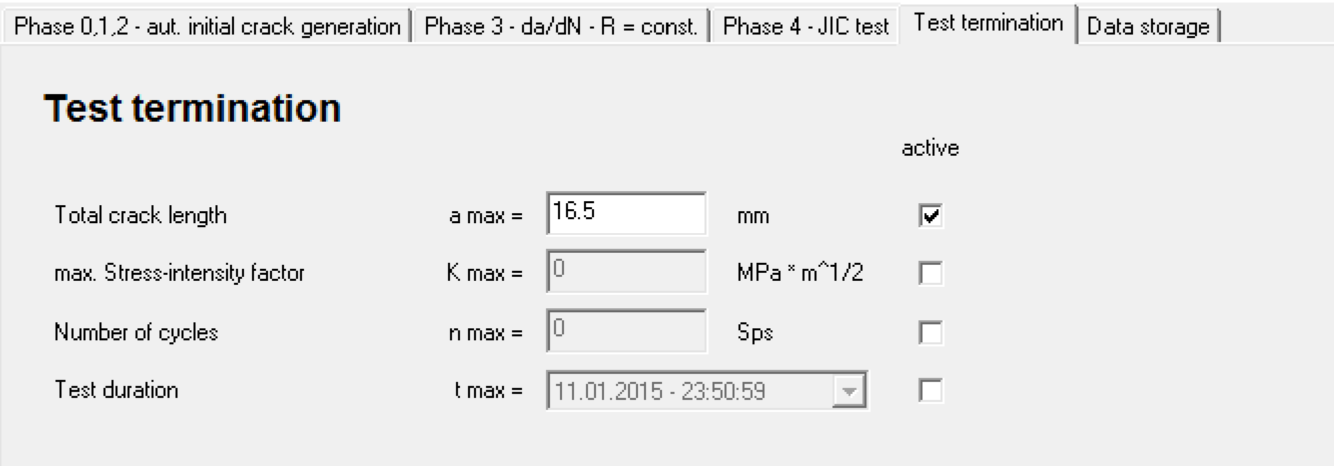

Via context menu you can define additional diagram settings:



# 7 Test termination

You can activate here test end criterions, which are checked in all phases (Phase 1,2,3) of this test procedure. If you have activated one criterion, this will stop the test execution, when this criterion will be true.

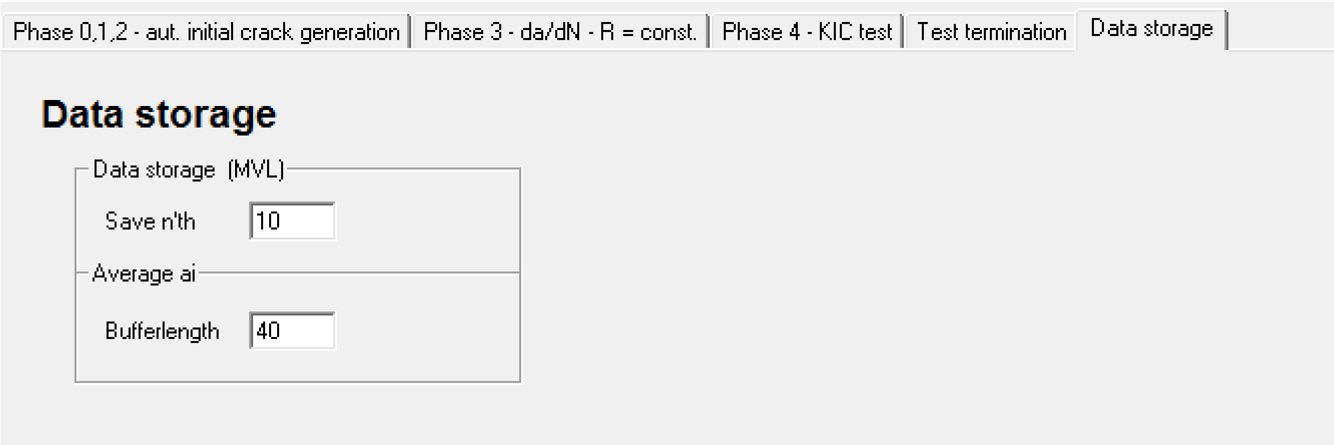
You can check the stress-intensity factor with **K max**, set a maximal limit for cycle's **N max**, set a maximal crack length **a max**, or terminate the test, when we have reached a specified time limit **T max**.



# 8 Data storage

In this dialog we enter settings for data storage. This test creates a graphic curve **da / dN** in VAL-window. How many values we have to save? The first 2 edit windows control the data storing into VAL window. In this example the result of every 20'th (**delta N**) cycle will be stored or if the difference between the calculated crack length of the actual cycle and the crack length of the last stored cycle less than **"delta a"**.

**MVL:** Into MVL window completes cycles from offset to offset are stored here. At first the list of cycles from dialog "Test settings | Settings dynamic | MVL | Button define cycles" defines the cycles. If this list is ready, we continue with input value **"Save n'th", than** every 100'th cycle (see dialog below) will stored to MVL window.




We have different USER identities, which are predefined for this test. Two of these identities are the crack length **‚ai'**, and the average curve **‚Fit ai'**. This user identity contains the same values as **‚ai'** but averaged over an range of n values (sliding average, n = Buffer length). The advantage of this averaging is, that the fitted curve is much smoother than the original **'ai'**- curve. All switch points between the phases, and also the test end criterions are using the averaged 'ai'. The number of values for averaging is the input value ‚Buffer Length - Average ai. If we enter here ‚1' , so we have the unaveraged ‚ai' for the criterions.