FractureLab

TEST CONTROLLER SOFTWARE

USER MANUAL

14 January 2026

Contents

1. INSTALLATION

1.1. Device Driver and ADBasic Software

- Prior to download, disable the power saving modes (hibernation, lock screen, standby) active on the target computer.
- Additionally, edit the display preferences in Windows File Manager to ensure that all file extensions (e.g. ".txt", ".csv", etc.) and all hidden files are visible.
- Go to the ADwin website: https://www.adwin.de/us/download/download.html
- Download the complete software package for the computer's operating system.
- Install the program following the instructions in the document "ADwin Installation Manual for the Installation of ADwin Systems" located in the \ADwin\Documents\Setup folder.

1.2. Controller Software

- Download and double click on the FLcgs_installer.exe file.
- It will then display a prompt for the installation location. In the general case the "Program Files (x86)" folder is not advisable because of potential IT ownership restrictions, so it is recommended to use the root directory (e.g., C:\) instead.
- Select "Create a desktop shortcut" if desired.
- Confirm install location and hit "Install".

1.3. Program Initialization

- Initial execution of the program will bring up the splash screen (described in detail below); however before first use, the license key must be generated to access the program.
- To initialize the process, hit "Boot", then "Start Process". A dialog window will appear asking for the device serial number.
- Enter the serial number from the back of the device and hit "OK"
- This will generate a file that must be sent to FractureLab to get the program license.

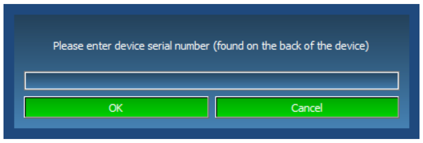


Figure 1: Dialog Window to Generate the Program License Key

2. PROGRAM DESCRIPTION AND FEATURES

2.1. Splash Screen

Upon execution, the splash screen will appear with the FractureLab logo, the version number, and several start options. Each of these sections will be explained in more detail in the sections below.

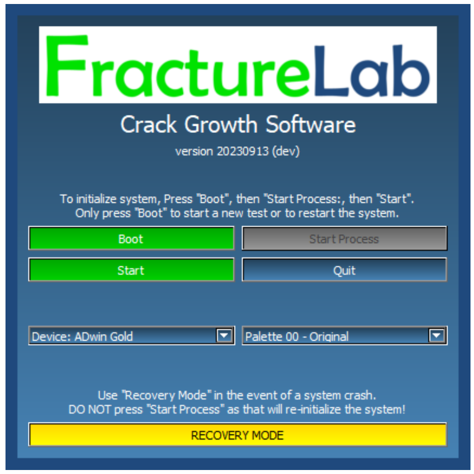


Figure 2: Splash Screen

- "Boot" will boot the device. The LED on the ADwin should go from red to flashing green. There may be a several second delay for the ADwin-X.
- "Start Process" starts the binary and initializes the program. This selection will not be enabled until the "Boot" button is pressed, and will deactivate after being pressed once.
- "Start" shuts down the splash screen and opens the controller interface, which consists of three main sections:
  - Configuration: contains options to set calibration factors, specimen dimensions, crack solutions, and the input waveform.
  - Controller: contains the primary interface between the rig and the controller, and acts as the 'control panel' for both running and visualizing a test.
  - Data: contains tables and plots of the data generated during the test.

  The "start" button may also be used to return to the GUI is the "splash" option is selected in the top menu.
- On the left, the user has the option to select the device; at this time the controller software supports both the ADwin Gold and the ADwin-X-A20 with synchronous data collection.
- The "Color Palette" option on the right allows the user to select between the "original" (black on white) and "blue" (white on blue gradient) options. Other than aesthetics there is no functional difference between the two selections.
- "RECOVERY MODE" restarts the program without re-booting or re-starting the binary, which would re-initialize the system and delete the data stored in the controller. This option can be used if the program terminated unexpectedly while the test was still running, and will re-start all of the load and data tracking threads such as log file and data file generation so the data can be recovered. It will also extract the contents of the Data[ ] array with the ADwin device and save it to a local .csv file.

2.2. Configuration

2.2.1. Hardware Setup

The program opens up in the "Hardware Setup" tab within the "Configuration" main tab. Here, the user has the option to adjust parameters related to hardware configuration, such as the calibration factors for load, displacement, active / reference potential drop, the fixture weight for dynamic correction, the PID control parameters, and input for auxiliary channels (ADWin-X only).

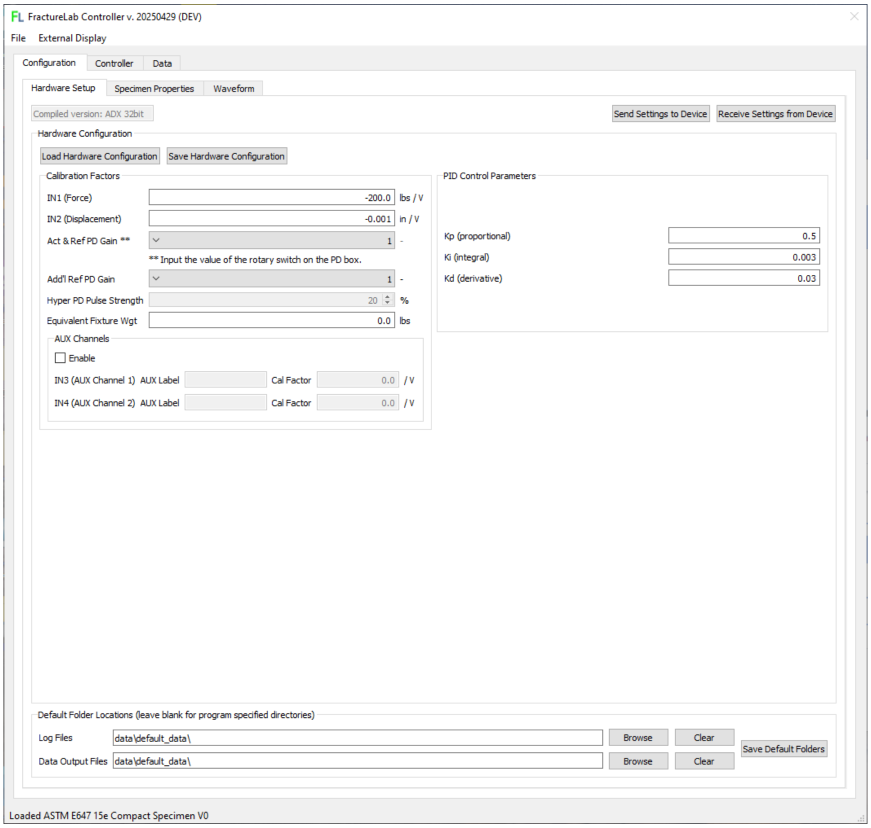


Figure 3: Configuration / Hardware Setup Tab

2.2.1.1. Hardware Configuration

- The values of the force and displacement calibration factors are based on the individual rig setup, and are used to convert voltage in input channels IN1 and IN2 to load and displacement, respectively. (NOTE: for back face strain gauge tests, the displacement calibration factor is the product of the strain calibration factor and the width W.) The range of the device output is $\pm$10V, so it is important that the calibration factors are such that the voltage required to achieve the loads necessary for testing fall within this range.
- Channels IN5 and IN6 are used for active and reference DCPD, respectively. There are two gain factors related to PD that can be changed in this section. The first is the overall PD gain factor, given by the value selected on the rotary switch on the PD box. This value is not sent to the device and is only used to correctly calculate the PD current. Below that is the reference PD gain, which communicates with the device and sets the multiplexer gain to a value of 1, 2, 4, or 8 (the latter two exclusive to the ADWin Gold) when switching to the PD channels. Below that is the Active PD gain factor
- The HyperPD pulse strength ranges from 10-100% and determines the voltage value sent to the charging capacitor.

- The equivalent fixture weight is used to correct for the effect of inertial weight on the load transferred to the test specimen, which can be significant at higher frequencies and results in inaccurate test specimen stress or stress intensity calculations. Additional information about dynamic calibration and its significance can be found in the References Section (Dahlberg), but a brief example is outlined below:
  - User commands a specimen load of 100#.
  - The load cell returns a value of 100#, however:
  - Depending on the contribution of the inertial response of the fixture weight, especially at elevated frequency, the actual specimen load may be higher (e.g. 105#).
  - Thus, the dynamic correction reduces the commanded load (e.g. 95#).
  - The load cell will then read the reduced load, and the specimen will be subject to the correct commanded load.
- The PID (proportional / integral / derivative) control parameters are used to iteratively correct the device command signal based on the output from the load cell. Further information on this topic can be found in the Appendix (Araki, 2009). For cyclic testing, only the proportional coefficient is used; however for static or dwell testing, all three parameters are necessary. For most purposes, the default PID values should be sufficient. If it becomes apparent they need adjustment during testing they can be changed later on.
- The "Aux Channels" option commands the AdWin-X to read ADC Channels 3 and 4 and average their values over a crack length or cycle count measurement interval. Optional data labels and calibration factors are user-specified.
- The options "Send Settings to Device" and "Receive Settings from Device" send the settings of the entire GUI to the device and vice versa. As values are changed from the defaults, the fields will turn yellow and the font red as a way to show that the values in the GUI are different from the device and it should be updated for these values to be sent to ADwin.
- Additionally, once the parameters and file locations are configured properly, the command "Save Hardware Configuration" saves the current configuration to an external file for future use.

2.2.1.2. Default Folder Locations

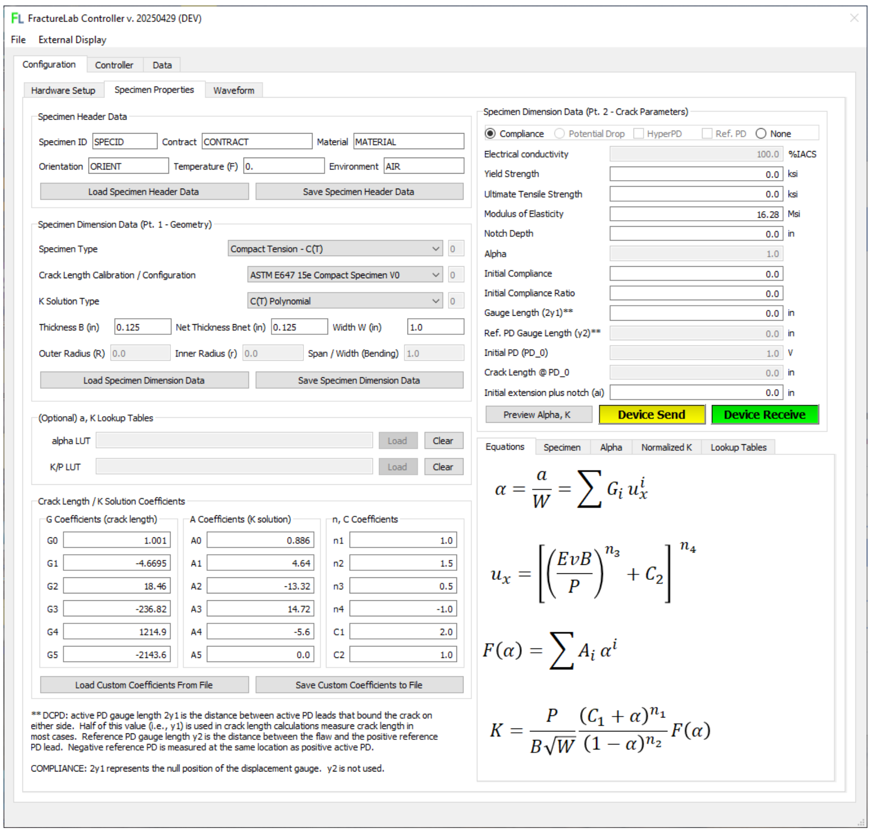
There are two fields available for the user to select the locations for the log and data files. The default for both file types are located in the program directory (data\default_data\). The file locations will be automatically saved upon program exit and are locked during test execution.

2.2.2. Specimen properties

This tab contains four main sections:

- Specimen dimensional data and general information. The dimensional data can both be saved to a file and sent to / received from the device by GUI command ("Send Settings to Device", "Receive Settings from Device"). Saving dimensional information also saves the specimen selection and its associated crack length / K solution choices, which can be recovered on loading. Additionally, the general information can only be saved to file as it contains text fields that cannot easily be saved to device memory. Thus, it is advisable to do so in order to better facilitate file and test recovery in the unlikely event of a system crash.

- Specimen type, crack length calibration, K solution menu selections and corresponding coefficients. As options within this subsection are selected, the downstream menu options are populated with the crack length and K solutions relevant to the particular specimen type. Additionally, the equations display will update as the user selects both crack length and K solution from the menus below. There is also the option to use lookup tables; if these are selected, the fields are activated for the user to specify the file containing the data.
- Crack measurement parameters (notch depth, gauge length, initial compliance, etc.).
- Graphical display of the equations selected to calculate crack length and stress intensity.



$$\alpha = \frac{a}{W} = \sum G_i\, u_x^i$$

$$u_x = \left[\left(\frac{EvB}{P}\right)^{n_3} + C_2\right]^{n_4}$$

$$F(\alpha) = \sum A_i\, \alpha^i$$

$$K = \frac{P}{B\sqrt{W}} \frac{(C_1 + \alpha)^{n_1}}{(1-\alpha)^{n_2}} F(\alpha)$$

Figure 4: Configuration / Specimen Properties Tab

The hierarchy of specimen geometries and solutions are organized as follows:

- Compact (C(T)) Specimen
  - Crack length calibration options
    - ASTM E647 15e Compact Specimen V0
    - ASTM E647 15e Compact Specimen V1
    - ASTM E647 15e Compact Specimen VX1
    - ASTM E647 15e Compact Specimen VLL
    - ASTM E647 15e Back Face Strain
    - Johnson's PD Solution

        - Crack Length Lookup Table
    - K solution options
        - C(T) Polynomial (Type 1; ASTM E647)
        - K Lookup Table
- Eccentrically-Loaded Single Edge Notch (ESE(T)) Specimen
    - Crack length calibration options
        - Front-face compliance
        - Back-face compliance
        - Johnson's PD Solution
        - Crack Length Lookup Table
    - K solution options
        - ESE(T) Polynomial (ASTM E647)
        - K Lookup Table
- Single Edge Notch (Tension) Specimen
    - Crack length calibration options
        - Johnson's PD Solution
        - Crack Length Lookup Table
    - K solution options
        - SEN Polynomial
        - Rigid SEN
        - Pin Loaded SEN
        - K Lookup Table
- Single Edge Notch (B) Specimen
    - Crack length calibration options
        - Johnson's PD Solution
        - Crack Length Lookup Table
    - K solution options
        - Bending SEN
        - K Lookup Table
- Surface Flaw Specimen
    - Crack length calibration options
        - Simplified Roe Coffin Solution
        - Simplified Roe Coffin Solution w. Back Face Correction
        - Crack Length Lookup Table
    - K solution options
        - FTA Surface Crack Solution
        - Newman Raju Solution (J. C. Newman, 1981)
        - K Lookup Table
- Middle Tension (M(T)) Specimen
    - Crack length calibration options
        - ASTM E647 15e Compliance: Uniform Stress
        - ASTM E647 15e Compliance: Uniform Stress
        - ASTM E647 15e Compliance: Uniform Stress
        - Johnson's PD Solution

        - Crack Length Lookup Table
    - K solution options
        - Middle Tension Solution
        - User Specified Polynomial
        - K Lookup Table
- Flat Bottom Hole (FBH) Specimen
    - Crack length calibration options
        - FBH Crack Length Calibration
        - Crack Length Lookup Table
    - K solution options
        - $E_P/E_S = 3$ (Nickel)
        - $E_P/E_S = 9$ (Aluminum)
        - K Lookup Table
- Surface Flaw Bending (SF(B) Specimen)
    - Crack length calibration options
        - Generalized Roe Coffin Solution
        - Crack Length Lookup Table
    - K solution options
        - Newman Raju Solution - Bending (J. C. Newman, 1981)
        - K Lookup Table
- Smooth Fatigue Cyl. Bar – LCF (SC)
    - Additional Measurement Options
        - Compliance
        - Potential Drop
        - None
- Smooth Fatigue Rect. Bar – LCF (SR)
    - Additional Measurement Options
        - Compliance
        - Potential Drop
        - None
- Notched Fatigue Cyl. Bar – LCF (NC)
    - Additional Measurement Options
        - Compliance
        - Potential Drop
        - None
- Notched Fatigue Rect. Bar – LCF (NR)
    - Additional Measurement Options
        - Compliance
        - Potential Drop
        - None

Both crack length calibrations and K solutions can be provided by text based lookup tables, the requirements of which are enumerated below:

- two columns, comma delimited (.csv)

        - EvB/P and a/W for compliance crack length calculations
        - PD/PD_0 and a/W for DCPD crack length calculations
        - a/W and K/P (normalized K) for K calculations
    - no column headers
    - limited to 2,000 rows
- Unless any changes were made to the polynomials used to calculate either crack length or K, there is no need to save a separate equations file; however the option exists if the test makes use of a special user-specified polynomials.
- Once complete, the specimen dimension data may be saved to an external file.

2.2.3. Waveform

The Waveform tab allows the user the flexibility to create, save, and load command waveforms from external .csv files. Basic waveforms can be generated from either sine or triangle templates in the “Waveform Type” subtab. This should accommodate most users’ needs. More complex, customized waveforms can be created in the “Load Points” subtab.

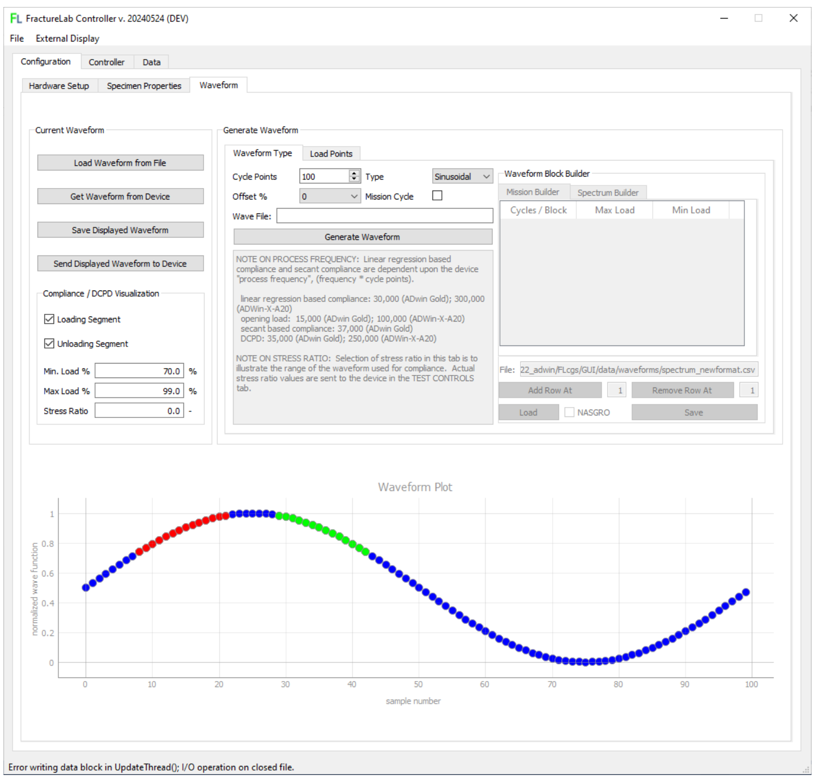


Figure 5: Configuration / Waveform Tab

2.2.3.1. A note on frequency, points per cycle, and process frequency

During a test, the device processes its internal command list at a rate equal to the test command frequency times the number of data points in a cycle; this value is called the *process frequency*. This means, for example, that a waveform of 100 points running at 100 Hz and another of 1000 points running at 10 Hz would both have the same process frequency of 10,000. This is relevant for two reasons: first, the higher the process frequency, the higher the processor workload. If the workload exceeds 99%, the controller will freeze. Additionally, higher process frequencies mean that there is less time available for interstitial calculations (such as those necessary for compliance or DCPD). As of the writing of this manual, the upper limit are the following:

ADwin Gold

- Linear compliance: 30,000
- Opening Load: 15,000
- Secant Compliance: 37,000
- DCPD: 35,000

ADwin-X-A20

- Linear compliance: 300,000
- Opening Load: 100,000
- Secant Compliance: n/a
- DCPD: 250,000

Thus it is advisable to build waveforms with the test frequency in mind to ensure proper data collection.

2.2.3.2. Generate Waveform: Waveform Type

The fastest and simplest method for selecting a waveform is by selecting an option from the “Waveform Type” tab. It contains the following options to quickly generate either a triangle or sinusoidal waveform:

- The “Type” dropdown menu allows the user to select either “Sine” or “Triangle”
- “Number of points”: total number of points within the cycle. Again the user must keep in mind the limitations of the device when running at higher process frequencies (above).
- “Offset Waveform %” moves the waveform starting load by the selected percentage. NOTE: for constant amplitude loading it is generally best to leave the waveform offset to the default value of 0%. Setting it such that either the maximum or minimum loads are split between the start and end of the waveform makes it difficult for the controller to properly converge on the location of the extrema.
- “Generate” creates the waveform and only display on the screen; *it does not send it to the device*. If the option to measure crack length with compliance has been selected, the display command will also show the range of the waveform included in the compliance calculations. This specific feature does not set the compliance load range in the device; this is done later in the Control tab. This is for visualization purposes only.

2.2.3.3. Generate Waveform: Waveform Block Builder

The ADwin X-20 has the ability to handle variable amplitude waveform loading up to 125,000 user defined load points to accommodate FALSTAFF and FULTWIST type input from

NASGRO. To the right of the waveform type selector is a table with two tab options: one for mission block type input, and another for spectrum loading (below).

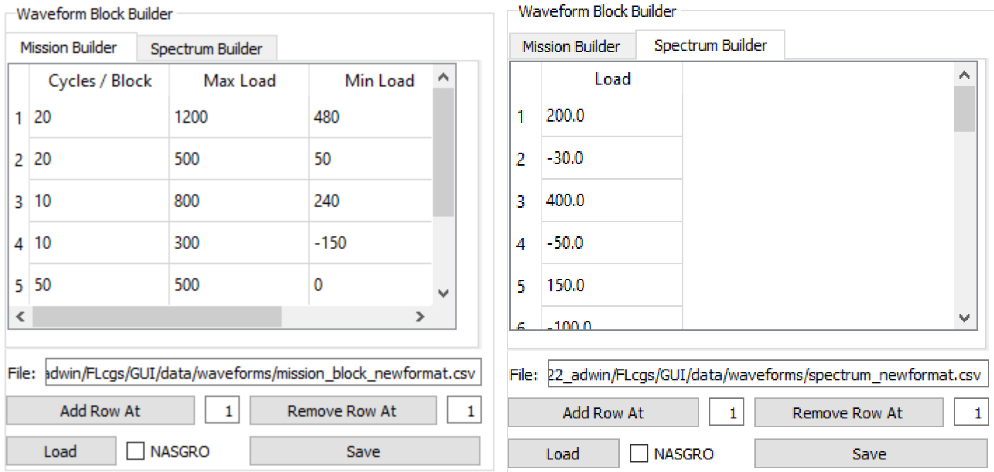


Figure 6a, b: Mission Block (a) and Spectrum (b) Builders for Variable Amplitude

The “Mission Builder” tab (left) gives the user the ability to input loading blocks of a specified max and min load and any number of cycles. This is useful for missions in which there are large blocks of cycles that run at set amplitude. The “Spectrum Builder” tab is for missions with no set pattern of loading. Every “block” is assumed to run once before the max or min loads are updated. (NOTE: the spectrum builder requires that the starting point represents a maximum load.)

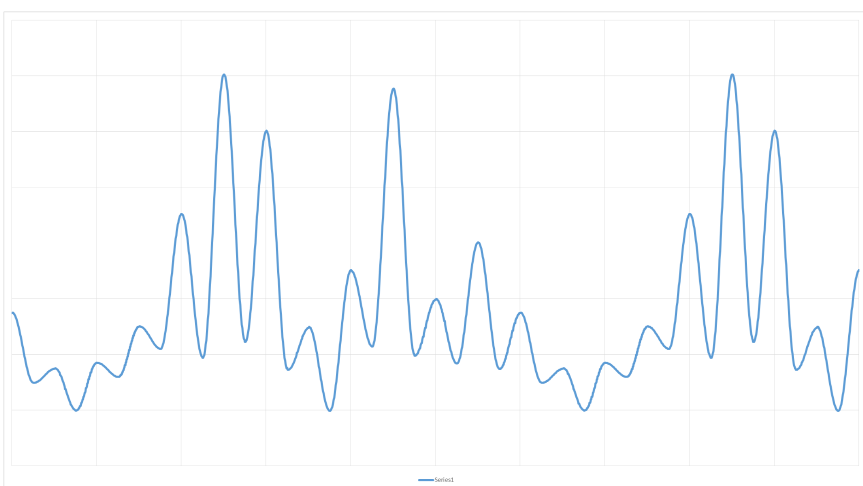


Figure 7: Arbitrary Spectrum Loading Cycle

It is also equipped with line insert / delete and a Load / Save feature to import previously generated mission blocks or space delimited files generated via NASGRO. For the latter, the user must check the “NASGRO” option to ensure proper data parsing.

Note that for variable amplitude loading, the waveform offset is set to 75%, with the minimum load located at the middle of the cycle. While inadvisable for constant amplitude testing, it is necessary for spectrum and mission loading given the variable nature of the waveform endpoints. In this case, the extrema are calculated for every reversal instead of every subcycle.

2.2.3.4. Generate Waveform: Load Points

It is possible to build more complex waveforms within the controller GUI through the "Load Points" tab. This feature allows the user to input – for each row – the desired load, the number of points to include to get to the load in the following row, and the type of interpolation (0 for linear and 1 for sine) to connect them. For example, with load values of 0 and 100, and points of 100 and 50 respectively, the user can create a simple triangular cycle that will start at a load of 50 (since cycles start at the midpoint), take 50 points to get to 100, another 50 to get to zero, and then a final 50 points to get back to mid load before cycle repeats. Note that these points will be normalized between 0.0 and 1.0. The maximum and minimum loads are represented by 1.0 and 0.0 respectively, regardless of stress ratio.

While it is possible to construct a "spectrum" type waveform using this tool, it is strongly recommended that the user instead generate all variable amplitude waveforms within the mission block generator to properly bookkeep compliance / DCPD calculations.

- "Add Row" adds a blank row of data to the waveform generator table with fields to enter the starting load, the number of points to get to the load in the following row, and the type of interpolation to connect the points (linear or sine)
- "Delete Row" removes the selected row.
- "Import Load Sequence" loads a .csv file containing three columns of data: the load points, number of data points to the next load, and the type of interpolation used to connect them. The format of this file is located in the Appendix.
- "Export Load Sequence" saves the displayed load sequence to a .csv file in the format described above.
- "Display" generates the waveform based on the input provided by the user and displays it on the screen. If compliance was selected in the previous section, the region of the curve used for compliance calculation is highlighted in red and green.

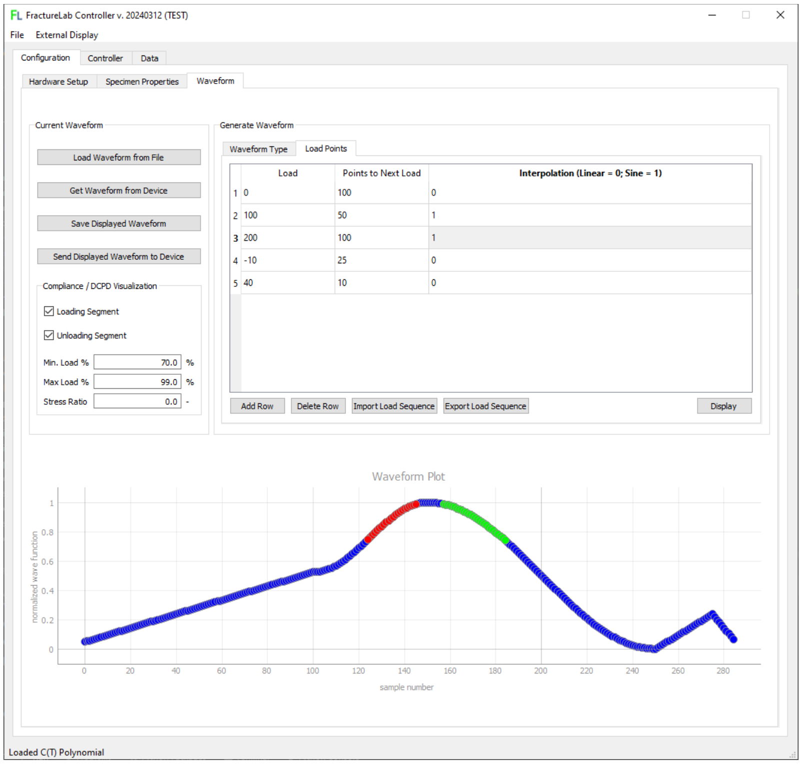


Figure 8: Example of Arbitrary Waveform Using Load Points Option

2.2.3.5. Current Waveform

The remainder of the waveform commands are in this section, which contains options to load / save to and from files, and send / receive to and from the device.

- "Load Waveform from File" loads a file into the GUI, generates the waveform, and displays it on the screen. These files consist of a single comma delimited list of numbers normalized to a range of 0 to 1. There is no associated "time" data as each point in the waveform takes place at intervals divided evenly based on the frequency of the cycle.
- "Get Waveform from Device" queries the ADwin for the current cycle stored in the device.
- "Save Displayed Waveform" saves the displayed waveform into a standalone comma delimited (.csv) file in a user-selected directory for future use.
- "Send Displayed Waveform to Device" sends the displayed waveform to the ADwin. It is essential that the user perform this as the final step after generating their waveform or the device will simply use the system default. It is also advisable to select "Get Waveform from Device" afterward to make sure the data was properly sent.

2.3. Controller

This section consists of two parts: the first is an expository summary of all of the features within the Controller tab and what they do. The second shall give examples of how to conduct the different types of tests available in this program.

2.3.1. The Dashboard

The Controller dashboard is a live feed of the current status of the device input channels. Real-time updates of load, displacement, and voltage command are provided both during the “wait” state and during the execution of a test. Additional features such as test status, cycles complete / remaining, frequency, and device workload are available only while a test is running. Further, the “Response Fields” group box provides additional information for instantaneous K values, crack growth intervals, and compliance / DCPD during crack growth tests. A pair of RUN / STOP buttons are placed in the bottom center for high visibility and access, with the intent that they can be easily seen from a distance away from the rig.

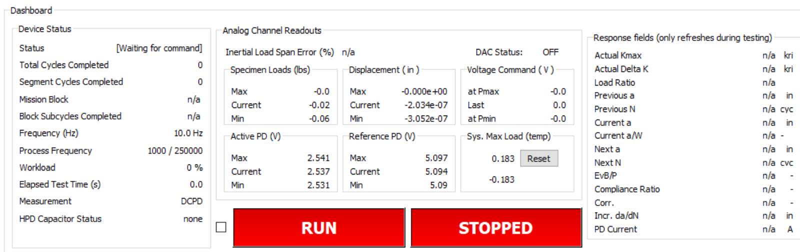


Figure 9: Controller Live "Dashboard"

- The “Device Status” section tells the user the status of the test as it is running; otherwise it is idle. During test, it updates the user on the type of test being run (“cycling”, “dwell increase”, etc.), the number of total and segment cycles completed, the test frequency, processor workload, total elapsed time, crack length measurement type, and (if needed) then HyperPD capacitor status. Depending on the type of control specified, it will tailor the units used to inform the user how much of the test remains (e.g. until target crack length, crack growth rate, etc.)
- The “Specimen Loads”, “Displacements”, “Active PD”, and “Reference PD” subsections of “Live Load Cell Readouts” are constantly updating, informing the user of the current state of load and displacement. As with “Device Status”, the “Voltage Command” is only updated while a test is running. A status message above the command group box tells the user whether the DAC command is active.
- “Inertial Load Span Error” is calculated only if dynamic correction is selected, and shows the difference in load range between the load cell and the test specimen due to the effect of the fixture weight and the applied frequency.
- “Response Fields” are specific to crack growth tests, and give the user information about the current crack length, stress intensity factor, compliance, DCPD, the correlation factor for compliance, crack growth rate, and PD electrical current.

2.3.2. Controls

This page is the heart of the controller program. It is where all of the test condition details are specified for each test segment and where the tests are run, controlled, monitored, and changed if necessary.

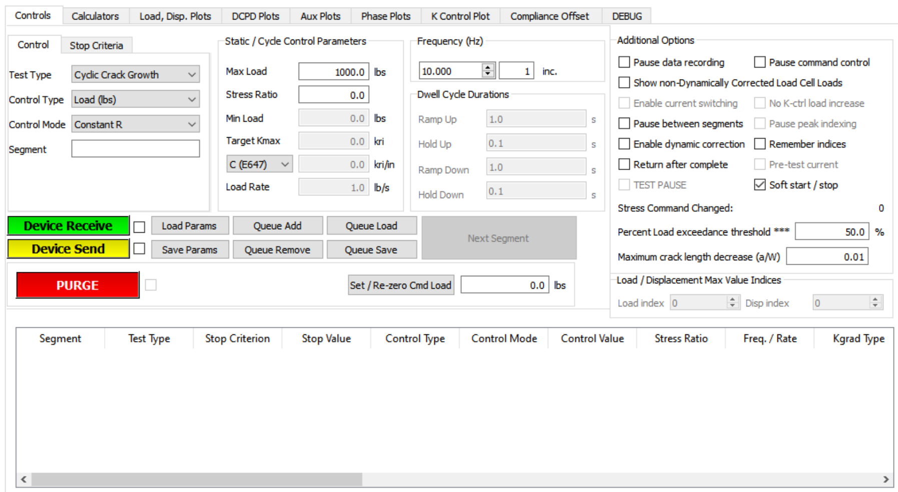


Figure 10: Controller / Controls Tab

2.3.2.1. Test Control Options

The dropdown box on the left shows the test options currently available in the software:

- static (i.e. tensile test)
- cyclic fatigue
- dwell fatigue
- cyclic crack growth
- dwell crack growth
- da/dt crack growth
- elastic-plastic fracture toughness

Choices made in the “Test Type” menu will result in activation / de-activation of other options that are specific to the execution of that particular test type.

The line items within the "Test type" menu option will populate based on the type of test selected. For example, a static test will only have the option of the "load" control type, a control mode of constant load rate, and a stop criterion of load in the “Stop Criteria” tab. Cyclic crack growth, on the other hand, will have both load and K control available with control modes of constant R or constant K_{max}.

Adjacent to the Control tab is the Stop Criteria tab that provides a selection of typical static and cyclic fatigue / crack growth stop criteria, including test time, cycle count, crack growth rate, etc.

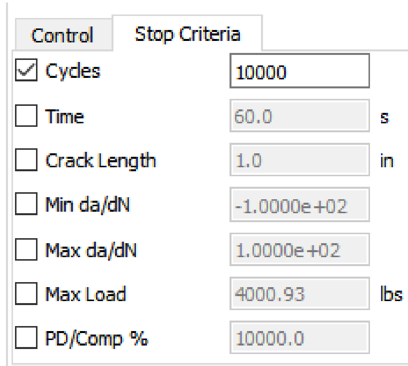


Figure 11: Stop Criteria Tab

The user can select multiple stop criteria for all test types with the exception of static loading, and the test will stop at whichever value is reached first within the options selected. Below is a breakdown of each test type and their corresponding control options.

- Static
    - Control Type
        - Load (lbs)
    - Control Mode
        - Const. Load Rate
    - Stop Criterion
        - Load (lbs)
- Cyclic or dwell fatigue, elastic-plastic fracture toughness
    - Control Type
        - Load (lbs)
    - Control Mode
        - Const. R
    - Stop Criterion
        - Cycle (count)
        - Time (sec)
        - Max load (lbs)
        - PD/Compliance %
- Cyclic, dwell, or da/dt crack growth
    - Control Type
        - Load (lbs)
        - K
    - Control Mode
        - Const. R
        - Const. K_{max} (for K control only)
    - Stop Criterion
        - Cycle (count)
        - Time (sec)
        - Crack length (in)

- Min da/dN rate
- Max da/dN rate
- Max load (lbs)
- PD/Compliance %

As the test type is selected, there are additional options that will either activate or deactivate based on the selection for clarity. For example, dwell ramp and hold durations are not applicable for a static test, so they are deactivated and do not accept any user input.

Cyclic cyclic crack growth: time, cycle count, crack size, crack growth rate (min or max), allowing the flexibility to perform K-decreasing or K-increasing tests to a preset growth rate limit.

2.3.2.2. Static / Cycle Control Parameters

This section is largely self-explanatory. Test control parameter fields are activated for user input based on the type of test being run. The available parameters are:

- Max load: the maximum applied load to the specimen. Note that this can differ from the load cell readout value if dynamic correction is active and the frequency is sufficiently high.
- Stress ratio (R): the ratio of min to max applied specimen load.
- K_{max} (ksi-in$^{1/2}$ or kri): maximum stress intensity factor; specific to crack growth tests.
- K gradient / C (kri / in): again, this is specific to crack growth testing and is rate of change of K_{max} as a function of crack length. There are two gradient options. The first is based on E647 and has the functional form:

  $$K = K_0 e^{C(a-a_0)}.$$

  The second option uses a variable shed rate that is proportional to the instantaneous Irwin plastic zone size, which allows for accelerated load shedding while maintaining a constant wedge thickness angle, thereby eliminating remote closure. It has the functional form:

  $$K = K_0 \sqrt{1 + 2C\left(\frac{\sigma^y}{K_0}\right)^2 (a - a_0)}.$$

- Load rate (lb / sec): the rate of load increase for static tests.
- Frequency (Hz): number of cycles per second. A spinbox with separate increment field allows for on-the-fly adjustment during a test without the need to send to the device.
- In the case of K control, the Max Load and K fields will update regularly to reflect the instantaneous load being applied to generate the correct K value. This is done to allow the “Send to Device” command (explained in more detail below) to send the correct load value back to the device during the middle of a test. If there is interest in changing conditions mid-test, it is necessary to check the “Pause command control” before any edits are made.

2.3.2.3. *Dwell Cycle Durations*

These options are only relevant for dwell or (in part) elastic-plastic fracture toughness; they will only activate if either test type is selected. It allows the user to specify the ramp and hold rates for a dwell test, or the former for a toughness test. The values should be entered in units of seconds.

2.3.2.4. *Test Execution Commands*

- "Send to device" sends values from the GUI to the device. This happens automatically when the test or test queue begins, but it is advisable to do this as often as possible when updating the conditions to make sure there is agreement between the GUI and the ADwin. This feature is also capable of changing test conditions while a test is running, making it necessary to protect it with a check box in the event an errant value is entered in one of the control condition fields.
- "Receive from device" queries the device to bring the currently stored values into the GUI. It also has the same safety feature, only to prevent the user from accidentally overwriting the current conditions in the control tab.
- "Load / save parameters" are similar to send / receive, but the GUI values are read from / written to a standalone file instead of the device similar to what is done for the hardware configuration or specimen dimension parameters. This is a useful time saving tool if there is a certain type of test that is run often.
- If the test queue (explained below) is empty, "Run" will send the conditions displayed on the screen to the device and tell the ADwin to execute the test.

2.3.2.5. *Test Segment Queueing System*

The controller program is also capable of executing a single test consisting of multiple segments with different maximum loads, stress ratios, frequencies, and K values, broken up into a queue of separate line items for each unique condition.

	Segment	Test Type	Stop Criterion	Stop Value	Control Type	Control Mode	Control Value	Stress Ratio	Freq. / Rate	Kgrad Type	Kgrad Value	Cyc Interval
1	A	Cyclic Crack Growth	Cycles, , , , ,	10000, , , , ,	Load (lbs)	Constant R	1000.0	.1	10.000	none	0	1000
2	B	Cyclic Crack Growth	Cycles, time, , , ,	10000, 60, , , ,	Load (lbs)	Constant R	1000.0	.3	10.000	none	0	1000
3	C	Cyclic Crack Growth	, , , , maxdadN, ,	, , , , 100.0, ,	Load (lbs)	Constant R	1500	.5	10.000	none	0	1000
4	D	Cyclic Crack Growth	, , a, , maxdadN, ,	, , 0.05, , 100.0, ,	K	Constant R	20	.5	10.000	C (E647)	-6	1000

Figure 12: Sample Test Command Queue

- Each line item is created by specifying the desired condition, assigning a unique segment number or letter, and then pressing "Queue Add". This can be done any number of times, provided there is sufficient ligament or fatigue life available for all of the segments to be completed.
- The stop criteria and stop values are presented as a list within the queue. Only the active stop criteria and their associated values are shown, with the remainder values shown as blank.
- Provided the test is not currently running, the contents of the line items can be edited if an error is discovered; however, if the user wishes to add another stop criterion and value to the existing list, both entries must be added with the correct names and values

in the proper location within the list. The criteria list is: “Cycles, time, a, mindadN, maxdadN, Pmax, pdcomp%”. So, for example, if the min da/dN rate were to be added to the next segment along with the prior stop criterion of time, it would look like this:

	Segment	Test Type	Stop Criterion	Stop Value	Control Type	Control Mode	Control Value	Stress Ratio	Freq. / Rate	Kgrad Type	Kgrad Value	Cyc Inter
1	A	Cyclic Crack Growth	, time, , , ,	, 1000, , , ,	K	Constant R	20	.5	10.000	C (E647)	-6	1000
2	B	Cyclic Crack Growth	, time, , , maxdadN, ,	, 1000, , , 0.001, ,	K	Constant R	20	.5	10.000	C (E647)	-6	1000

Figure 13: Edited Command Queue

Note how all of the commas remain in the queue, even if there is no value associated with them.

- “Queue Remove” removes the *last* item in the queue.
- “Queue Load” and “Queue Save” load and save the contents of the test queue to a .csv file in a separate folder. This is useful for saving time for tests with identical conditions or loading sequences.
- Though it is possible to add new items to the queue when a test is running, it is necessary to check “Pause command control” to prevent updates from the current test while changing conditions. Given this risk it is highly recommended that the user not add any more line items after the test has started.

2.3.2.6. Additional options

- “Pause Data Recording” prevents the device from recording data for the duration this box is checked. When this option is selected, the dashboard will display a warning in red informing the user that recording has been suspended.
- “Pause Command Control” prevents device from responding to changes in crack length or received load that would otherwise require an adjustment of commanded load. When this option is selected, the dashboard will display a warning in red informing the user that test control has been suspended.
- “Show non-Dynamically Corrected Load Cell Loads”: while running with dynamic correction on, displays the load cell loads in the Live Load Cell Readouts instead of the specimen loads.
- “No Load Increase During K-dec. test” forces the commanded load to remain constant in the event of a lower calculated crack length during a K – decreasing test.
- “Pause Between Segments” allows testing to stop between each segment and wait for user input (“Next Segment”) to proceed. This is only used if the test consists of multiple segments.
- “Enable Current Switching”: for potential drop, allows the device to rapidly change current polarity from positive to negative.
- “Enable Dynamic Correction” adjusts the compliance based on the weight of the fixture and the frequency of the test.

- "Enable Reference PD" flags the device to record reference PD data from a second set of leads.
- "Return After Complete": normally, the device stops at the mid-load point after completion of a test. This commands ADwin to return to a specific load instead.
- "Pause peak indexing" allows user to temporarily pause the calculation of the index at which the peak load can be found. This can be useful if there is a lot of variation in the signal that would cause the average to otherwise fluctuate.

  The group box labeled "Load / Displacement Max Value Indices" works in parallel with this option to allow the user to manually set the peak indices of load and displacement by hand to stabilize the variation in compliance measurement.

- "Remember Indices" keeps an internal record of the location of the max load and displacement from one test segment to another, reducing the likelihood of a drop in crack length during test transition as the controller re-calculates the peak indices.
- "Pre-test current" applies the DCPD current through the specimen to allow the user to read both active and reference values before the beginning of the test.
- "Test Pause" suspends the test along with the cycle and time counters while telling the controller to maintain PID control at mid-load. This option should be used with caution at elevated temperatures where time dependent deformation is possible.
- "Stress Command Changed" is not an option per se, but a useful indicator that at some point the stress was told to change value by some external criterion, like a change in the K value because of a non-zero gradient, a change to the dynamic correction factor, or user input. After reaching its new value to within a small tolerance, this value returns to zero.
- "Percent load exceedance Threshold" can be used to trigger the controller to stop if either the load cell load or the commanded load exceed a certain percentage. This works in concert with a number of internal exceedance traps to prevent potential damage to the load frame.
- "Maximum crack length decrease (a/W)" sets a trigger to stop the test if the measured normalized crack length increment falls below a user specified value.

2.3.2.7. Stop Controls

- "Stop Current Action" stops the current test segment. If there are more than one segment then the next will be run, so it is advisable to select "Pause Between Segments" in the event the user wishes to remove the other items from the queue.
- "Set / Re-Zero load" returns the load to a neutral position, or a preset value based on user specification.
- "Purge Data" erases the data array within the device and re-initializes (but does not re-boot) the program.

2.3.3. Calculators

- The "Average PD / Compliance Tracker" outputs the latest ten PD or compliance average calculations in both graphical and list format. A rolling average of these values – minus the largest and smallest – is displayed on the bottom of the list and on the plot in green. These values are used during the initial stages of a crack growth test, when either the initial PD value (PD0) has not yet been determined in the case of potential drop, or the elastic modulus has not yet been adjusted to reflect the initial crack length in the case of compliance. In either situation, the user may wish to input a rolling average of either value to represent the basis for calculating initial crack size instead of the instantaneous value, which is inherently subject to more scatter.

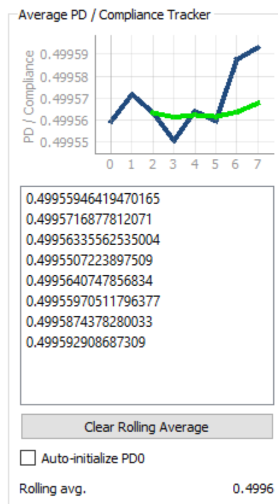


Figure 14: Average PD / Compliance Tracker Plot and List

- "Auto E Adjust (Compliance Only)" is a calculator that applies to tests that use compliance based crack length measurement only. At the start of the test, it is possible that the resulting calculated crack length measurement is not equal to the initial crack length by some small error. This feature allows the user to calculate a new elastic modulus based on a value of compliance and initial crack length based on user selected input. Updating this value will change the modulus field in the Specimen Properties tab and the resulting crack length value.

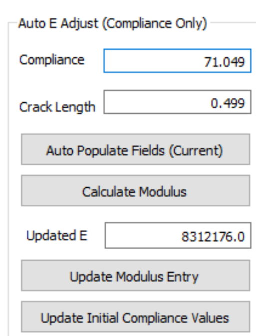


Figure 15: Auto Modulus Adjustment Calculator

- "Initialize Starting PD / PD_{ref}" sets the initial PD value (PD_0) or PD/PD_{ref} ratio to a non-unity value, and is necessary to start crack length calculations for testing using active PD only. Here, the user has several options: select "auto-initialize PD_0" under the tracker plot to automatically select an initial PD_0 when the standard deviation of the rolling average is sufficiently small, use the automatically calculated rolling PD average at the user's discretion, or enter a separate value entirely. This will provide the basis for all subsequent crack length calculations during the test. Additionally, the value can be adjusted later in the test if additional corrections are needed.

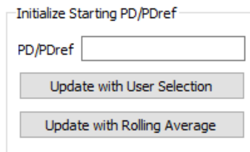


Figure 16: Initialize Starting PD / PDref

- "Load from K_{max} Calculator" allows the user to calculate the load required to achieve a desired value of K_{max} at a given crack length. There is also the option to update the load field with this updated value, but it is not sent to the device unless commanded by the user.

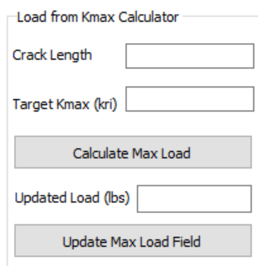


Figure 17: Auto Modulus Adjust and Load Calculator with Sample Inputs

- "K Gradient Info": shows the base values for calculating the K gradient in a K-increasing or K-decreasing test. When conditions are re-sent to the device in the middle of one of these tests, the gradient is reset and restarts based on the current conditions.

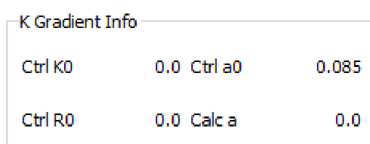


Figure 18: K Gradient Information

- "Measurement Output Controls": If compliance is selected for crack length measurement, the user has the option to select using either the loading, unloading or both to calculate the average compliance. It is recommended that both be selected for improved stability. The option for opening load measurements can be selected here, and it requires that the loading segment of compliance is checked. Additionally, one direction must be selected at all times to enable crack length measurement.

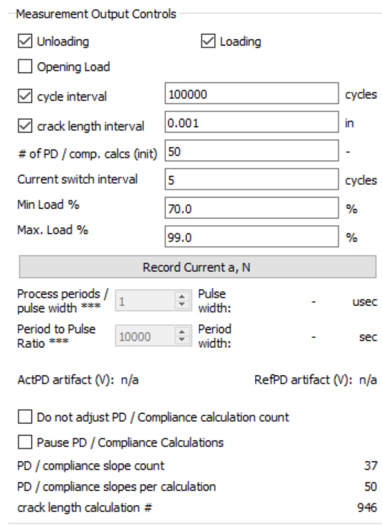


Figure 19: Measurement Output Controls Group Box

There are two options available for selecting criteria for when to output data: cycle intervals and crack length intervals.

- During a cyclic fatigue test with compliance or DCPD measurement selected, the cycle interval option will average compliance / DCPD and load output values over the specified interval and return the values at the end.
- During a crack growth test with compliance or DCPD measurement selected, the cycle interval option will output data for the first crack length measurement that exceeds or equals each cycle interval. This may result in data that does not completely correspond, for example, to increments of 1000 cycles, but rather 1046, 2035, 3021, etc. because that is when the crack length calculation was made based on the calculation interval (below).
- Selecting crack length interval will provide both a real-time crack length calculation during the course of the test but only output a line of data after the specified crack length interval has been reached. Both options can be selected; they average over different independent intervals.
- "# of PC / comp. calcs (init.)" is the initial number of DCPD / compliance calculations the program will perform before taking the average and (if a crack growth test is running) calculate crack length.
- "Current switch interval" represents the number of DCPD measurements to be made before switching the current polarity. If active, crack length calculations will be performed only when there is an equal number of positive and negative measurements.
- "Load percentages" represent the percent of maximum load at which to measure compliance or DCPD for crack length calculations. Depending on either the initial or instantaneous stress ratio (e.g. for a constant K_{max}, K-decreasing test), these percentages may change to account for the load limits of the waveform.
- "Record Current a, N" forces the completion of a crack length calculation to prompt the controller to output a line of data representing the current crack length and cycle count.

The crack length and cycle intervals ("next a", "next N") are updated based on these values.

NOTE: when running a test with opening load, this button will only be available when there is a complete opening load measurement; otherwise it will be inactive. It is recommended for convenience that the user drop the test frequency to under 10 Hz before attempting to use this feature.

- "Process periods per pulse width" and "Period to pulse ratio" are for Hyper PD only, and represent the length of the HPD pulse in terms of the number of process frequency cycles and the time in between pulses, respectively. Because time is measured in the ADwin device by the process frequency, it is necessary to set the pulse and wait time in this way. The corresponding time in seconds is provided to the right of the spin boxes.
- Active and reference PD artifact measures the voltage inherent to the HPD system in between pulses.
- The number of PD / compliance slopes used per crack length calculation are, by default, internally adjusted over the course of the test in order to ensure that the number of calculations per crack interval remains between 10 and 20. However this adjustment can be shut off by checking "Do not adjust PD / Compliance calculation count". Additionally, they may be paused temporarily by checking "Pause PD / Compliance Calculations". No crack measurements or gradient-based adjustments on K will be done if this option is selected.

Below the input fields in this section are additional output values that update during the course of the test.

- "PD / compliance slope count": tells the user how many compliance calculations have been performed within one averaging interval.
- "PD / compliance slopes per calculation": this value starts at the default value as specified by the user in the "# of PC / comp. calcs (init.)" field.
- "Crack length calculation number": the number of crack length calculations performed within a user specified crack interval.

2.3.4. Live Plots

As the test is running, the live plots will regularly update the user with plots of selected outputs depending on the type of test. These plots can be displayed separate from the main window by selecting the appropriate plot from the "External Display" option in the top menu above the main tabs.

- Load, Displacement: these plots will always update, regardless of test status. The load plot will show commanded vs. load cell load in lbs; the displacement plot will show measured displacement in inches.

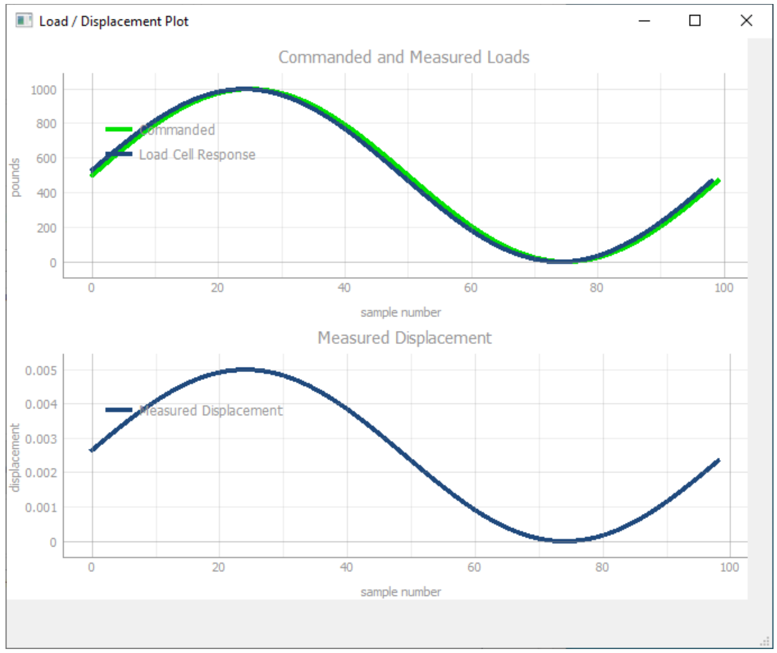


Figure 20: Live Plot of Sample Cycle (1000#, R = 0)

- DCPD Plots: as with load and displacement, these plots will also update even in the “wait” state, provided the PD crack measurement option is selected. Both plots are in units of voltage. Because of the need to switch channels within the ADwin device, there is a brief time delay between each update to the PD plots.

Figure 21: DCPD Plots

- Phase: plots that show the relationship between measured load and load command, and measured loads versus displacement during the test.

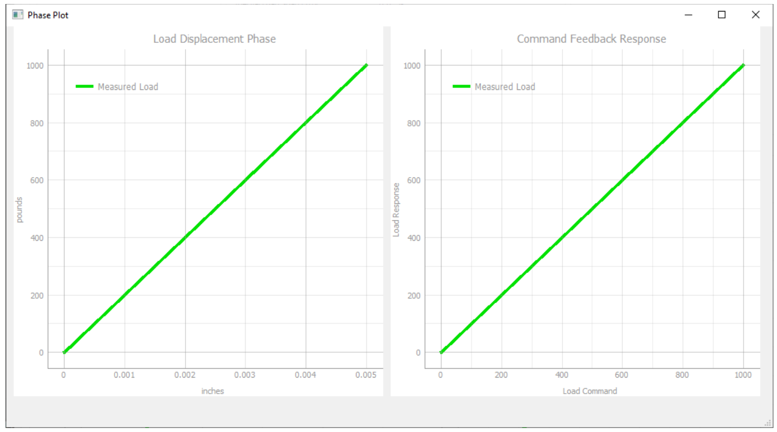


Figure 22: Load Displacement and Load Command Phase Plots (in Simulation Mode)

- K Control: This plot is only active during a K control test, showing the target vs. actual K value over time.

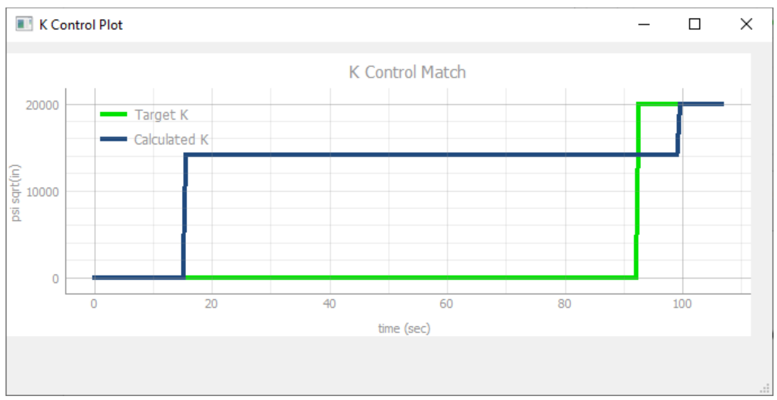


Figure 23: K Control Plot (Target, Calculated vs. Time)

- Compliance Offset: Active only when opening load is selected, this plot displays the instantaneous percentage offset between the incremental slopes of the loading and unloading segments relative to the full-scale compliance value of the unloading portion of the load waveform. These values are averaged over the span of the user specified PD / compliance calculation count and output as the opening load ratios in the postprocessor file.

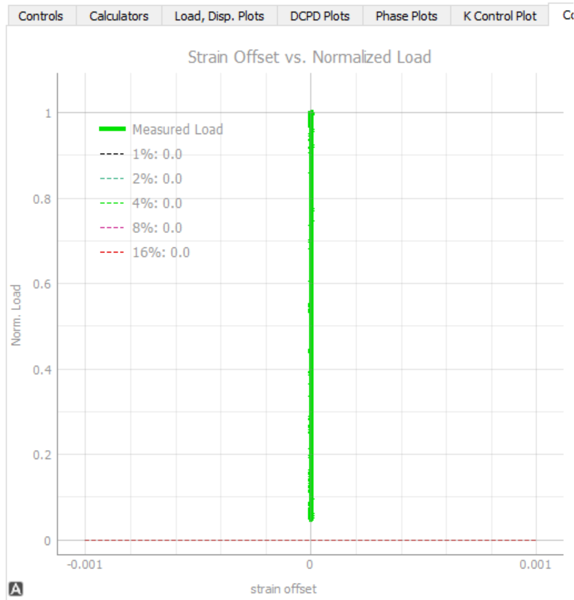


Figure 24: Compliance Offset Plot (Percent Offset vs. Normalized Load)

2.3.5. The Heads-Up Display (HUD)

The heads-up display is a new addition to the controller that provides the user with test execution and command options along with a summary of all relevant test information in a single window while providing room on the screen for addition external plots like load / strain vs time, and command response.

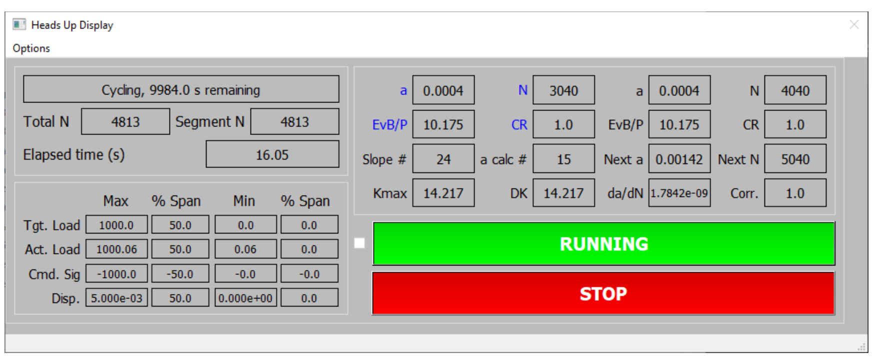


Figure 25: Controller Heads-Up Display (HUD)

Display summary information includes test execution data including total and segment cycle counts and time. Command and feedback data are available along with the fraction of the total ADC span, and the resulting PD or compliance output for the current and previous measurement intervals.

2.4. Data (tab)

As data from different segments is generated, the segment label is added to the drop down menu, allowing the user to select data from a specific segment rather than the entire data set (though that remains an option). To bring the data into the table, press the "Get Data" button; this will bring the data into all four tabs as needed.

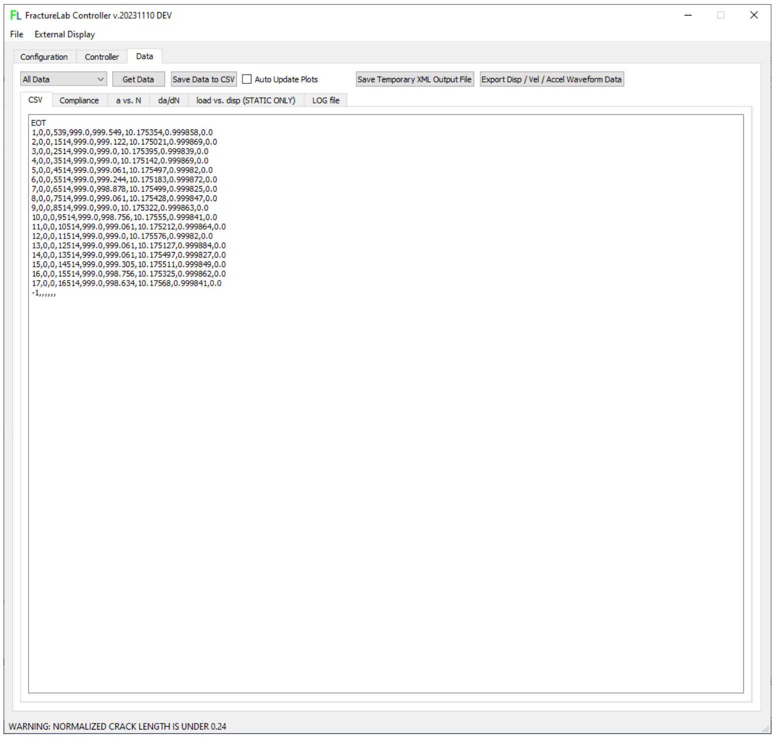


Figure 26: Data / CSV Tab with Sample Data

2.4.1. Commands

- Data Segment Dropdown Menu: during a multiple segment test, this feature can be used to select, display, and save data from a specific segment. Thus, it is important to not only label each segment with a value (versus leaving it blank) but also with unique values to be easily differentiated by the program.
- “Get Data”: queries the device for the data and displays it in each of the tabs. Depending on the type of test, not all of the display tabs will be populated; da/dN will be empty for fatigue and static tests, and load vs. displacement will not populate for crack growth or fatigue tests.
- “Save Data to CSV”: this option is useful is the user wishes to output the data in a readable user friendly format. It is used almost exclusively to record the results of a static test that does not need the type of analysis regularly done during a crack growth test. The latter is automatically recorded in another format type that interfaces directly with the FractureLab postprocessor program.
- “Auto Update Plots”: checking this option automatically updates all of the crack growth related data fields: CSV, compliance, a vs. N, da/dN, and the log file contents.
- “Export Temporary XML Output File”: takes a snapshot of the current test and outputs it .xml format for on the fly postprocessing.

- "Export Disp., Vel., Accel. Waveform Data" outputs the displacement, velocity, and acceleration data for the current cycle to check against the dynamic calibration factor calculation.

2.4.2. Data Tabs

- CSV: displays the recorded device data and formats it based on the test type. The second and third columns of data are reserved for the postprocessor and indicate whether the line of data should be skipped for da/dN calculations or excluded completely.
  - Static: index, 0., 0., time, average load, max load, average displacement, max displacement, 0.
  - Cyclic: index, 0., 0., cycles, max load, load range, [average compliance / active DCPD], [compliance ratio / reference DCPD], dynamic correction factor
- Compliance: displays either normalized compliance (EvB/P) or active DCPD as a function of cycle count.
- a vs. N: displays crack length vs. cycle count.
- da/dN vs. applied ΔK: displays the cyclic crack growth rate calculated from the recorded device data as a function of. This tab is also available as a standalone plot in the top menu.
- da/dN vs. a: displays the cyclic crack growth rate as a function of crack length
- load vs. disp (STATIC ONLY): displays the load-displacement curve results from a static test in units of lbs vs. inches.
- LOG file: displays the current contents of the log file, and provides a simple interface to append user notes.

3. DATA

Data is handled in the FractureLab crack growth software in three ways: through log files, XML data files, and comma delimited (.csv) files.

3.1. Log Files

The log file is created for each test segment run by the controller. It is initiated at the start of the test and given a name consisting of the specimen ID and segment number with the .log extension. The file is given a header consisting of the general specimen information (ID, contract number, etc.), specimen geometry, operating conditions, and test sequence information if it is part of a multiple segment test queue. The GUI regularly queries the device for information at a rate that ensures near real-time updating of the log file.

If the user updates any of the condition fields (e.g. maximum load, frequency, etc.) the log file will re-send the entire header field indicating the change. Additionally, in the event of a system crash, the log file will record the event upon restart and dump all of the data recorded to data into the file.

3.2. CSV Data Files

Comma delimited data files are useful primarily for recording the results of static tests, but their relative simplicity in format makes them useful for recording data for analyzing cyclic fatigue and crack growth. They are also far easier to interpret at a glance than the postprocessor files. Each csv file is recorded in the same format as displayed in the "CSV" tab above, and saved under a filename consisting of the specimen number and test segment with the .csv extension.

3.3. XML Data Files

The XML data type is specifically designed for interface with the FractureLab postprocessor software package. As its name would suggest, it is in XML format, which allows the code to organize information about the specimen and test in a way that is easily parsed by the postprocessor. It is, however, less user-readable than simpler formats like .csv or .txt files.

The data for each XML file is generated at the start of each test segment, at the same time as the log file; however the file itself is not created until the completion of the test, at which point it is done automatically. In the event of a system crash, the data for this file is automatically recovered and saved either upon system restart (if the test was completed in the interim) or upon subsequent completion.

3.4. Load-Displacement Loop (*_ss) Files

Load-displacement loop data is provided automatically for all non-dwell cyclic tests in both fatigue and fatigue crack growth. Cycles 1-20 are recorded automatically; data is then taken essentially at log base 10 intervals (e.g. every 10 cycles from N = 20-100, every 1,000 cycles from N = 1,000-10,000, etc.) to ensure behavior such as cyclic hardening is captured while keeping the size of the data file manageable. This data can be used to create a library of cyclic stress strain curves for constitutive modeling and calculating actual stress-strain response for fatigue life calculation.

APPENDIX: Crack Length and K Solutions for Common Specimen and Crack Geometries

Compact Tension C(T) Specimen, Eccentrically Loaded Single Edge Crack ESE(T) Specimen

Crack Length Calibration

The crack length for compact tension and eccentrically loaded single edge crack specimen is calculated from compliance using a 5th degree polynomial, which is referenced in (ASTM E647 15e1: Standard Test Method for Measurement of Fatigue Crack Growth Rates, 2015):

$$\alpha = \frac{a}{W} = \sum G_i u_x^i$$

Where, in the case of front-face compliance, u_x is expressed as

$$u_x = \left[\left(\frac{E v B}{P} \right)^{n_3} + C_2 \right]^{n_4}$$

If compliance is measured through back face strain, the displacement v is replaced with the product of strain and the width W; the resulting expression becomes:

$$u_x = \left[\left(\frac{\varepsilon E W B}{P} \right)^{n_3} + C_2 \right]^{n_4}$$

The values of n_3, n_4, and C_2 are 0.5, -1, and 1 respectively. The coefficients are numbered in this way due to the way they are built into the generic coefficient array and are not indicative of additional unseen parameters that affect the equation. (Again, note that in the case of back face strain, the displacement calibration factor is the product of the strain calibration factor and the width W.) This solution is applicable to an a/W range from 0.2 to 0.975. The values of G will vary depending on the choice of measurement at the crack mouth. Several common choices for the C(T) geometry are shown in Figure 22 with their corresponding G values in Table 1.

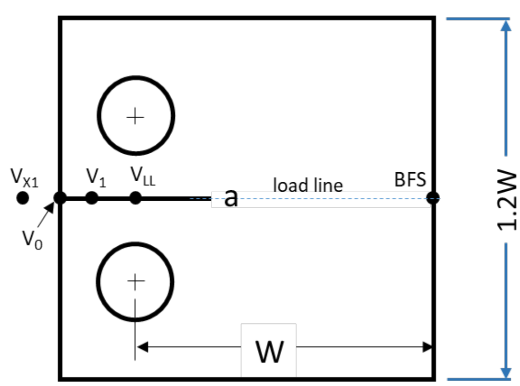


Figure 27: Compact Tension Specimen with Compliance Measurement Locations (Also Applicable to ESE(T))

Table 1: Normalized C(T) Crack Length Calibration Coefficients Based on Measurement Location

Location	G0	G1	G2	G3	G4	G5
VX1	1.0012	-4.9615	23.057	-323.91	1798.3	-3513.2
V0	1.0010	-4.6695	18.460	-236.82	1214.9	-2143.6
V1	1.0008	-4.4473	15.400	-180.55	870.92	-1411.3
VLL	1.0002	-4.0632	11.242	-106.04	464.33	-650.68
Back Face	1.0033	-2.35	1.369	-15.294	63.182	-74.42

Compliance calculations based on back face strain are made using the same equations as above but are limited to a single set of crack calibration coefficients.

Table 2: Normalized ESE(T) Crack Length Calibration Coefficients Based on Measurement Location

Location	G0	G1	G2	G3	G4	G5
Front Face	1.00132	-3.58451	6.59941	-19.22577	41.54678	-31.75871
Back Face	1.007	-2.171	1.537	-7.615	22.181	-20.745

The generic crack length solution for all single edge – type crack geometries types (e.g. C(T), ESE(T), and SEN(T,B)) where the crack length is measured using potential drop is given by Johnson's Solution, which is referenced in ASTM E647-15e1 Section A 2.5.3.1 "M(T) Geometry Voltage Versus Crack Size Relationship". The equation below shows the value of voltage (normalized by initial PD) in terms of crack length:

$$\frac{V_1(a)}{V_1(a_o)}=\frac{\cos h^{-1}\left(\dfrac{\cos h\left(\dfrac{\pi\,y_1}{2W}\right)}{\cos\left(\dfrac{\pi a}{2W}\right)}\right)}{\cos h^{-1}\left(\dfrac{\cos h\left(\dfrac{\pi\,y_1}{2W}\right)}{\cos\left(\dfrac{\pi\,a_o}{2W}\right)}\right)}$$

The value of y_1 refers to ***half*** of the distance between active PD leads; y_2 is equal to half the distance between the reference leads. In the case of DCPD measurement normalization using reference voltages, crack length is calculated using a polynomial function similar in format to that used for compliance:

$$\frac{V^{\square}}{V_0^{\square}}=fn(a);V^{\square}=\frac{V_1(a,y_1)}{V_2(a,y_2)}=\sum G_i\left(\frac{a}{W}\right)^i$$

This equation is based on a 3-wire active / reference PD configuration, and requires that the current be applied to the top of the specimen at a point located halfway between the pin and the far edge opposite the crack mouth.

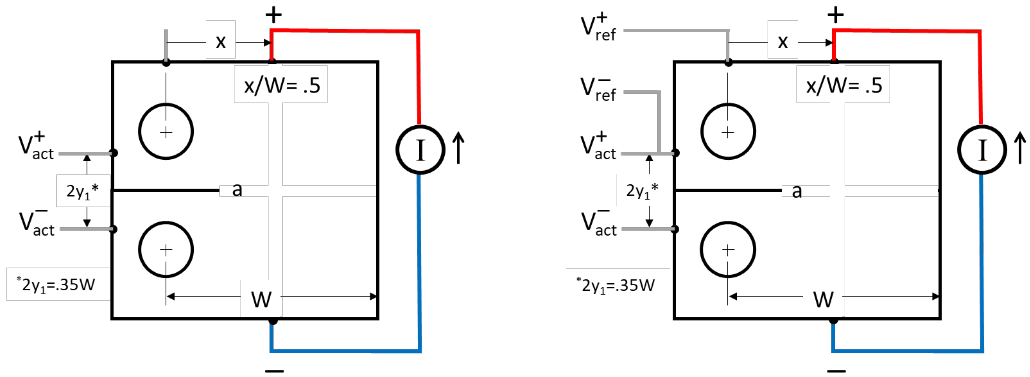


Figure 28: Compact Tension Specimen with Active Only and Active / Reference PD Configurations

K Solution: C(T)

The K solution for the Compact Tension specimen is taken from ASTM E647 Section A 1.5.1.1 and has the generalized form:

$$K = \frac{P}{B\sqrt{W}} \frac{(C_1+\alpha)^{n_1}}{(1-\alpha)^{n_2}} F(\alpha)$$

where:

$$F(\alpha) = \sum A_i \alpha^i$$

The coefficients C_1, n_1, and n_2 are equal to 2, 1, and 1.5 respectively. F(α) coefficients are as follows:

	A0	A1	A2	A3	A4
ASTM C(T)	0.886	4.64	-13.32	14.72	-5.6

K Solution: ESE(T)

The K solution for the Eccentrically Loaded Single Edge Crack specimen has the form:

$$K = \frac{P}{B\sqrt{W}} \sqrt{\alpha} \frac{(C_1+\alpha)^{n_1}}{(1-\alpha)^{n_2}} F(\alpha)$$

where, as with the compact tension specimen:

$$F(\alpha) = \sum A_i \alpha^i$$

The coefficients C_1, n_1, and n_2 are equal to 1.4, 1, and 1.5 respectively. F(α) coefficients are as follows:

	A0	A1	A2	A3	A4	A5
ASTM ESEN(T)	3.97	-10.88	26.25	-38.9	30.15	-9.27

Single Edge Notch Specimens (SEN(T), SEN(B))

Crack Length Calibration

As stated in the previous section, the crack length solution for the axial and bending single edge notch specimens (e.g. SEN(T) and SEN(B)) normalized by initial PD is given by Johnson's Solution:

$$\frac{V_1(a)}{V_1(a_o)}=\frac{\cos h^{-1}\left(\frac{\cos h\left(\frac{\pi y_1}{2W}\right)}{\cos\left(\frac{\pi a}{2W}\right)}\right)}{\cos h^{-1}\left(\frac{\cos h\left(\frac{\pi y_1}{2W}\right)}{\cos\left(\frac{\pi a_o}{2W}\right)}\right)}$$

In the case of normalization by reference PD, the PD to crack length relationship is given by:

$$\frac{V^{\square}}{V_0^{\square}}=fn(a);V^{\square}=\frac{V_1(a,y_1)}{V_2(a,y_2)}=2\left\{\frac{\cos h^{-1}\left(\frac{\cos h\left(\frac{\pi y_2}{2W}\right)}{\cos\left(\frac{\pi a}{2W}\right)}\right)}{\cos h^{-1}\left(\frac{\cos h\left(\frac{\pi y_1}{2W}\right)}{\cos\left(\frac{\pi a}{2W}\right)}\right)}-1\right\}^{-1}$$

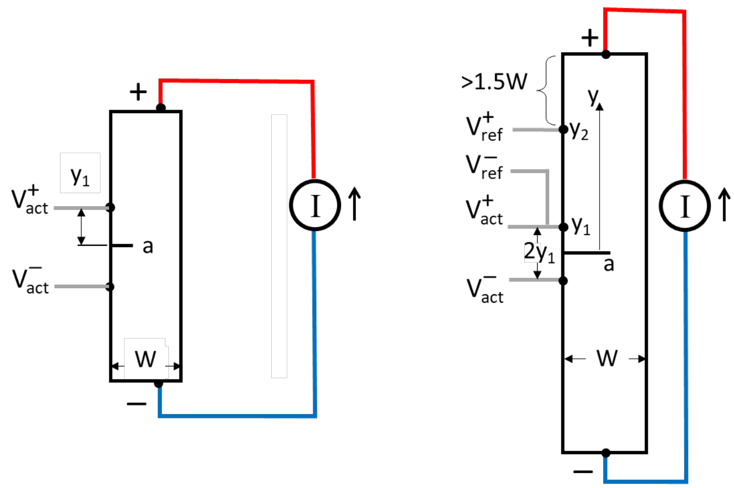


Figure 29: Single Edge Notch Specimen with Active Only and Active / Reference PD Configurations

As with the C(T) specimen formulation, this equation presumes a three wire active / reference PD configuration.

K Solution – SEN(T)

The K solution for a single edge notch specimen depends on its geometry and the way in which it is loaded. For rigid and pin loaded specimens, the formulation is:

$$K = \frac{P}{B\sqrt{W}}\sqrt{\pi\alpha}\frac{(C_1+\alpha)^{n_1}}{(1-\alpha)^{n_2}}F(\alpha)$$

However, for a fixed end (buttonhead) specimen, the equation is identical to the compact tension specimen solution:

$$K = \frac{P}{B\sqrt{W}}\frac{(C_1+\alpha)^{n_1}}{(1-\alpha)^{n_2}}F(\alpha)$$

Additionally, the F(α) solution varies by geometry as well. The pin loaded solution is

$$F(\alpha) = \sqrt{\frac{2}{\pi\alpha}\tan\left(\frac{\pi\alpha}{2}\right)}\left(A_0 + A_1\alpha + A_2\frac{\left(1-\sin\left(\frac{\pi\alpha}{2}\right)\right)^{n_3}}{\cos\left(\frac{\pi\alpha}{2}\right)}\right)$$

while the rigid and fixed end solution is a simple polynomial equation similar in form to the one for crack length.

$$F(\alpha) = \sum A_i \alpha^i$$

The coefficients for all three specimen types are shown in the table below:

Table 3: A, n, and C Coefficients for SEN(T) Specimen Geometries

	A0	A1	A2	A3	A4	A5	n1	n2	n3	C1
Pin Loaded	0.752	2.02	0.37	0	0	0	0	0	0	0
Rigid	1.1216	0.1103	1.9889	2.2911	-10.0095	8.441	0	0	3	0
Fixed End	0.2633	4.326	-5.7818	15.6185	-12.9715	4.9913	0	0	0	0

K Solution – SEN(B)

The K solution for a single edge notch specimen in a bending field is very similar to the equation for uniaxial tension, except is has an additional term to account for the ratio of specimen span to width:

$$K = \frac{P \cdot SOW}{B\sqrt{W}} \frac{(C_1 + \alpha)^{n_1}}{(1-\alpha)^{n_2}} F(\alpha)$$

The equation for F(α) is expressed as:

$$F(\alpha) = \frac{A_0 \alpha^{1/2} \left[A_1 - \alpha(1-\alpha)\left\{ A_2 - A_3 \alpha + A_4 \alpha^2 \right\} \right]}{2(1+2\alpha)(1-\alpha)^{3/2}}$$

To allow for slightly wider flexibility, the actual expression in the controller code uses the coefficients A_i instead of set numerical values. This gives the user the option to use the same functional form but adjust the values of the coefficients if so desired. The standard coefficient values for the SEN(B) solution are shown in the table below.

Table 4: A, n, and C Coefficients for SEN(B) Specimen Geometries

	A0	A1	A2	A3	A4	A5	n1	n2	n3	C1
Bending	3	1.99	2.15	3.93	2.7	0	0	0	0	0

Middle Tension Specimens (M(T))

Crack Length Calibration

The crack length for a middle tension specimen can be calculated based on either compliance or potential drop. The expression for compliance uses a 5th degree polynomial similar in form to the compact tension specimen and is shown below:

$$2\alpha = \frac{2a}{W} = \sum G_i u_x^i$$

The parameter u_x is given by:

$$u_x = 1 - e^{\left(\frac{-\sqrt{\left(\frac{EvB}{P} + \lambda\right)\left(\frac{EvB}{P} - \lambda + n_1\lambda + n_2\lambda^{n_3}\right)}}{2.141} \right)}; \lambda = \frac{GL}{W}$$

The expression λ is the ratio of the opening length of the clip gauge and the width of the specimen. The values of coefficients n_i depend on the loading configuration: uniform stress, pin loaded, or uniform displacement. A table of these values is shown below:

Table 5: u_x Compliance Coefficient Values for M(T) Specimen

	n1	n2	n3
Uniform Stress	0	0	0
Pin Loaded	0.005	0.0184	3
Clamped Uniform Displacement	-0.03	0.013	4

The values of G according to the E647 standard are:

Table 6: Normalized Crack Length Calibration Coefficients for M(T) Specimen

	G0	G1	G2	G3	G4	G5
ASTM M(T)	0	1.06905	0.588106	-1.01885	0.361691	0

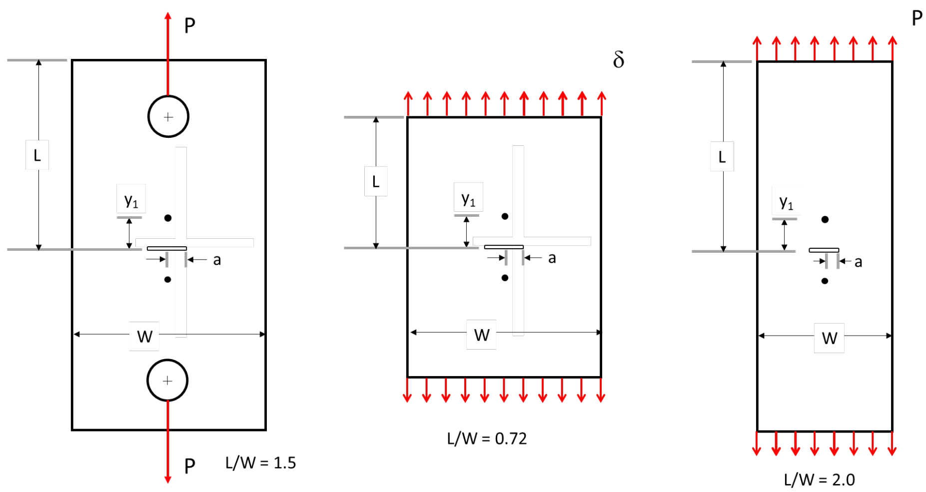


Figure 30: Middle Tension Specimen, Compliance Configurations

Crack length based on potential drop normalized by initial PD is given by Johnson's Solution. This expression is identical to that of the single edge notch geometry except for the factor of two applies to width W:

$$\frac{V_1(a)}{V_1(a_o)} = \frac{\cos h^{-1}\left(\dfrac{\cos h\left(\dfrac{\pi y_1}{W}\right)}{\cos\left(\dfrac{\pi a}{W}\right)}\right)}{\cos h^{-1}\left(\dfrac{\cos h\left(\dfrac{\pi y_1}{W}\right)}{\cos\left(\dfrac{\pi a_o}{W}\right)}\right)}$$

In the case of normalization by reference PD (using a 3-wire configuration), the PD – crack length relationship is given by:

$$\frac{\overline{V}}{\overline{V}_o} = fn(a); V^{\square} = \frac{V_1(a, y_1)}{V_2(a, y_2)} = 2\left\{\frac{\cos h^{-1}\left(\dfrac{\cos h\left(\dfrac{\pi y_2}{W}\right)}{\cos\left(\dfrac{\pi a}{W}\right)}\right)}{\cos h^{-1}\left(\dfrac{\cos h\left(\dfrac{\pi y_1}{W}\right)}{\cos\left(\dfrac{\pi a}{W}\right)}\right)} - 1\right\}^{-1}$$

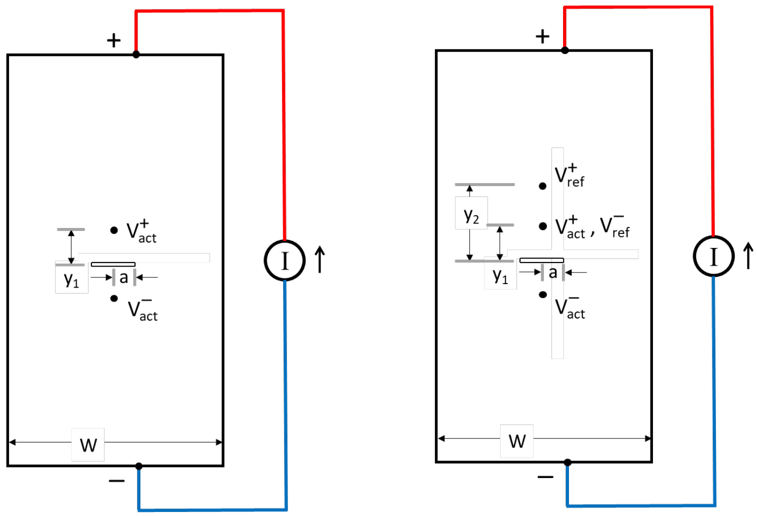


Figure 31: Middle Tension Specimen with Active Only and Active / Reference PD Configurations

K Solution

The K solution for the middle tension specimen is similar to that of the compact tension, though with a different functional form for F(α):

$$K = \frac{P}{B\sqrt{W}} \frac{(C_1 + \alpha)^{C_2}}{(1-\alpha)^{n_4}} F(\alpha) \ ; \ F(\alpha) = \sqrt{\frac{\pi\alpha}{2} sec \frac{\pi\alpha}{2}}$$

The coefficients C_1, C_2, and n_4 are all equal to zero; however, they are written in this more generic form to allow the user some flexibility in K solution customization.

Surface Flaw Specimen

Crack Length Calibration

Crack length for a surface crack geometry can be calculated through the use of the simplified Roe Coffin equation (Gangloff). Expressions are shown for cases in which PD is normalized using either initial PD or reference values:

$$\frac{V_1(a)}{V_1(a_o)} = \left[\frac{a + y\tan^{-1}\left(\frac{y_1}{a}\right)}{a_{PD0} + y\tan^{-1}\left(\frac{y_1}{a_0}\right)} \right]$$

$$\frac{\overline{V}}{\overline{V}_o} = fn(a); \overline{V} = \frac{V_1(a, y_1)}{V_2(a, y_2)} = \left[\frac{a + y_1\tan^{-1}\left(\frac{y_1}{a}\right)}{\frac{1}{2}\left\{\left(a + y_2\tan^{-1}\left(\frac{y_2}{a}\right)\right) - \left(a + y_1\tan^{-1}\left(\frac{y_1}{a}\right)\right)\right\}} \right]$$

Recent work to adjust this model based on proximity of the crack front to the back face of the specimen has resulted in a modified expression for both initial and reference PD normalized formulations above:

$$\frac{V_1(a)}{V_1(a_o)} = \left[\frac{a + y_1\tan^{-1}\left(\frac{y_1}{a}\right) + g(\alpha)}{a_{PD0} + y_1\tan^{-1}\left(\frac{y_1}{a_0}\right) + g(\alpha_0)} \right]$$

$$\frac{\overline{V}}{\overline{V}_o} = fn(a); \overline{V} = \frac{V_1(a, y_1)}{V_2(a, y_2)} = \left[\frac{a + y_1\tan^{-1}\left(\frac{y_1}{a}\right) + g(\alpha_1)}{\frac{1}{2}\left\{\left(a + y_2\tan^{-1}\left(\frac{y_2}{a}\right) + g(\alpha_2)\right) - \left(a + y_1\tan^{-1}\left(\frac{y_1}{a}\right) + g(\alpha_1)\right)\right\}} \right]$$

The function g(α) is the back face correction factor, shown below:

$$\frac{1}{\alpha}\left[f_1 - (f_1 - f_2 + \alpha) f_3\right]$$

$$f_1 = -.13\alpha^4 + .485\alpha^3 - .25\alpha^2 - .5\left[\alpha + \ln(1-\alpha)\right]$$

$$f_2 - \ln(1-\alpha)(1 - .938\alpha^{1.1384} + .4965\alpha^{1.457})$$

$$f_3=\left\{sec\,h\left[\left(.14+2.247\,\alpha^{.74}\right)\gamma\right]\right\}^{\left(-.09+.497\,\alpha^{.17}\right)}$$

The variables a and g are normalized expressions for crack length and gauge length, respectively, i.e. α=a/W and γ=y/a.

As with the SEN formulation, y_1 and y_2 represent half of the distance between the active and reference PD leads, respectively. W represents the specimen width and is the dimension corresponding to the propagation of crack length a *into* the specimen. This expression assumes a semicircular crack with an aspect ratio (a/c) equal to 1 and no z-offset for the PD leads. Since crack length is the desired value, this equation must be solved iteratively to within a strict convergence criterion.

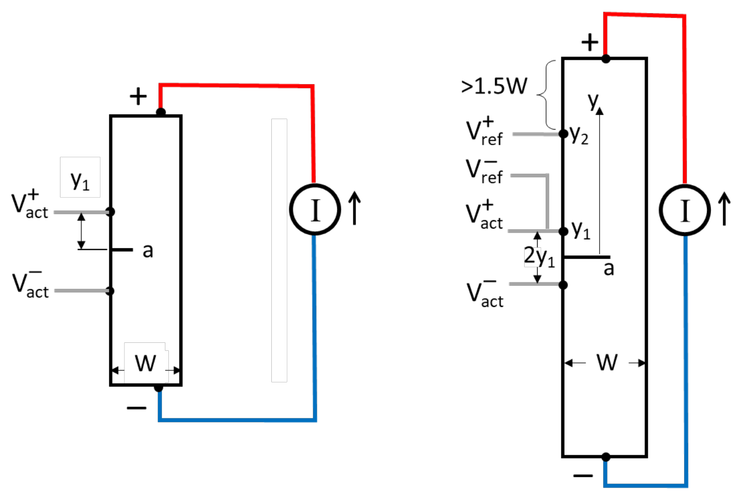


Figure 32: Surface Flaw Specimen with Active Only and Active / Reference PD Configurations

K Solution

There are two K solutions that can be used for surface flaw specimens. The first follows a format similar to other specimen geometries, as shown below:

$$K=\frac{P}{B\sqrt{W}}\frac{\left(C_1+\alpha\right)^{n_1}}{\left(1-\alpha\right)^{n_2}}F(\alpha)$$

Here, the function F(α) is expressed as:

$$F(\alpha)=\sqrt{\frac{\pi\alpha}{A_3\cos\left(\frac{\pi\alpha\,W^{3/2}}{B}\right)}}\left(A_0+A_1\alpha^2+A_2\alpha^4\right)$$

The second method, a simplified (remote uniform tension) form of an equation developed by J. Newman and I. Raju based on finite element analysis results, is a somewhat more complex formulation. The stress intensity solution is:

$$K = \sigma_{ten}\sqrt{\pi \frac{a}{Q}} F_{TOT}$$

The derivation for the term F_{TOT} is shown below:

$$Q = 1 + 1.464 + \left(\frac{a}{c}\right)^{1.65}$$

$$M_1 = 1.13 - .09\frac{a}{c}; M_2 = -0.54 + \frac{0.89}{0.2 + \frac{a}{c}}; M_3 = 0.5 + \frac{1}{0.65 + \frac{a}{c}} + 14\left(1 - \frac{a}{c}\right)^{24}$$

$$M_{TOT} = M_1 + M_2\left(\frac{a}{W}\right)^2 + M_3\left(\frac{a}{W}\right)^4$$

$$G = 1 + \left(0.1 + 0.35\left(\frac{a}{W}\right)^2\right)(1 - sin\varphi)^2$$

$$F_\varphi = \left(\left(\frac{a}{c}\right)^2 \cos^2\varphi + \sin^2\varphi\right)^{\frac{1}{4}}; F_W = \left(\cos\left(\frac{\pi a}{B}\sqrt{\frac{a}{W}}\right)\right)^{\frac{-1}{2}}$$

$$F_{TOT} = M_{TOT} F_\varphi G F_W$$

One advantage to this formulation is that it is capable of calculating K for a/c values other than unity. Thus, for cracks with significant deviations between values of a and c, this may be a useful approach.

Flat Bottom Hole Specimen (FBH)

Crack Length Calibration

Crack length for the flat bottom hole specimen is calculated using a 5th order polynomial and applies only for configurations that include a reference voltage:

$$\frac{V_1(a,y_1)}{V_2(a,y_2)}=1.483+1.006\left(\frac{a}{W}\right)-1.605\left(\frac{a}{W}\right)^2+7.544\left(\frac{a}{W}\right)^3-11.85\left(\frac{a}{W}\right)^4+7.041\left(\frac{a}{W}\right)^5$$

K Solution

The FBH K solution is shown below. It is similar in format to the C(T) specimen, but expresses the thickness B in terms of the outer and inner radii (R and r) instead:

$$K=\frac{P}{\left(\frac{R}{r}+1\right)r\sqrt{W}}\frac{(C_1+\alpha)^{n_1}}{(1-\alpha)^{n_2}}F(\alpha)$$

where:

$$F(\alpha)=\sum A_i\alpha^i$$

The values of Ai depend on the ratio of elastic moduli between the plunger material and that of the specimen being tested. The current model includes coefficients for two materials – nickel and aluminum – with ratios of 3 and 9 respectively.

Table 7: A, n, and C Coefficients for FBH Specimen Geometries

	A0	A1	A2	A3	A4	A5	n1	n2	n3	C1
Ep/Es = 3 (Ni)	-0.0001612	0.5328	-0.9282	1.689	-1.48	0.5798	-1.113	0.4353	0	0
Ep/Es = 9 (Al)	-0.0001076	0.5046	-0.8288	1.514	-1.323	0.5242	-1.137	0.4373	0	0

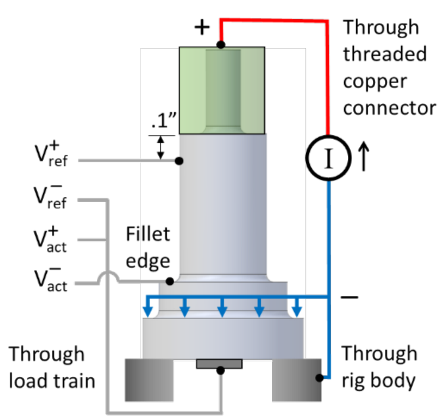


Figure 33: Flat Bottom Hole Specimen with Active / Reference PD Configuration Only

Surface Flaw Bending Specimen (SF(B))

Crack Length Calibration

Crack length for the surface flaw bending specimen is based on the generalized form of the Roe-Coffin equation (Gangloff) superposed with a two dimensional potential field resulting from the application of two point current sources – I_+ and I_- -- applied symmetrically from the crack at a distance y_s.

The total voltage at point (x,y) is calculated by integrating the summed effect of both singularities at points (0, y_s) and (0, -y_s).

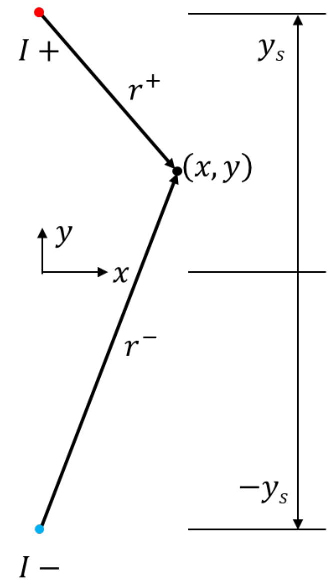


Figure 34 Source and Sink Currents Applied to Infinite Plate

$$V_{p2D}(x,y)=\frac{-I}{2\pi W\kappa_E}$$

where

$$r^{+¿\sqrt{x^2+(y_s-y)^2}}r^{-¿\sqrt{x^2+(y_s+y)^2}}$$

Integrating gives:

$$V_{p2D}(x,y)=\frac{-I}{2\pi W\kappa_E}\left[\ln\left(\sqrt{x^2+(y_s-y)^2}\right)-\ln\left(\sqrt{x^2+(y_s+y)^2}\right)\right]$$

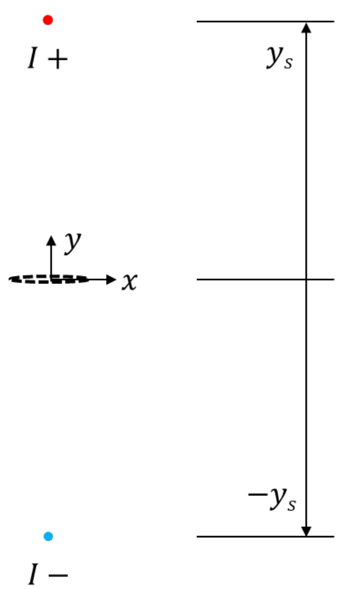


Figure 35 Source and Sink Centered on a Crack

The corresponding flux is then:

$$J_y(x,y)=-\kappa_E\frac{\partial V}{\partial y}=\frac{-I}{2\pi W}\left[\frac{(y_s-y)}{x^2+(y_s-y)^2}+\frac{(y_s+y)}{x^2+(y_s+y)^2}\right]$$

Setting y to 0 in the above equation gives us the flux at the location of interest:

$$J(x,y)=-\kappa_E\frac{dV}{dy}=\frac{-I}{\pi t}\left[\frac{y_s}{x^2+y_s^2}\right]=\frac{-I}{\pi t y_s}\left[\frac{1}{\left(\frac{x}{y_s}\right)^2+1}\right]$$

Thus, the flux within the crack domain ranges from J(0,0) to J(a,0):

$$J_y(0,0)=\frac{-I}{\pi W y_s};J_y(a,0)=\frac{-I}{\pi W y_s}\left[\frac{1}{\left(\frac{a}{y_s}\right)^2+1}\right]$$

Because the Roe-Coffin PD solution assumes a uniform flux, an intermediate denominator value $a/\sqrt{2}$ was used as an approximation on the logic that a circle of that radius divides area of the crack domain in half:

$$J_{y_{eff}} \cong -\frac{I}{\pi W y_s}\left[\frac{1}{\frac{a^2}{2{y_s}^2}+1}\right] = \frac{-I}{\pi W y_s}\text{⌘}$$

This approximation also neglects the non-circularity of the crack ($c \geq a$) in the formulation of ζ, but the aspect ratio is incorporated in Roe-Coffin.

The crack itself is introduced as a change in voltage resulting from the growth of a crack starting at a=0. The corresponding expression for Δa based on the Roe Coffin potential solution is:

$$\Delta V_{RC}(a, y) \cong \frac{2 I \text{⌘}}{\pi W \kappa_E} \frac{y}{y_s}\left(\frac{\frac{\sqrt{1-k^2 \sin^2\theta}}{tan\theta}+E(k,\theta)-Q}{E\left(k,\frac{\pi}{2}\right)-Q}-1\right)$$

Setting the expression for crack-free potential field to be limited to a location y along a centerline connecting the current sources (i.e. x=0) and adding to the Roe-Coffin DV, we get the expression for the surface flaw in a plate. See Figure 29 for additional information.

$$V_{PRC}(a, y) = \left(\frac{I}{\pi W \kappa_E}\right)\left[-\ln\left[\frac{y_s - y}{y_s + y}\right] + \frac{2\zeta y}{y_s}\left(\frac{\frac{\sqrt{1-k^2 \sin^2\theta}}{tan\theta}+E(k,\theta)-Q}{E\left(k,\frac{\pi}{2}\right)-Q}-1\right)\right]$$

The expressions E(k,x) are elliptical integrals of the second kind; I is the applied current, κ_E is the conductivity, and ζ is the variation of the flux with respect to crack length:

$$\zeta = \left[\frac{1}{\frac{a^2}{2{y_s}^2}+1}\right]$$

The expression Q is given by

$$Q = E(k, \theta_0) + \frac{b\beta^2}{ac\lambda}$$

where, for c > a > b:

$$\beta^2 = a^2 - b^2\lambda^2 = c^2 - b^2 k^2 = 1 - \frac{\beta^2}{\lambda^2}$$

For cases where for a > c > b, the equations of β and λ are reversed. Additional information regarding the full derivation of the generalized Roe-Coffin Solution, refer to the paper in the bibliography by Slavik and Gangloff.

K Solution

The SF(B) K solution is shown below. It is based on the same Newman Raju solution as the axial surface flaw solution, but contains additional terms to quantify the effect of bending stress:

$$K = H\sigma_{bending}\sqrt{\pi \frac{a}{Q}} F_{TOT} F_{CL}$$

where

$$\sigma_{bending} = \frac{3P}{W^2}\left\{\frac{1-v}{4\pi}\left[\left(\frac{d_2}{d_1}\right)^2 - \left(\frac{d_3}{d_1}\right)^2\right] - \frac{1+v}{2\pi}\ln\frac{d_3}{d_2}\right\}$$

P is the applied load, dimensions d_1, d_2, and d_3 represent the specimen diameter and the locations of the downward and upward loads respectively. The derivation for F_{TOT} is shown in the axial surface flaw section and will not be repeated here. However, the bending stress has a multiplier H that is given by the expression:

$$H = H_1 + (H_2 + H_1)\sin^p \varphi$$

The multipliers for H are

$$H_1 = 1 - 0.34\frac{a}{W} - 0.11\frac{a}{c}\frac{a}{W}; H_2 = 1 - G_1\frac{a}{W} - G_2\left(\frac{a}{W}\right)^2$$

with

$$G_1 = -1.22 - 0.12\frac{a}{c}; G_2 = 0.55 - 1.05\left(\frac{a}{c}\right)^{0.75} + 0.47\left(\frac{a}{c}\right)^{1.5}$$

And the expression for the power p of the sine term is:

$$p = 0.2 + \frac{a}{c} + 0.6\frac{a}{W}$$

where:

$$F(\alpha) = \sum A_i \alpha^i$$

The Mode I SIF was corrected for the bending moment across the annular displacement-controlled region, and normalized to the load at each crack length to obtain an estimate of the effect of contact load non-uniformity associated with the crack.

$$F_{CL} = 1 - .252(a/W)^{3.87}$$

The correction was found to be the same along a (90°) or along a direction within 5° of c (the SIF is technically undefined right at the free surface). While the actual correction would be slightly dependent on the a/c evolution, it is of such small magnitude that this dependence is considered negligible.

As stated previously, the advantage to this formulation is that it is capable of calculating K for a/c values other than unity. The controller code expresses the relationship between c and a per NASGRO crack case SC01 for this specimen geometry and dimensions as:

$$c = \frac{a}{min\left(1.02 - 1.19\frac{a}{W}, 1.\right)}$$

The postprocessor calculates this relationship differently, taking the ratio of the K values in the a and c directions and backsolving for c based on a given a and user-selected value of Paris Law exponent n. This gives the user the ability to select the proper value to match the observed relationship between a and c for the duration of the test.

Additionally, the SIF along the c direction is multiplied by β_R to account for constraint effects where the crack meets the free surface.

$$\beta_R = \begin{cases} 0.9 + 0.2R^2 - 0.1R^4 & 0 \le R < 1 \\ 0.9 & R < 0 \end{cases}$$

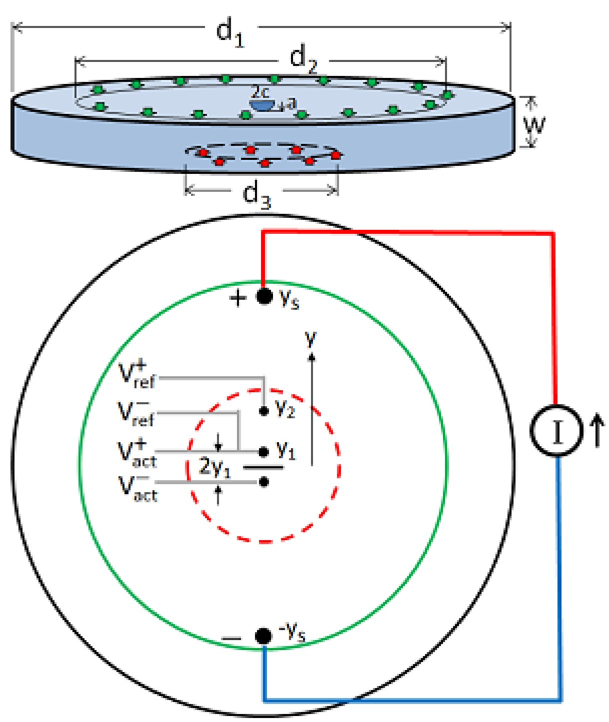


Figure 36: Surface Flaw Bending Specimen with Active / Reference PD Configuration Only

APPENDIX: Automatic Peak Indexing

The calculation of compliance is dependent upon the controller knowing the location of the maximum values of load and displacement within the respective input waveforms. Because of variation and noise inherent to any test setup, steps are taken to mitigate their effects on reliably calculating these values. The first is a user selected data averaging function (up to three points) of every point in the input for a rudimentary smoothing effect. The second is the application of a rolling average of peak index values over a range of cycles that is dependent on the process frequency. Generally, this is effective in finding the peaks and keeping the resulting compliance values relatively stable.

Shown in Figure 29, compliance is calculated using the maximum indices of load and displacement as starting points, which has the effect of automatically taking signal phase lag into consideration. Plotting the phase relationship based on these maxima should result in a straight line, showing the "effective" phase based on the data being used to calculate compliance. The GUI shows both max indices in the "controls" sub tab.

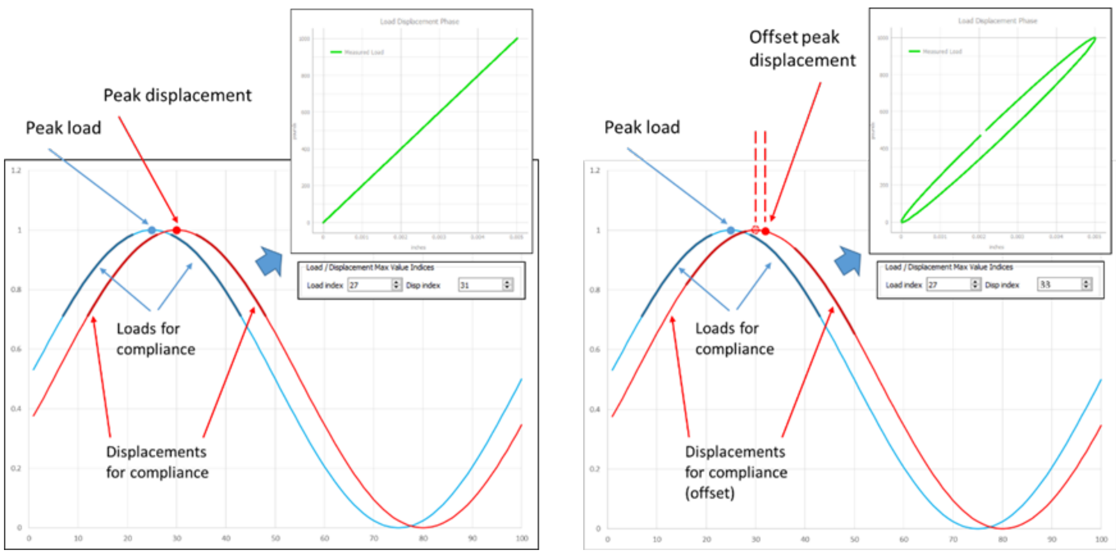


Figure 37 Relative Indices for Load and Displacement

However, there is a possibility that the signal of either channel may have enough noise to produce a "false peak", resulting in the controller identifying a maximum offset from the true value. In this case, the load – displacement phase relationship will be elliptical, showing the user that there is a mismatch between the two sets of values. By selecting "pause peak indexing", manual control of peak index selection is given to the user to adjust as needed. Care is recommended here to interrogate both signals to determine the location and magnitude of offset so that the appropriate value can be adjusted. Once identified, the index can be moved to the proper location, restoring the phase relationship between load and displacement and improving the calculational accuracy of the compliance.

APPENDIX: Sample Configuration Save Files

Below are samples of the different save files available in the controller program. Each file consists of a header row with the text “parameter,value” followed by the parameters to be saved. Examples of these

Hardware Configuration Data
GUI Location: Configuration \ Hardware Setup
Default Folder Location: \data\hardware_configuration

```
parameter,value
load_calibration_factor,-200.0
disp_calibration_factor,-0.001
actPD_calibration_factor,1.0
refPD_calibration_factor,1.0
kp,0.5
ki,0.003
kd,0.03
fixture_wgt,0.
```

Default Folder Locations
GUI Location: Configuration \ Hardware Setup
Default Folder Location: \data

```
parameter,value
log_files,data\default_data\
data_files,data\default_data\
```

Test Header Data
GUI Location: Configuration \ Specimen Properties
Default Folder Location: \data\header_data

```
parameter,value
specid,90125
contract,19742112
material,ASM65000
orient,XV
temperature,1261
environment,AIR
```

Specimen Dimensions – C(T)
GUI Location: Configuration \ Specimen Properties
Default Folder Location: \data\specimen_dimensions

```
parameter,value
b,.063
bnet,.063
w,.23
sow,3
conductivity,1
syield,130000
emod,16280000.0
notch_depth,.002
alpha,1.0
evbpi,0.0
cri,0.0
pdgl,.023
```

```
rpdgl,.085
pd0,1.0
apd0,.002
ai,.002
outer_r,0.0
inner_r,0.0
```

Specimen Configuration - Compact Tension, V0, Polynomial 1
GUI Location: Configuration \ Specimen Properties
Default Folder Location: \data

```
n_1,1.0
n_2,1.5
n_3,0.5
n_4,-1.0
C_1,2.0
C_2,1.0
G,[ 1.0010e+00 -4.6695e+00  1.8460e+01 -2.3682e+02  1.2149e+03 -2.1436e+03]
A,[ 0.886  4.64  -13.32  14.72  -5.6    0.   ]
```

Waveform
GUI Location: Configuration \ Waveform
Default Folder Location: \data\waveforms

```
0.49999999999999994
0.5313952597646567
0.5626666167821521
0.5936906572928623
0.6243449435824274
0.6545084971874735
0.6840622763423388
0.7128896457825363
0.7408768370508577
.
.
.
0.2591231629491424
0.28711035421746367
0.31593772365766093
0.3454915028125263
0.37565505641757263
0.40630934270713764
0.43733338321784776
0.46860474023534326 ← no carriage return after last line
```

Mission Block
GUI Location: Configuration \ Waveform \ Waveform Block Builder
Default Folder Location: \data\waveforms

```
subcycles,max load,min load
20,1200,480
20,500,50
10,800,240
10,300,-150
50,500,0
10,700,140
```

Spectrum Mission
GUI Location: Configuration \ Waveform \ Waveform Block Builder
Default Folder Location: \data\waveforms

```
load
200.0
-30.0
400.0
-50.0
150.0
-100
-50
-200
-30
-80
100
20.0
500.0
-10
1000
50
800
-50
100
-200
300
30
950
0.0
```

Test Parameters
GUI Location: Controller \ Controls
Default Folder Location: \data\test_parameters

```
parameter,value
test_type,3
control_type,0
control_mode,0
stop_criterion,1
stop_value,10000
max_tgt_spec_load,280
tgt_load_ratio,.5
waveform_freq,80.000
targetkmax,0.0
kgrad,0.0
kgrad_type,0
static_rate,0.0
cycle_interval,1000
crack_interval,0.001
UCP_loadcomp,1
UCP_unloadcomp,1
compliance_minload_ratio,70.0
compliance_maxload_ratio,99.0
cycle_interval_flag,0
crack_interval_flag,0
load_exceed_thresh,50.0
allowable_aw_drop,0.01
ramp_up_duration,1.0
hold_up_duration,0.1
ramp_dn_duration,1.0
hold_dn_duration,0.1
```

Preset Test Queues
GUI Location: Controller \ Controls

Default Folder Location: \data\test_queues

Seg,TType,SCrit,SVal,CType,CMode,CVal,R,Freq. / Rate,Kgrad Type,Kgrad Val,Cyc Int,Crk Int,Load,Unload,MinSlp%,MxSlp%,RUTime,HUTime,RDTime,HDTime,OP
A,Cyclic Crack Growth,Time (sec),20,Load (lbs),Constant R,1000,0.3,300.0,none,0,1000,0.001,1,1,70.0,99,0.0,0.0,0.0,0.0,0
B,Cyclic Crack Growth,Time (sec),20,K,Constant R,10,0.3,300.0,C (E647),0,1000,0.001,1,1,70.0,99,0.0,0.0,0.0,0.0,0
C,Cyclic Crack Growth,Time (sec),20,Load (lbs),Constant R,800,.4,300.0,C (E647),-10,1000,0.001,1,1,70.0,99,0.0,0.0,0.0,0.0,0
D,Cyclic Crack Growth,Time (sec),20,K,Constant Kmax,10,0.3,200.0,C (E647),-15,1000,0.001,1,1,70.0,99,0.0,0.0,0.0,0.0,0
E,Cyclic Crack Growth,Time (sec),20,Load (lbs),Constant R,800,0.5,200.0,none,0,1000,0.001,1,1,70.0,99,0.0,0.0,0.0,0.0,0

APPENDIX: Sample Lookup Tables

Normalized PD, Compliance to a/W (normalized a)
GUI Location: Configuration \ Specimen Properties
Default Folder Location: (user specified; no default)

```
,val_norm,a_w
0,8.0,-0.13070855811590798
1,8.12,-0.12108168440080025
2,8.239999999999998,-0.11182964487376346
3,8.359999999999998,-0.10292947284844978
4,8.479999999999997,-0.09435992045723163
5,8.599999999999996,-0.08610131053033543
6,8.719999999999995,-0.07813540284488996
7,8.839999999999995,-0.07044527319621885
8,8.959999999999994,-0.06301520392674886
9,9.079999999999993,-0.05583058470743074
10,9.199999999999992,-0.04887782250578088
```

…

```
190,209.39999999999998,0.7311308599862372
191,213.26,0.7333993303825546
192,217.11999999999998,0.7356079829182467
193,220.97999999999996,0.7377594198652583
194,224.83999999999997,0.7398560880722239
195,228.7,0.7419002906504487
196,232.55999999999997,0.7438941976080762
197,236.41999999999996,0.7458398555421037
198,240.27999999999997,0.7477391964849741
199,244.14,0.7495940459912217
```

a/W to K/P (normalized K)
GUI Location: Configuration \ Specimen Properties
Default Folder Location: (user specified; no default)

```
,val_norm,k_p
0,-0.13070855811590798,0.03817781797078614
1,-0.12108168440080025,0.2263973701747017
2,-0.11182964487376346,0.40614369257698685
3,-0.10292947284844978,0.5780030736939877
4,-0.09435992045723163,0.7425130963042966
5,-0.08610131053033543,0.9001671762575616
6,-0.07813540284488996,1.0514186515732593
7,-0.07044527319621885,1.1966844659370535
8,-0.06301520392674886,1.336348487094053
9,-0.05583058470743074,1.4707644970655211
10,-0.04887782250578088,1.6002588876791042
```

…

```
190,0.7311308599862372,36.16692483949242
191,0.7333993303825546,36.66096924712385
192,0.7356079829182467,37.15259939642923
193,0.7377594198652583,37.641860782432474
194,0.7398560880722239,38.12879758506126
195,0.7419002906504487,38.61345271656244
196,0.7438941976080762,39.095867867011066
197,0.7458398555421037,39.57608354799608
198,0.7477391964849741,40.054139134560266
199,0.7495940459912217,40.53007290546825
```

APPENDIX: Sample .log File Text

```
LOG FILE FOR TEST 90125A STARTED 2024-05-31 15:41:20.714104

SEGMENT A

Specimen ID: 90125 :: Contract Number: 19742112
Material: ASM65000 :: Orientation: XV
Temperature (F): 1261 :: Environment: AIR
Thickness (B): 0.125 :: Net Thickness (Bnet): 0.125
Width (W): 1.0 :: Span / Width (SOW): 1.0
Outer Radius: 0.0 :: Inner Radius: 0.0

Yield Strength: 0.0 :: Modulus: 16280000.0
Notch Depth: 0.0 :: Alpha Ratio: 1.0
Init. Compliance: 0.0 :: Init Compliance Ratio: 0.0
Act. PD Gauge Length: 0.0 :: Initial PD: 1.0
Ref. PD Gauge Length: 0.0
Crack Length @ PD0: 0.0 :: Init crack length: 0.001

Test Type: Cyclic Crack Growth :: Control Type: Load
Control Mode: Constant R :: Stop Criterion: Time (sec)
Stop value: 1000.0
Crack Interval Flag: 1 :: Crack Interval: 0.001
Cycle Interval Flag: 1 :: Cycle Interval: 1000

Max Load: 1200.0 :: Stress Ratio: 0.4
Frequency: 100.0 :: Load Rate: 1.0

Wave Type: wave_sine :: Mission Type: variable amplitude - mission block
Waveform File: ''
Load / Mission Points File:
'C:/Users/User/Documents/FLcgs/GUI/data/waveforms/mission_block_newformat.csv'
is NASGRO Mission File: 0

Kmax: 0.0 :: K Gradient: 0.0
Specimen Geom: Compact Tension - C(T) :: Crack Length Calibration: ASTM V0
K Calculation: Polynomial
Alpha LUT: ''
K LUT: ''
G (alpha solution): [1.001, -4.6695, 18.46, -236.82, 1214.9, -2143.6]
A (F(alpha) solution): [0.886, 4.64, -13.32, 14.72, -5.6, 0.0]
C coeffs: [2.0, 1.0] :: n coeffs: [1.0, 1.5, 0.5, -1.0]

Data for XML interpreter
Test Type: 3 :: Control Type: 0
Control Mode: 0 :: Stop Criterion: 1
Specimen Type: 0 :: A Solution: 0
K Solution: 0 :: Crack Measurement Type: 1
Ref. PD flag: 0 :: Opening Load Flag: 0
Segment list: 90125A
OP flag list: [0]
Data length list (excluding current): []
Prior state list: [2]

DATA
XML OUTPUT DATA FORMAT:
Index,Exclude,Skip,N,Pmax,DP,Compliance,CR,MaxCycLoad

Cycle data (N, K, Pmax, R, comp, CR, a): [5, 17.083, 1200.986, 0.397], 10.1759, 1.00001,
0.00047
Cycle data (N, K, Pmax, R, comp, CR, a): [8, 17.084, 1201.047, 0.095], 10.1759, 1.0, 0.00047
Cycle data (N, K, Pmax, R, comp, CR, a): [10, 17.085, 1201.108, -0.006], 10.176, 0.99999,
0.00047
Cycle data (N, K, Pmax, R, comp, CR, a): [12, 17.084, 1201.108, 0.797], 10.1758, 1.0, 0.00046
Cycle data (N, K, Pmax, R, comp, CR, a): [15, 17.083, 1200.986, -0.507], 10.1759, 1.00002,
0.00047
```

```
Cycle data (N, K, Pmax, R, comp, CR, a): [17, 17.085, 1201.108, 0.095], 10.176, 0.99999,
0.00047
Cycle data (N, K, Pmax, R, comp, CR, a): [20, 17.085, 1201.108, 0.297], 10.1759, 0.99999,
0.00047
Cycle data (N, K, Pmax, R, comp, CR, a): [22, 17.082, 1200.925, 0.397], 10.1758, 1.00003,
0.00046
Cycle data (N, K, Pmax, R, comp, CR, a): [24, 17.083, 1200.925, -0.006], 10.176, 1.0, 0.00047

.
.
.

Cycle data (N, K, Pmax, R, comp, CR, a): [991, 17.083, 1201.047, -0.006], 10.1758, 1.0,
0.00046
Cycle data (N, K, Pmax, R, comp, CR, a): [993, 17.081, 1200.925, -0.006], 10.1758, 1.00001,
0.00046
Cycle data (N, K, Pmax, R, comp, CR, a): [996, 17.083, 1201.047, -0.006], 10.1758, 1.00001,
0.00046
Cycle data (N, K, Pmax, R, comp, CR, a): [998, 17.084, 1201.108, 0.296], 10.1758, 1.00002,
0.00046
Cycle data (N, K, Pmax, R, comp, CR, a): [1000, 17.082, 1200.925, 0.095], 10.1759, 1.00001,
0.00047

1,0,0,500,1200.986,1353.695,10.175882,1.000005,0.0

-1,,,,,,

TEST SEGMENT ENDED 2024-05-31 15:58:01.197309
```

APPENDIX: Sample .XML Output File Text


```
<testrecord>
    <specid>
            <testid>90125A</testid>
            <altid> </altid>
            <contract>20222112</contract>
            <material>ASM65000</material>
            <geometry>Compact Specimen</geometry>
            <orientation>XV</orientation>
    </specid>
    <comments>
            <date>06/17/2022</date>
            <waveform>Sinusoidal</waveform>
            <wavefile />
    </comments>
    <dimensions>
            <b>.502</b>
            <bnet>.502</bnet>
            <w>2.001</w>
            <h>0.</h>
            <sow>0.</sow>
            <notch>.499</notch>
            <glength>0.0</glength>
    </dimensions>
    <initvals>
            <evbpi>24.666</evbpi>
            <cri>1</cri>
            <alpha>1.0</alpha>
            <pd0>0.0</pd0>
            <apd0>0.0</apd0>
    </initvals>
    <precrack>
            <pcp>0.</pcp>
            <pcr>0.</pcr>
            <pca>0.</pca>
    </precrack>
    <testparms>
            <dcpd>0</dcpd>
            <temperature>1261</temperature>
            <environment>AIR</environment>
            <humidity> </humidity>
            <yield>152800</yield>
            <e>28300000</e>
            <freq>300.0</freq>
            <r>0.0</r>
            <ai>.499</ai>
            <kcontroltype>0</kcontroltype>
            <kcontrolmode>0</kcontrolmode>
            <pmaxc>1000.0</pmaxc>
            <compdcpdstress>0.</compdcpdstress>
            <initkmax>0.0</initkmax>
            <kgrad>0.0</kgrad>
            <dkinit>0.0</dkinit>
    </testparms>
    <analysis>
            <fl_flag>1</fl_flag>
            <geometry_index>0</geometry_index>
            <acaltext>ASTM E647 15e Compact Specimen V0</acaltext>
            <ksoltext>C(T) Polynomial</ksoltext>
            <acaltype>0</acaltype>
            <ksoltype>0</ksoltype>
            <dadn_type>0</dadn_type>
            <pdref>0</pdref>
            <viscorrect>0</viscorrect>
            <closurecode>0</closurecode>
            <op>0</op>
            <acr>0</acr>
```

```
            <twopi>0</twopi>
            <knorm_analysis>0</knorm_analysis>
            <knormvariable>0</knormvariable>
            <knormexponent>0.</knormexponent>
            <g_coeffs>1.001,-4.6695,18.46,-236.82,1214.9,-2143.6</g_coeffs>
            <a_coeffs>0.886,4.64,-13.32,14.72,-5.6,0.0</a_coeffs>
            <nc_coeffs>1.0,1.5,0.5,-1.0,2.0,1.0</nc_coeffs>
    </analysis>
    <threshfit>
            <fitmax>3.937e-08</fitmax>
            <fitmin>3.937e-09</fitmin>
            <dadn>3.937e-09</dadn>
            <fit_app>0</fit_app>
            <fit_acr>0</fit_acr>
            <fit_2pi>0</fit_2pi>
            <fit_op>0</fit_op>
            <fit_norm>0</fit_norm>
    </threshfit>
    <output_opts>
            <index>1</index>
            <force>1</force>
            <delta_p>1</delta_p>
            <comp_dcpd>1</comp_dcpd>
            <a>1</a>
            <cyclecount>1</cyclecount>
            <dadn>1</dadn>
            <dk>1</dk>
            <kmax>1</kmax>
            <dkeffop>0</dkeffop>
            <dkeffacr>0</dkeffacr>
            <dkeff2pi>0</dkeff2pi>
            <knorm>0</knorm>
            <dispatzeroload>0</dispatzeroload>
    </output_opts>
    <visuals>
    </visuals>
    <alookup>
    <data>
  <row>
    <index>0</index>
    <val_norm>8.0</val_norm>
    <a_w>-0.13070855811590798</a_w>
  </row>
```


… (body of alpha lookup table data is here)


```
<row>
    <index>199</index>
    <val_norm>244.14</val_norm>
    <a_w>0.7495940459912217</a_w>
  </row>
</data></alookup>
    <klookup>
    <data>
  <row>
    <index>0</index>
    <val_norm>-0.13070855811590798</val_norm>
    <k_p>0.03817781797078614</k_p>
  </row>
```


… (body of K/P lookup table data is here)


```
<row>
    <index>199</index>
    <val_norm>0.7495940459912217</val_norm>
    <k_p>40.53007290546825</k_p>
  </row>
</data></klookup>
    <avndata>
    <data>
```

```
  <row>
    <level_0>0</level_0>
    <index>1</index>
    <exclude>0</exclude>
    <skip>0</skip>
    <cyclecount>119.0</cyclecount>
    <pmax>999.0</pmax>
    <pdelta>998.7561645507812</pdelta>
    <evbp>70.7518539428711</evbp>
    <cr>1.0035254955291748</cr>
    <fi>0.0</fi>
  </row>
```


… (body of a vs. N data is here)


```
  <row>
    <level_0>31</level_0>
    <index>32</index>
    <exclude>0</exclude>
    <skip>0</skip>
    <cyclecount>29167.0</cyclecount>
    <pmax>999.0</pmax>
    <pdelta>999.4876708984375</pdelta>
    <evbp>71.02619934082031</evbp>
    <cr>0.9999228119850159</cr>
    <fi>0.0</fi>
  </row>
</data></avndata>
</testrecord>
```

APPENDIX: Postprocessor Input File Template

```
<?xml version='1.0' encoding='utf8'?>
<testrecord>
    <specid>
            <testid>97005A</testid>
            <altid> </altid>
            <contract>0</contract>
            <material>0</material>
            <geometry>0</geometry>
            <orientation>0</orientation>
    </specid>
    <comments>
            <date>0</date>
            <waveform>0</waveform>
            <wavefile> </wavefile>
    </comments>
    <dimensions>
            <b>0.</b>
            <bnet>0.</bnet>
            <w>0.</w>
            <outer_r>0.</outer_r>
            <inner_r>0.</inner_r>
            <h>0.</h>
            <sow>0.</sow>
            <notch>0.</notch>
            <glength>0.</glength>
            <ref_glength>0.</ref_glength>
    </dimensions>
    <initvals>
            <evbpi>0.</evbpi>
            <cri>0.</cri>
            <alpha>0.</alpha>
            <pd0>0.</pd0>
            <apd0>0.</apd0>
    </initvals>
    <precrack>
            <pcp>0.</pcp>
            <pcr>0.</pcr>
            <pca>0.</pca>
    </precrack>
    <testparms>
            <dcpd>0</dcpd>
            <temperature>0.</temperature>
            <environment> </environment>
            <humidity> </humidity>
            <yield>0.</yield>
            <e>0.</e>
            <freq>0.</freq>
            <r>0.</r>
            <ai>0.</ai>
            <kcontroltype>0</kcontroltype>
            <kcontrolmode>0</kcontrolmode>
            <pmaxc>0</pmaxc>
            <compdcpdstress>0.</compdcpdstress>
            <initkmax>0.</initkmax>
            <kgrad>0.</kgrad>
            <dkinit>0.</dkinit>
    </testparms>
    <analysis>
            <fl_flag>1</fl_flag>
            <geometry_index>0</geometry_index>
            <acaltext> </acaltext>
            <ksoltext> </ksoltext>
            <acaltype>0</acaltype>
            <ksoltype>0</ksoltype>
            <dadn_type>0</dadn_type>
            <pdref>0</pdref>
            <viscorrect>0</viscorrect>
            <closurecode>0</closurecode>
```

```
            <op>0</op>
            <acr>0</acr>
            <twopi>0</twopi>
            <knorm_analysis>0</knorm_analysis>
            <knormvariable>0</knormvariable>
            <knormexponent>0.</knormexponent>
            <g_coeffs>0.,0.,0.,0.,0.,0.</g_coeffs>
            <a_coeffs>0.,0.,0.,0.,0.,0.</a_coeffs>
            <nc_coeffs>0., 0., 0., 0., 0., 0.</nc_coeffs>
    </analysis>
    <threshfit>
            <fitmax>3.937E-8</fitmax>
            <fitmin>3.937E-9</fitmin>
            <dadn>3.937E-9</dadn>
            <fit_app>0</fit_app>
            <fit_acr>0</fit_acr>
            <fit_2pi>0</fit_2pi>
            <fit_op>0</fit_op>
            <fit_norm>0</fit_norm>
    </threshfit>
    <output_opts>
            <index>1</index>
            <force>1</force>
            <delta_p>1</delta_p>
            <comp_dcpd>1</comp_dcpd>
            <a>1</a>
            <cyclecount>1</cyclecount>
            <dadn>1</dadn>
            <dk>1</dk>
            <kmax>1</kmax>
            <dkeffop>0</dkeffop>
            <dkeffacr>0</dkeffacr>
            <dkeff2pi>0</dkeff2pi>
            <knorm>0</knorm>
            <dispatzeroload>0</dispatzeroload>
    </output_opts>
    <visuals>
    </visuals>
    <alookup>
    </alookup>
    <klookup>
    </klookup>
    <avndata>
    </avndata>
</testrecord>
```

APPENDIX: References

Araki, M. (2009). PID Control. In *Control Systems, Robotics, and Automation.* Encyclopedia of Life Support Systems (EOLSS).

ASTM E647 15e1: Standard Test Method for Measurement of Fatigue Crack Growth Rates. (2015).

Dahlberg, G. (n.d.). Dynamic Calibration of Axial Fatigue Testing Machines. Why is it Important and How is it Accomplished? *EUROLAB International Workshop: Investigation and Verification of Materials Testing Machines*, 89-99.

Gangloff, R. P. (n.d.). Direct current electrical potential measurement of the growth of small cracks. In *Small-crack test methods* (Vol. 1, pp. 116-168).

J. C. Newman, J. a. (1981). Stress-Intensity Factor Equations for Cracks in Three-Dimensional Finite Bodies Subjected to Tension and Bending Loads. *Engineering Fracture Mechanics Vol. 15, No. 1-2*, 185-192.