



**Instruction Manual**  
**SURE-Pulse™ Software**  
**Version 1.9.x**

*2/4/2016*

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# Software Overview

## 1. Introduction

REL, Inc. would like to thank you for your interest in the *SURE-Pulse™* software package. *SURE-Pulse™* was originally written to be a high throughput testing software to handle REL's in-house high strain rate testing with the *SURE-Test Systems- Split Hopkinson Pressure Bar*. Due to its cross platform, non-proprietary and open source nature, REL hopes that *SURE-Pulse™* will become the standard method of processing material test data, especially high strain rate testing. REL is seeking engagement in the *SURE-Pulse™* project from the academic community to standardize and increase transparency of calculations.

*SURE-Pulse™* currently consists of two main packages, *Data Processor* and *Viewer*. *SURE-Pulse™ Data Processor* allows input of collected data and associates it with the user's testing equipment. *SURE-Pulse™ Viewer* allows viewing of data calculations in a chart, includes useful diagnostic tools, and enables the efficient exporting of data.

The *Data Processor* package includes *SURE-Pulse™ Viewer*, however *SURE-Pulse™ Viewer* is available as a stand-alone download allowing the user to share and view data without downloading the entire data processor package.

## 2. Licensing

*SURE-Pulse™* software is licensed under the GNU General Public License, version 3.0 (GPL-3.0). A copy of the license can be is available to view at the following web address <http://www.gnu.org/licenses/gpl-3.0.txt>.

## 3. Downloads

Source code - <https://github.com/relic/>

Reference material - <http://relic.net/reference-material>

*SURE-Pulse™* Software Page - <http://www.relic.net/software/>

## 4. System Requirements

Architecture: 64 bit (x64)

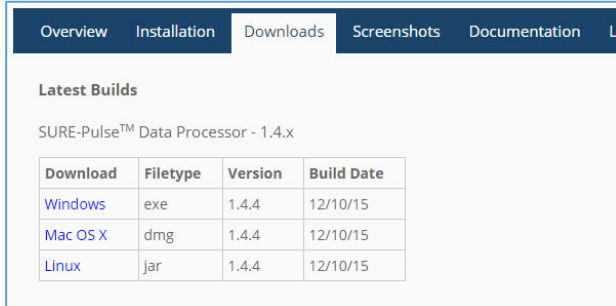
Operating Systems: Windows 7+, Mac OS X

Runtime: Java SE Runtime Environment 8

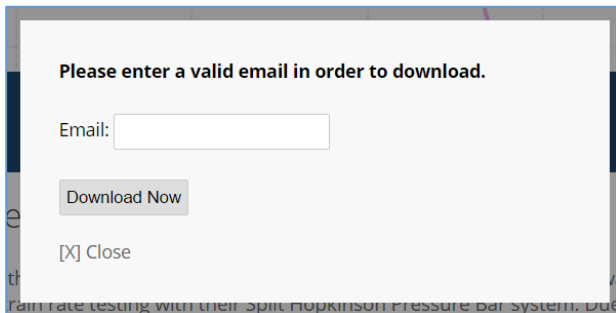
# Software Installation

## 1. Downloading SURE-Pulse™

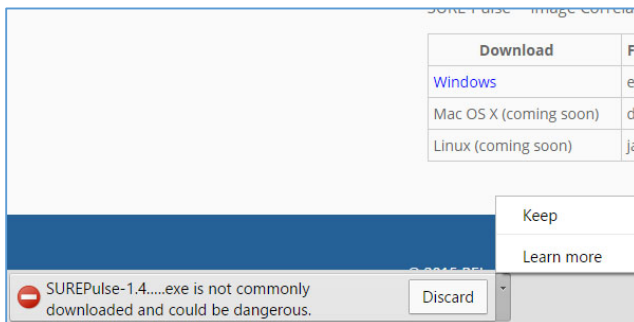
To download *SURE-Pulse™*, visit <http://relinc.net/software>. Click on the “Downloads” tab, and choose the correct link for user’s operating system.



The user will be prompted to enter an email. A valid email address is required to download the built software from the REL website. Enter your email and click “Download Now”. If you wish to exit this window at any time click the “Close” button in the bottom left.

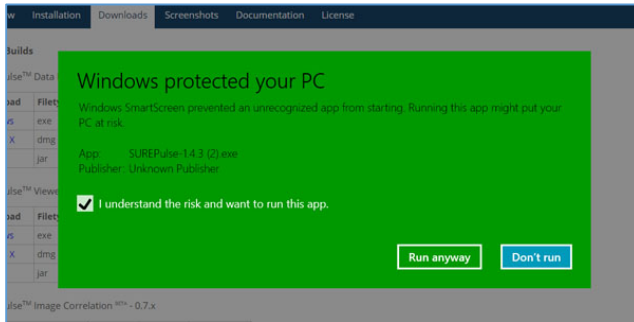


The download will start at this point. Once the download is finished the user may see a warning that the “file is not commonly downloaded and may be unsafe”. If you see this warning please ignore it by selecting to keep the file. The example below illustrates Google Chrome, other browsers appear differently.

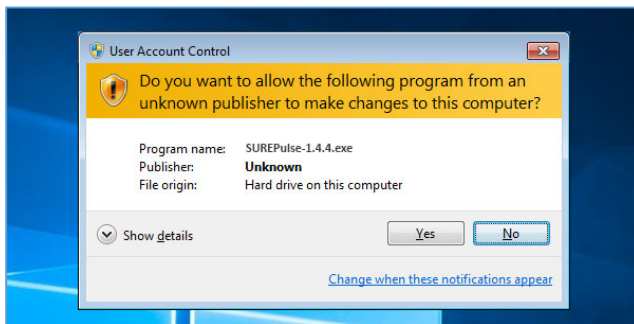


## 2. Installing *SURE-Pulse™*

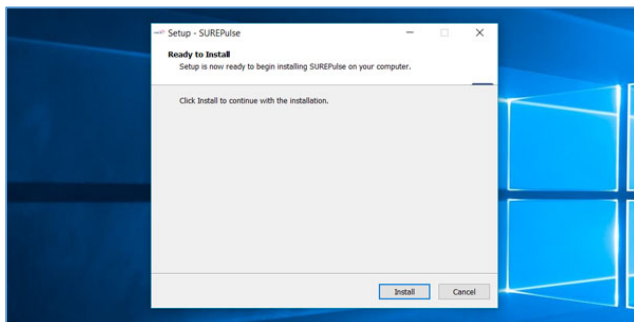
Find the downloaded file and click the file to run it. Again, the user may be prompted with messages from the computer's security system. These messages can change depending on the OS. The message shown in the picture below is Windows 10.



The computer may prompt you to allow the program to make changes to the computer. Click "Yes" to continue the installation. On Mac OS X, the user may be prompted to enter a username and password to give the program the privileges it needs to install.

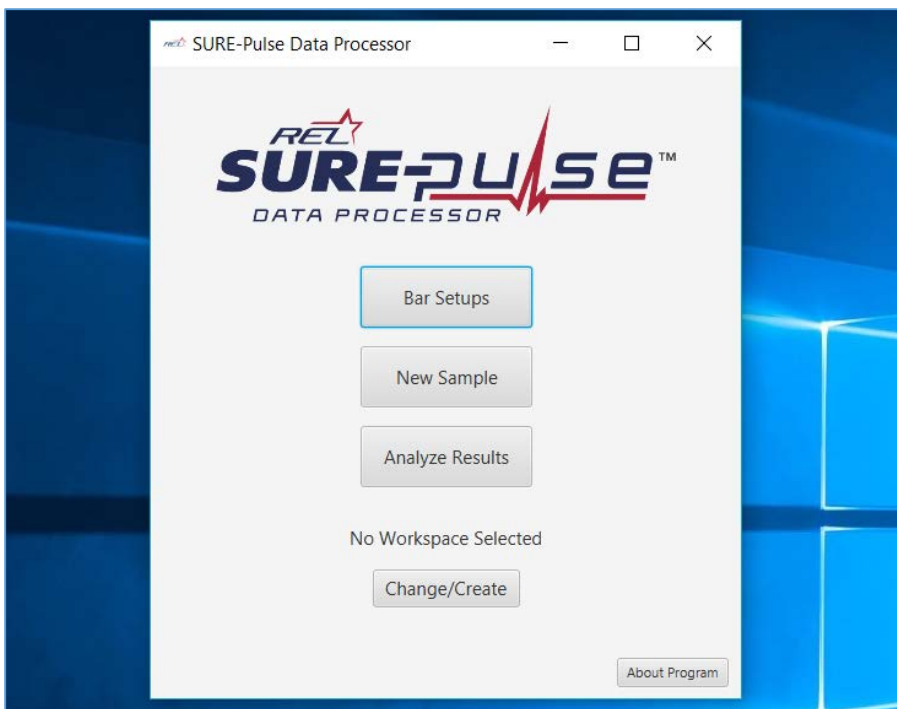
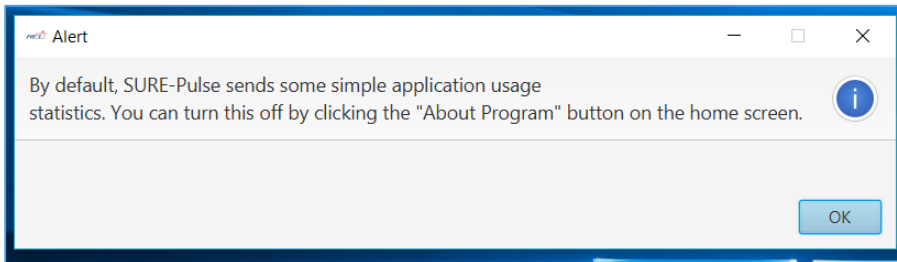


Click "install" on the installer that pops up. The user may be asked to close any running versions of *SURE-Pulse* if a previous version was installed. Follow the directions in setup and click "Finish" when done.



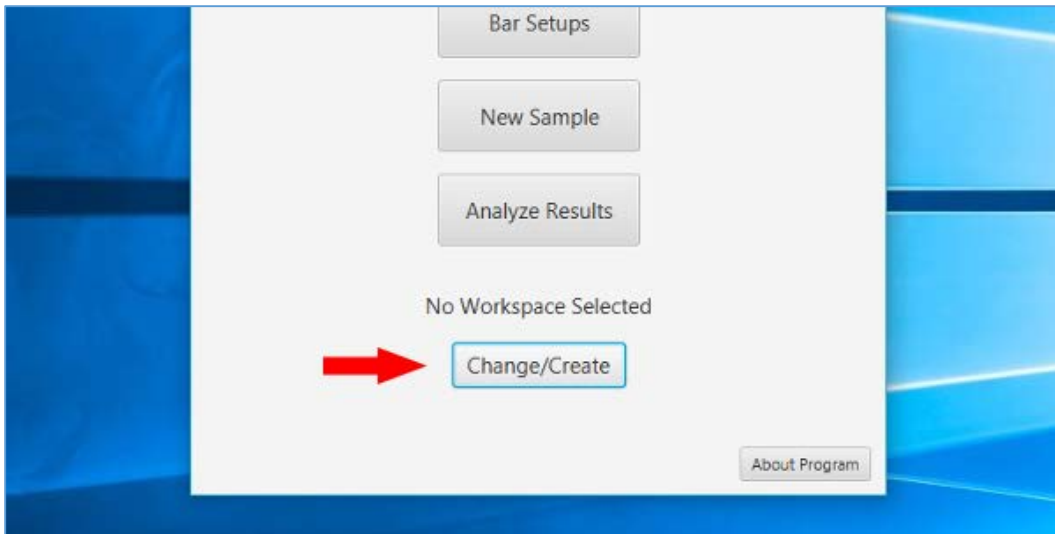
### 3. Running *SURE-Pulse™*

*SURE-Pulse™* should start automatically after it finishes installing. The user will be prompted that *SURE-Pulse* sends usage data. The usage data is useful for *SURE-Pulse* to see how users are using the program and what can be done to improve it. Click the “Ok” button to advance into the program. If you would like to turn off the sending of usage statistics, click the “About Program” button on the main screen and unchecking the box. If you see the screens pictured below, *SURE-Pulse™* has installed correctly and is ready for use. For future launches you can use the shortcut that has been created on your desktop or find the program at C:\Program Files\SUREPulse\SUREPulse.exe (Windows).

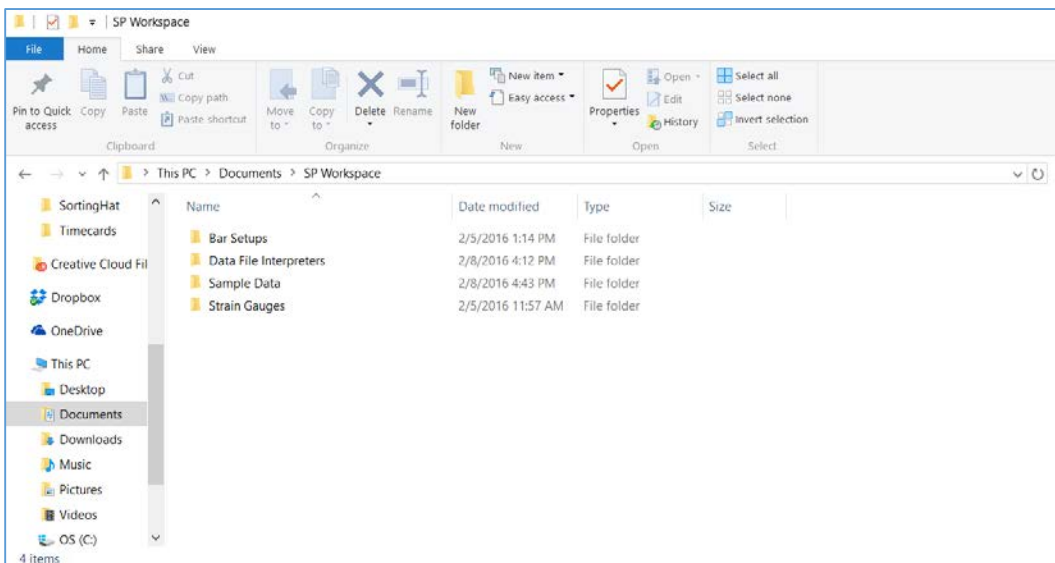


#### 4. Workspaces

The user must choose a workspace before starting program operation. A workspace holds bar setups, sample files, raw data, etc. Any directory can be used as a workspace. It is suggested that the directory be blank to start unless using an existing *SURE-Pulse* workspace. The user can switch between workspaces at any time making it easy to keep your data organized.



The workspace holds all of the saved *SURE-Pulse™* data. There are four folders that will show up in a workspace. These folders are where the respective file types are stored. Workspaces can be transferred across multiple computers and platforms.



## 5. Example Data

The data files referenced and utilized in this manual are available to download at <http://relinc.net/software>. The sample/example data can be useful while learning how to use *SURE-Pulse™*. The data is provided as a zip file. If you wish to use this example data, download the file at the link and extract the file. The data will be referenced throughout this manual.

*NOTE: If you have any problems downloading, installing, or running SURE-Pulse™, please email [softwaresupport@relinc.net](mailto:softwaresupport@relinc.net)*



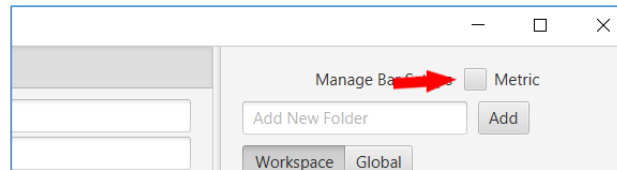
# SURE-Pulse™ Data Processor

## 1. Multi-Screen Functionality

There are a few common functions that the user will see appear on many screens across the software. These functions are explained below:

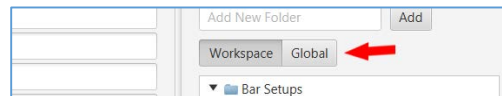
### a. Metric Checkbox

The metric checkbox converts units to metric. The metric checkbox can be checked and unchecked at any time, there is no need to carry this setting across other screens if it is not desired.



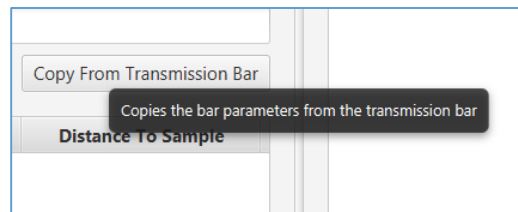
### b. Workspace/Global Selector

The workspace/global selector appears on the bar setup page and the strain gauge page above the file browser. The workspace/global selector allows you to select whether to save/reload the bar setup/strain gauge in your workspace or in the global workspace. The global workspace can be accessed at any time whereas the workspace files will only show up if you are currently using the workspace they are saved in.



### c. Tooltips

There are many tooltips that will appear when you mouse over a button or other control and hold it there for approx. 1 second. The tooltips are there to help explain what the control does.

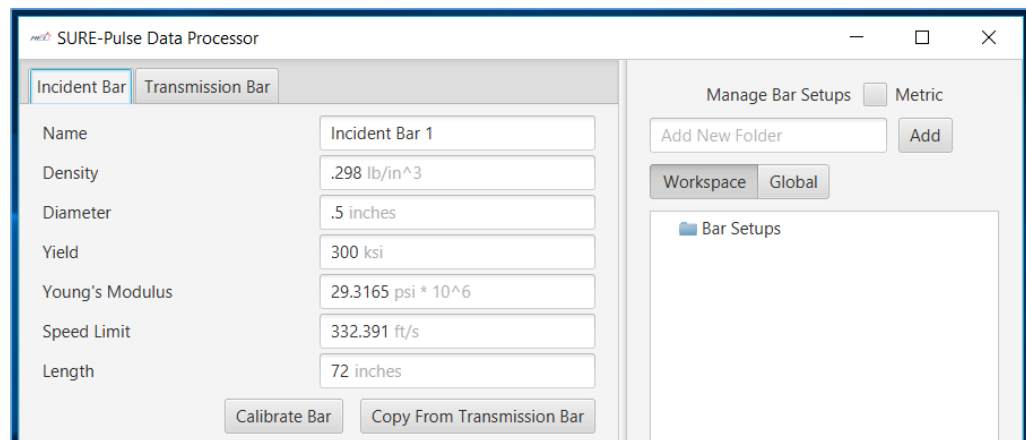


## 2. Creating a Bar Set-Up

Bar set-ups are explicitly used for Split Hopkinson Pressure Bar testing. Typically, the user will test many samples on one bar set-up. Bar set-ups are saved and can easily be re-used for as many test samples as needed.

### a. Setting Parameters

Click the “Bar Setups” button on the main screen. The screen shown below should pop up at this point. The screenshots contain example parameters entered in the text boxes, use these example parameters for learning the software. Actual testing will utilize the users own parameters. Speed limit will be automatically calculated.



#### Parameters:

Density – Material density of the bar

**Diameter\*** – Diameter of the bar

Yield – Material yield of the bar

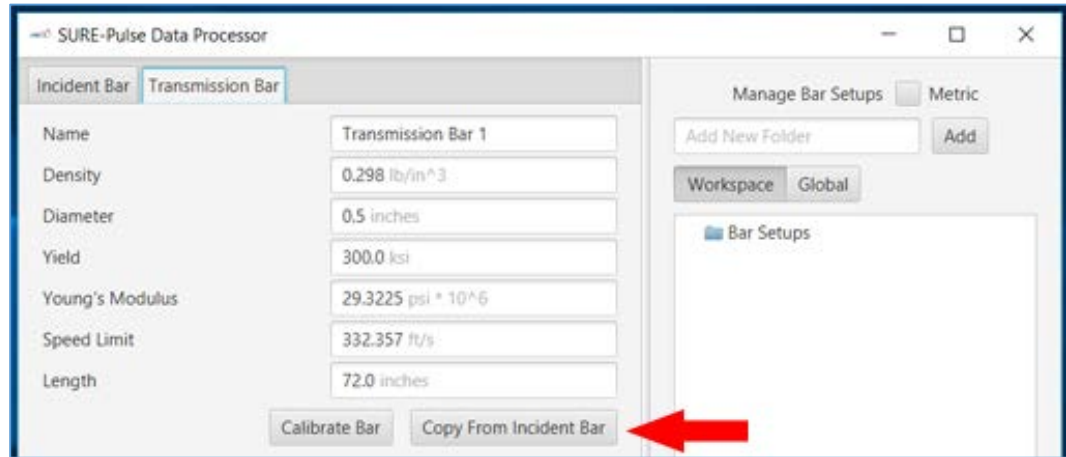
**Young's Modulus\*** – Young's Modulus of the bar

Speed Limit – Calculated speed limit of striker bar for this bar

Length – Length of the bar

*\*Items have direct impact on results*

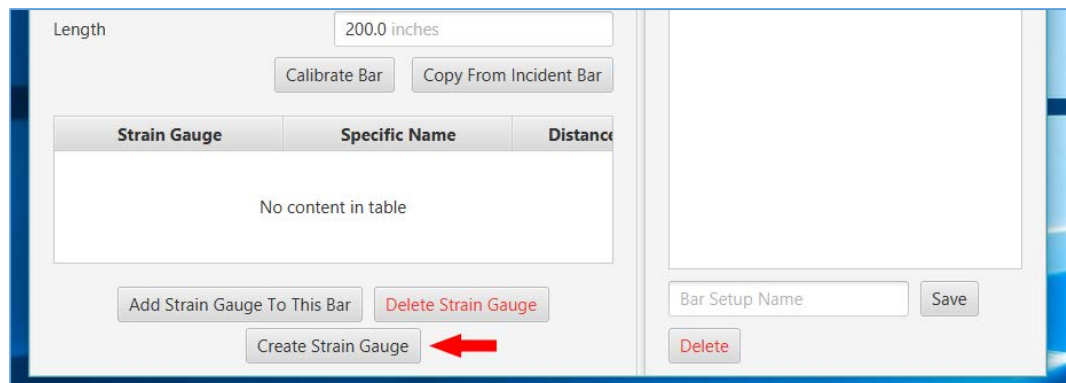
Once the user has entered parameters for the incident bar, click the “Transmission Bar” tab. Enter the correlating parameters. Often parameters will be similar between transmission bar and incident bar. If this is true, click the “Copy From Incident Bar” button and the parameters will automatically populate.



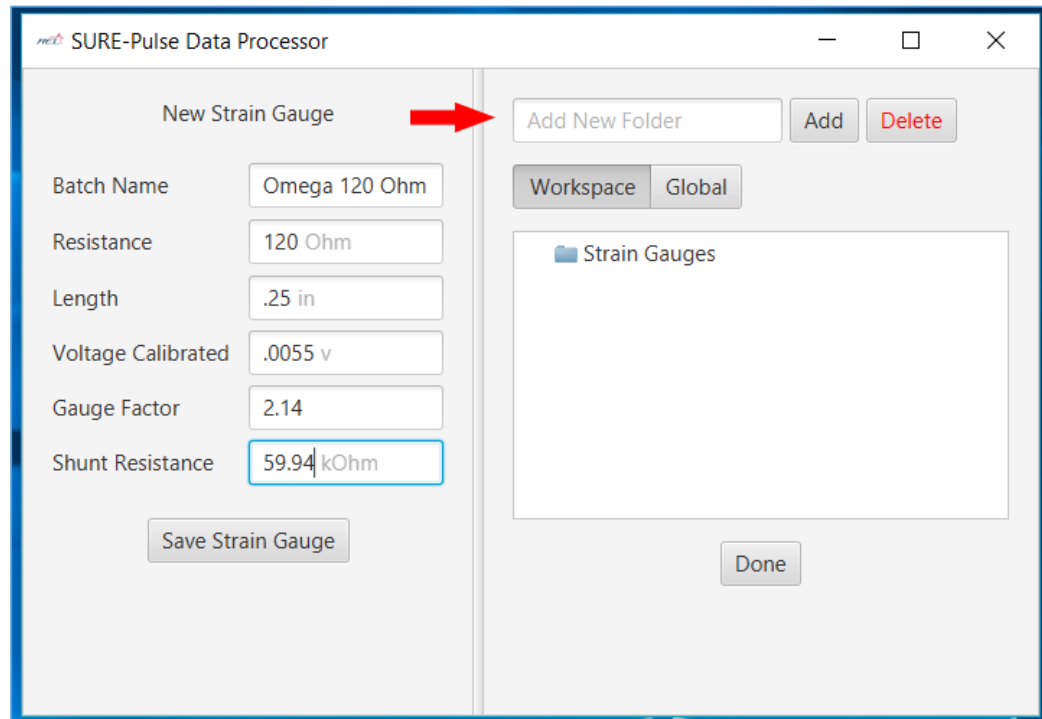
b. Creating Strain Gauges

Typically, the user will have a package of strain gauges with the same properties. The parameters of these strain gauges can be recorded one time in *SURE-Pulse™* and be used on as many bar set-ups as applicable.

To record strain gauge information, click the “Create Strain Gauge” button on the bottom of the bar set-ups page.



Enter the strain gauge information. Please note: the example parameters provided are for learning purposes only, use actual strain gauge parameters for testing. Strain gauges are saved so that they can be reused later. To allow for easy organization, the software allows the user to create a folder structure for your strain gauges. To add a folder type the folder name in the “Folder Name” text box, click the “Strain Gauges” folder, and click Add.



Parameters:

Batch Name – Input the name of your choosing

Resistance – Resistance of strain gauge

Length – Length of strain gauge

Voltage Calibrated\* – Voltage strain gauge was calibrated at

Gauge Factor – Gauge factor of the strain gauge

Shunt Resistance\* – Resistance the strain gauge was calibrated on

*\*See SURE-Test Setup Manual for further description*

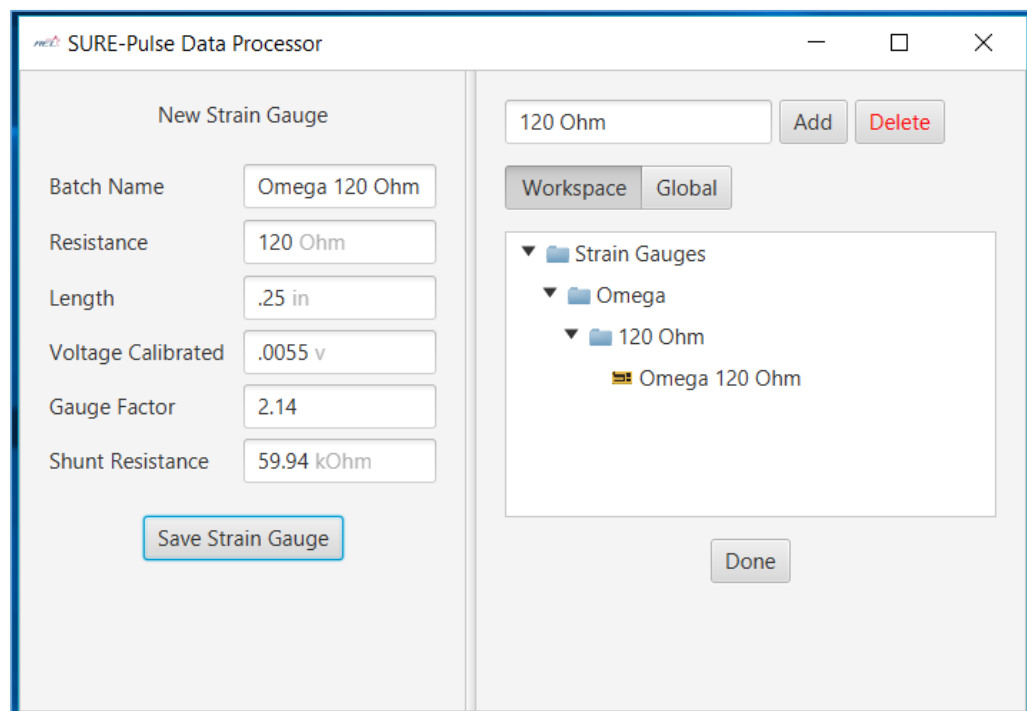
The user is also able to create nested folders for your strain gauges. To do this, click on the folder that you would like to nest your new folder underneath, set name, and click Add.

Once finished creating the folders, click the folder that you would like to save the strain gauge into and click “Save Strain Gauge”. The user will see the strain gauge show up in the folder at this point.

By default the “Workspace” option is selected. You can also select “Global” if you would like to save the strain gauge so that it can be used in any workspace. If you choose the global option, the strain gauge will show up in the global tab no matter what workspace you are using.

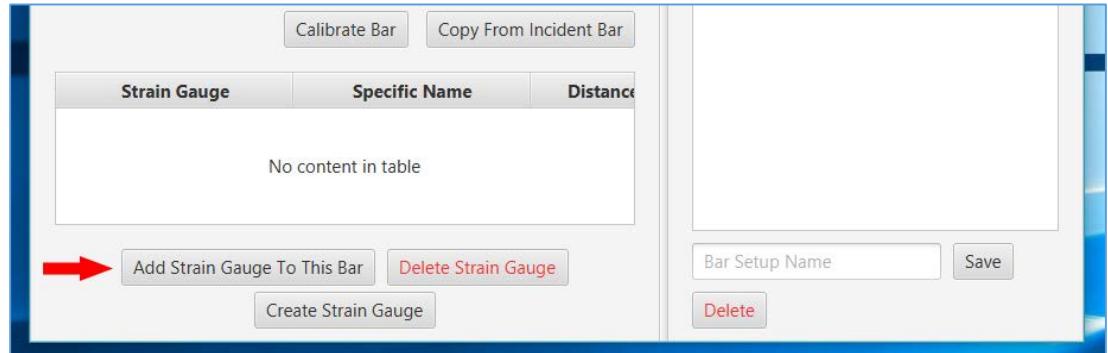
You can create new or delete strain gauges at this time. To delete a strain gauge or an entire folder select the strain gauge or folder that you would like to remove and click the “Delete” button in the top right.

Click the “Done” button when you are finished creating/deleting strain gauges.

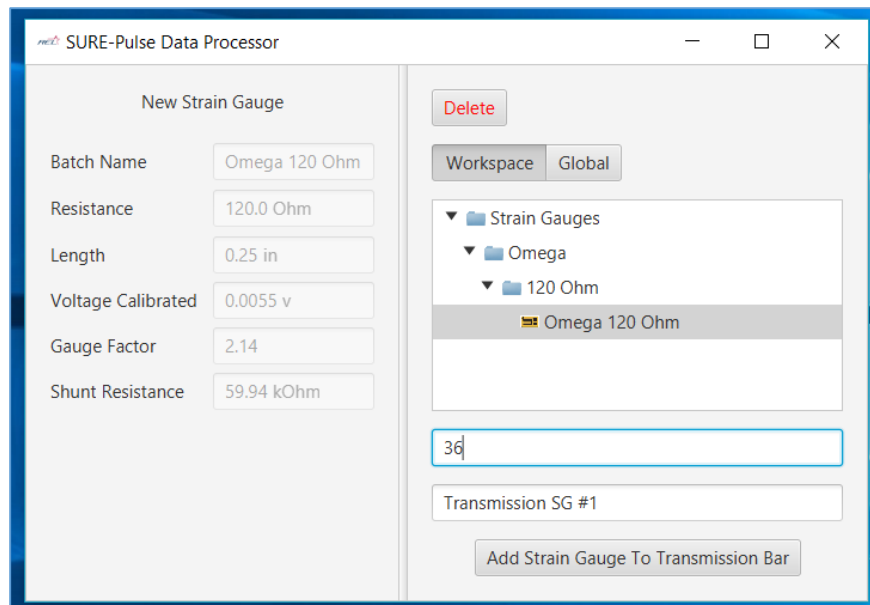


c. Adding a Strain Gauge

When “Adding Strain Gauge,” the user is identifying each gauge on a bar. To add a strain gauge to a bar, click the “Add Strain Gauge To This Bar” button. You must do this separately for each bar in a test set-up.



The user should notice a new window pop up. Select the desired strain gauge from the list on the right. Remember if you saved strain gauge information in global, make sure to choose the global tab. Enter a distance in the “Distance To Sample” field, rename if desired, and click the “Add Strain Gauge To Incident/Transmission Bar” button. Important: when entering a distance one must enter the ACTUAL DISTANCE from the specimen end of the bar to the MIDDLE of the strain gauge.



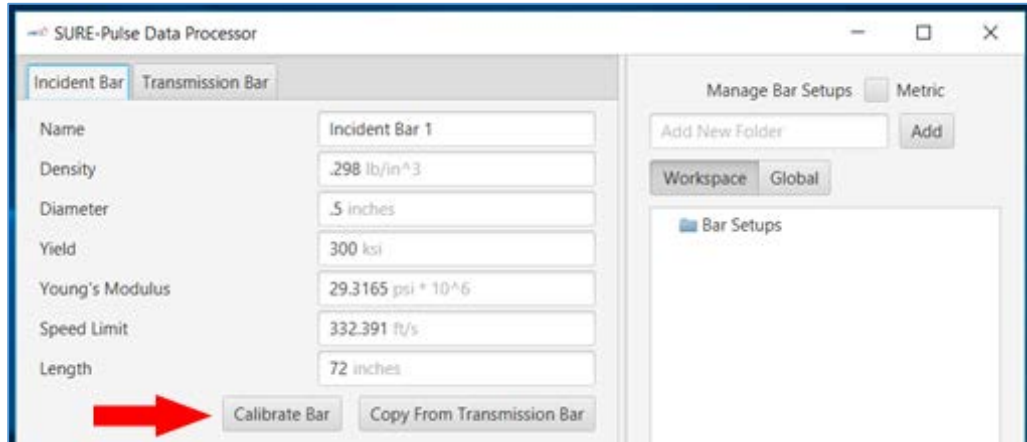
Once the strain gauge has been added, the user should see the strain gauge in the table below the bar set-up parameters. The process can be repeated for the other bar and any additional strain gauges you would like to add.

Speed Limit	<input type="text" value="332.357 ft/s"/>	
Length	<input type="text" value="72.0 inches"/>	
<input type="button" value="Calibrate Bar"/> <input type="button" value="Copy From Incident Bar"/>		
Strain Gauge	Specific Name	Distance To Sample
Omega 120 Ohm	Transmission SG #1	36.0
<input type="button" value="Add Strain Gauge To This Bar"/> <input type="button" value="Delete Strain Gauge"/>		
<input type="button" value="Create Strain Gauge"/>		

d. Bar Calibration (Young's Modulus Finder)

Use this tool to find the Young's Modulus of a bar from a calibration shot.

To calibrate your bar click the "Calibrate Bar" button on the bar set-ups window.



From the bar calibration screen load the data file by clicking the "Load Data" button. For information on loading data, reference section 4.c. Example calibration files are available online at <http://relinc.net/software> on the "Downloads" tab.

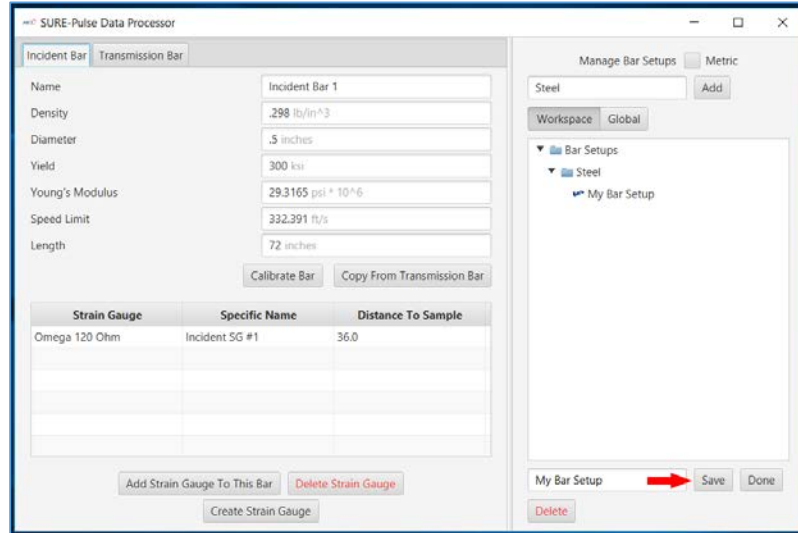


Once the data file has been loaded, drag the noise level slider until the red selection lines are identifying the start of two pulses with known distance between them. The left selection line should be at the beginning of the first pulse and the right selection line should be at the beginning of the second pulse. If done correctly a Young's Modulus will show up on the left. Click "Accept" to transfer the Young's Modulus to the bar set-up parameters.



e. Saving/Deleting Bar Setups

When saving a "Bar Set-Up", the user is identifying a particular set up of equipment used for certain tests. Typically the user is saving an incident bar with an identified gauge/set of gauges and a transmission bar with an identified gauge/set of gauges. As done with the strain gauges, the user can add a folder structure and choose to save the bar set-ups in the workspace or in the global directory. Once the folder structure is created, select the preferred file, name the bar setup, and click the "Save" button.

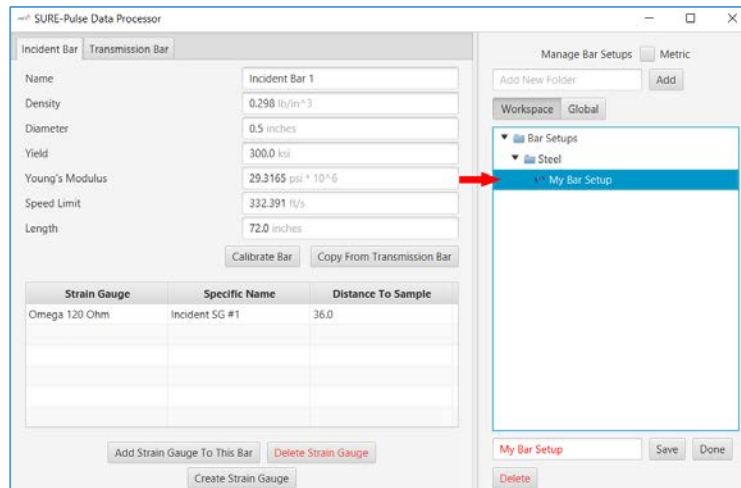


To delete a bar set-up, click on the bar setup you would like to remove and click the delete button on the bottom right.

After all bar set-up(s) are created click the “Done” button in the bottom right.

f. Viewing Previously Saved Data

If at any time it is desired to view or reuse parameters from a previously saved bar set-up, or strain gauge, visit the respective page and click on a bar set-up or strain gauge from the file browser on the right. The parameters will populate with the information you had previously saved. The data can be modified and saved under a new name. The original bar set-up/strain gauge will not be modified unless the same name is used in the same directory.

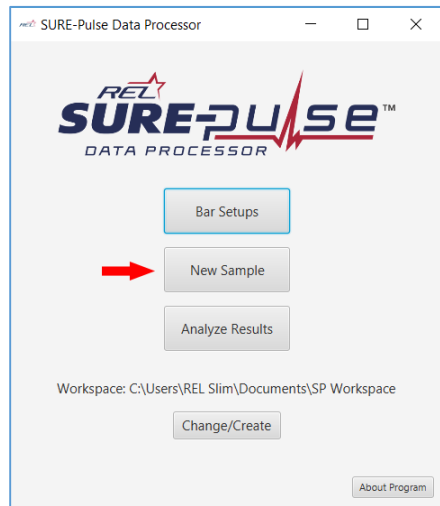


### 3. Creating a Sample

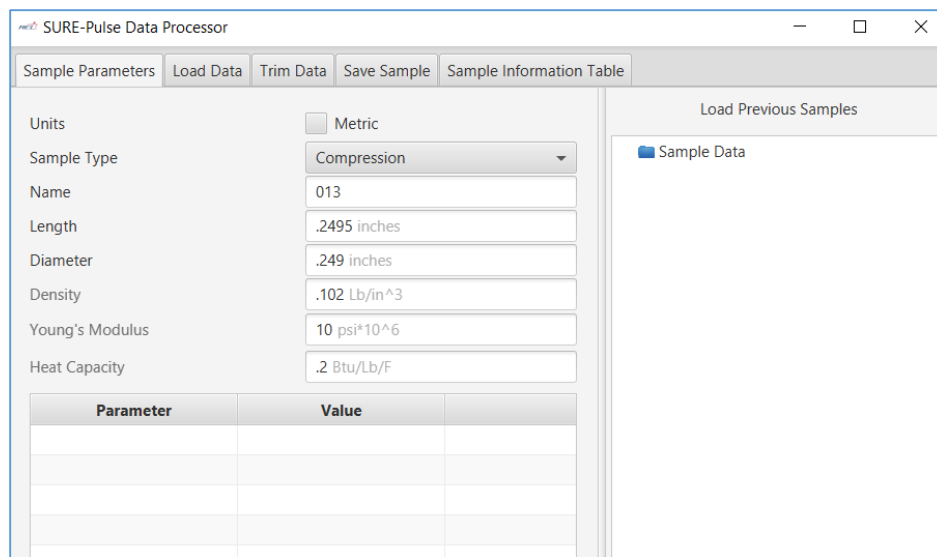
When “Creating A Sample” the user is identifying pertinent information about a test specimen and its test set-up. A sample consists of the sample tested, the bar set-up used, and the data collected. The information will be used for calculations, reference notes, and reporting statistics.

#### a. Setting Sample Parameters

Open the create sample window. Click on the “New Sample” button on the main screen.



Enter sample parameters. The user can use provided example data shown below for learning exercises. When calculating actual test information be sure to use correct parameters.



Sample parameters describe the sample that was tested. The user can also set custom parameters/values in the table for recording pertinent information that may not be a value used in typical calculation. The custom parameters are often useful notes for future testing. To add a custom parameter, double click on a cell in the table and type the parameter/value in the text box that appears. You must hit “Enter” to save the custom parameter. The entire table can be cleared by clicking the “Clear All” button below the table. To delete a single row out of the table, click on the row and click “Delete Descriptor”.

Density: .102 Lb/in<sup>3</sup>  
 Young's Modulus: 10 psi\*10<sup>6</sup>  
 Heat Capacity: .2 Btu/Lb/F

Parameter	Value
Pulse Shaper	No

Clear Table    Delete Descriptor

Current Bar Setup: Not Selected

Add Bar Setup    Remove

b. Adding a Bar Set-Up to the Sample

When “adding a Bar-Set Up to the Sample”, the user is identifying which strain gauge of the system was used to record each set of data. When identifying bar set-up in future steps, the user will be required to select the strain gauge from the bar set-up. The strain gauge and other bar setup parameters are used in calculations.

To add a bar set-up to the sample, click the “Add Bar Setup” button below the custom parameters table.

Density: .102 Lb/in<sup>3</sup>  
 Young's Modulus: 10 psi\*10<sup>6</sup>  
 Heat Capacity: .2 Btu/Lb/F

Parameter	Value
Pulse Shaper	No

Clear Table    Delete Descriptor

Current Bar Setup: Not Selected

**→** Add Bar Setup    Remove

Once the “Add Bar Setup” window is opened, click the desired bar set-up from the file viewer on the right. The information associated with that bar set-up should populate the fields in the window. Click “Add Bar Setup To Sample” button to add the bar set-up to the sample. The bar set-up that is selected should correlate to the equipment used for acquiring the data.

To remove the bar set-up, select the bar set-up you would like to remove, and click the “Remove” button below the bar set-up name on the “Create Sample” window.

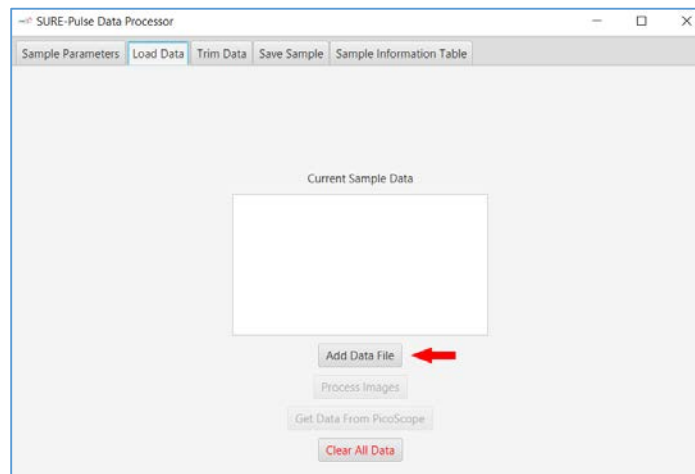
c. Loading Data

The “Load Data” tab is the primary location in *SURE-Pulse* for inputting raw data forms collected through hardware. Here, the raw data will be identified, characterized and categorized based on equipment used to collect it.

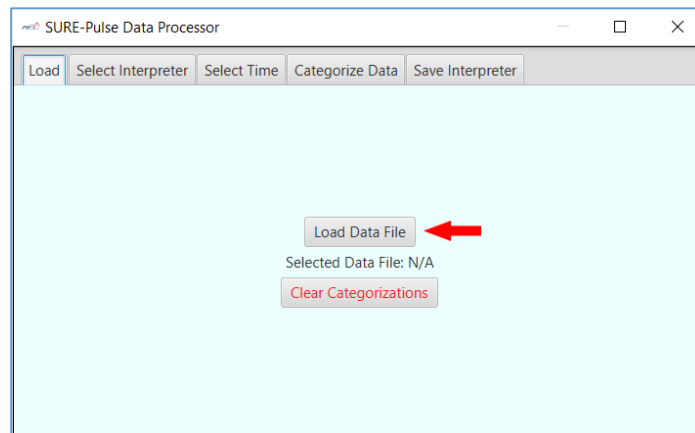
i. Load data from file system

To load data from saved locations of the computer, i.e. oscilloscope data, strain from digital image correlation, etc., click on the “Load Data” tab on the top of the create sample window. Alternatively, you can click the “Next” button when you are on the sample parameters tab.

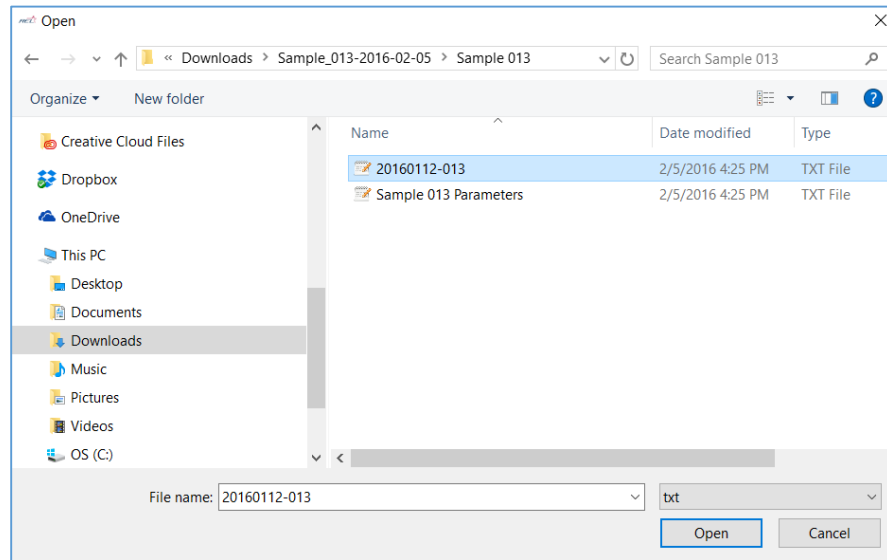
Click on the “Add Data File” button. The “Load Data” window should show up at this time.



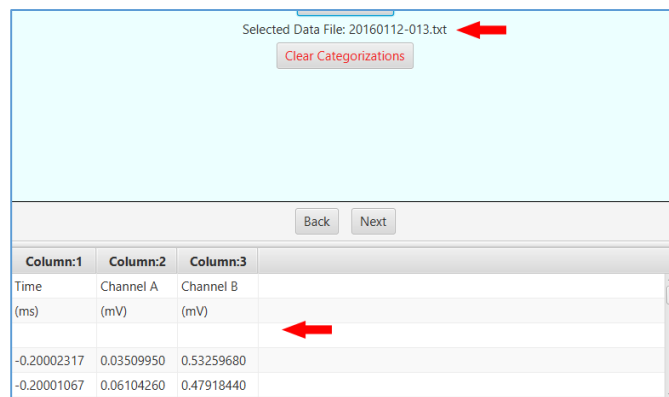
Once the “Load Data File” window is open, click the “Load Data File” button in the middle of the screen.



The “Load Data File” button will open a file browser. Browse for the desired data file and select it. SURE-Pulse will be using the sample data available at <http://relinc.net/software> in this manual. The sample data is for example purposes only, the user will replace this with actual data in a real testing scenario. Supported data file types are .csv (comma separated values) or .txt with values separated by a “tab”. REL will accommodate requests to add new data file formats, if you have a suggestion please send it to [softwaresupport@relinc.net](mailto:softwaresupport@relinc.net).



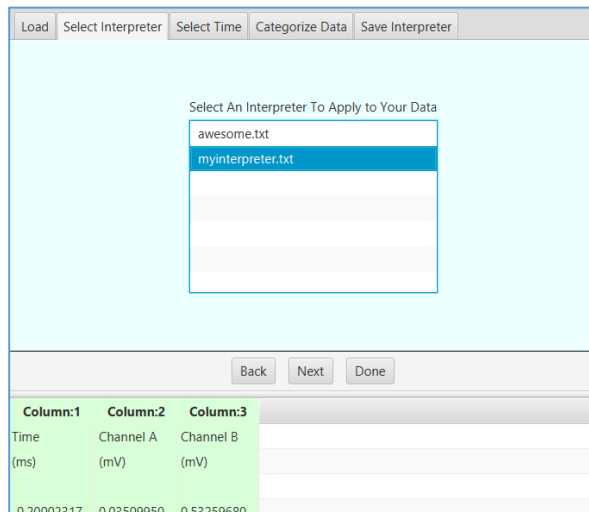
Once the file has been selected, data will populate the table at the bottom of the page. A populated table proves a data file has been imported correctly.



ii. Select an Interpreter

An interpreter is a saved characterization that looks at a data file and is able to automatically categorize the data file, based on previous samples. If many samples of the same type/set-up are entered, rather than manually identifying each set of data, an interpreter will remember the identification. If there are no saved interpreters, move to the next step.

If there are saved interpreters, choose the correlating interpreter from the list in the “Select Interpreter” tab. The interpreter will categorize the data automatically. The columns in the data table should turn green if the correct interpreter was selected. If all of the data is categorized/identified (green), click the “Done” button above the data preview table.



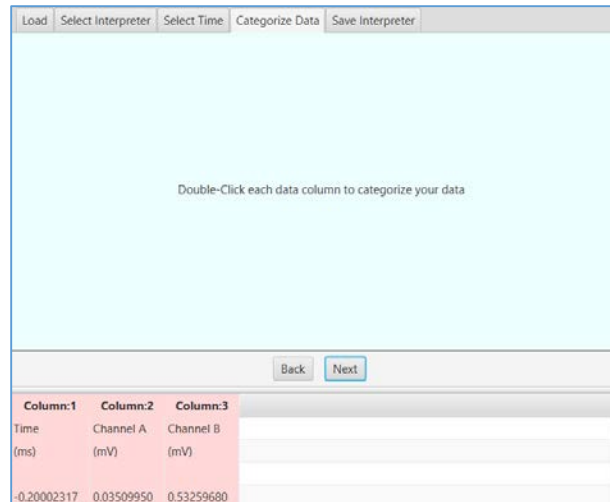
iii. Set Collection Rate

Collection Rate (Frame Rate) is used when identifying camera strain data.

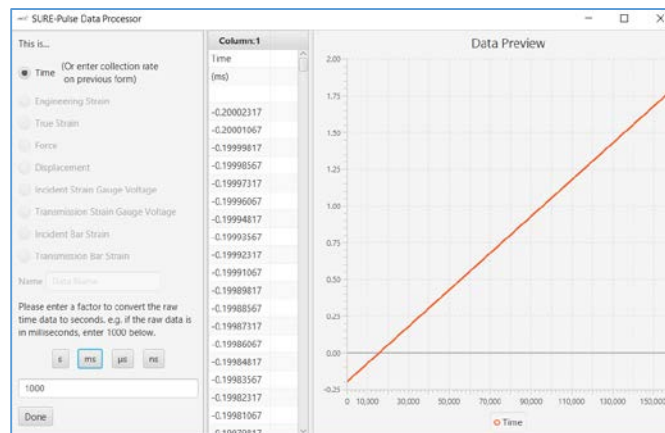
If using data from digital image correlation (d.i.c.) a collection rate is required. Enter the collection rate by clicking on the “Select Time” tab, enter your collection rate, and click “Enter”. If not, move on to the next step.

iv. Categorize Data

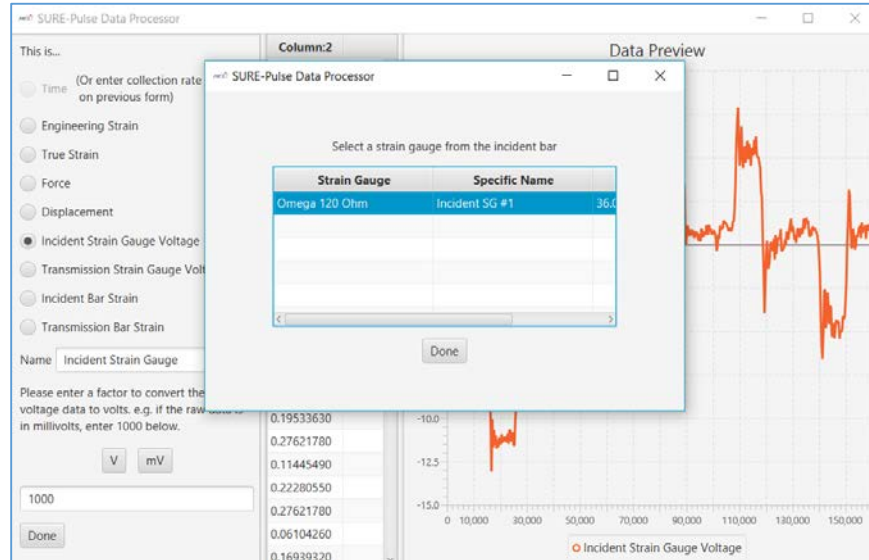
When “Categorizing Data,” the user is identifying which strain gauge correlates to a particular calculation. To categorize data, move to the “Categorize Data” tab and double click on the column you would like to categorize in the data preview table.



The user will be asked what type of data is in the column. The time column OR a collection rate (if using DIC data), must be identified before categorizing other data.

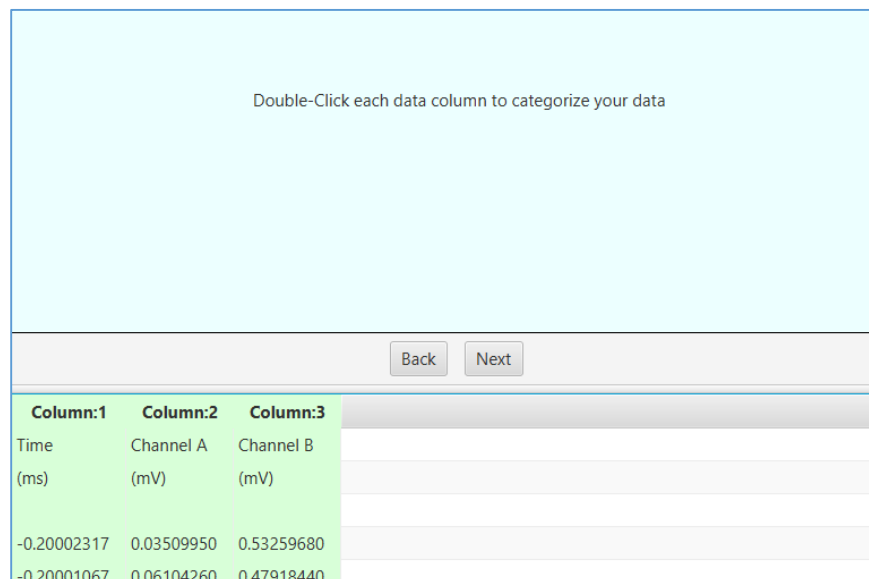


The categories tell the program how to interpret the data. If the data is from strain gauge you will be prompted to select which strain gauge the data corresponds to. The window will show the strain gauges present for the selected bar set-up selected for this sample.



For some data categorizations the user must select proper units. Once finished, click the “Done” button. The column will turn green in the data preview table, indicating that the data has been properly categorized.

Repeat the categorization process for each of the data columns that you would like to include in the calculations.



v. Save an Interpreter

If this particular data categorization is going to be common, create an interpreter file. To create an interpreter file go to the “Save Interpreter” tab, name the interpreter, and click the “Save Interpreter” button. The interpreter will now be useable for future similar data files. NOTE: Only interpreters using one strain gauge on per bar can be saved because of the software’s automatic categorization process.

When finished, click the “Done” button.

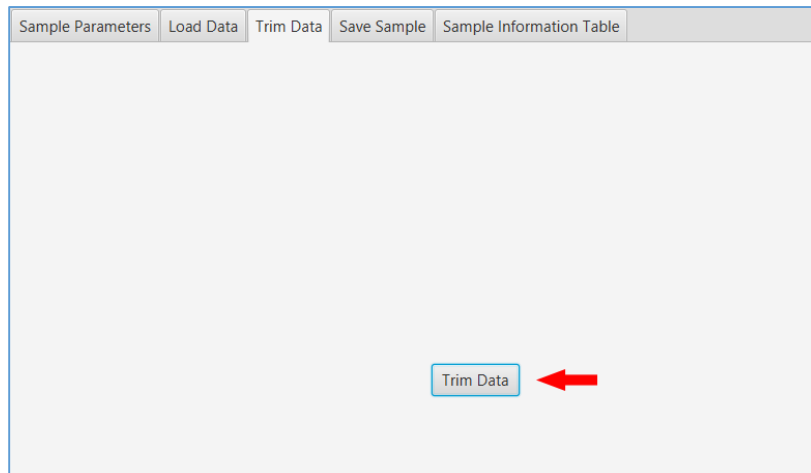
Column:1	Column:2	Column:3
Time (ms)	Channel A (mV)	Channel B (mV)
-0.20002317	0.03509950	0.53259680
-0.20001067	0.06104260	0.47918440

d. Trimming Data

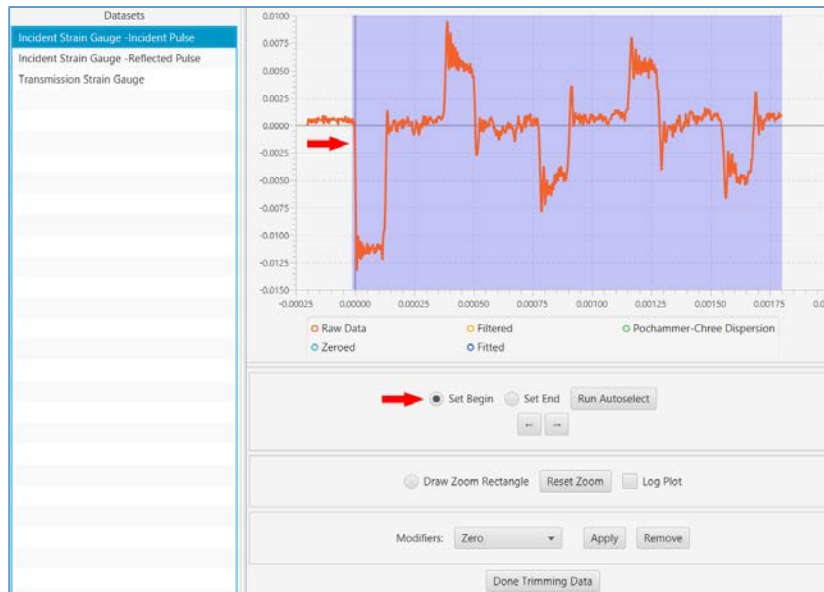
When trimming data, the user is selecting which parts of the raw data forms show pertinent information for calculations. The data can also be filtered, adjusted and saved while trimming.

i. Set Begin and End

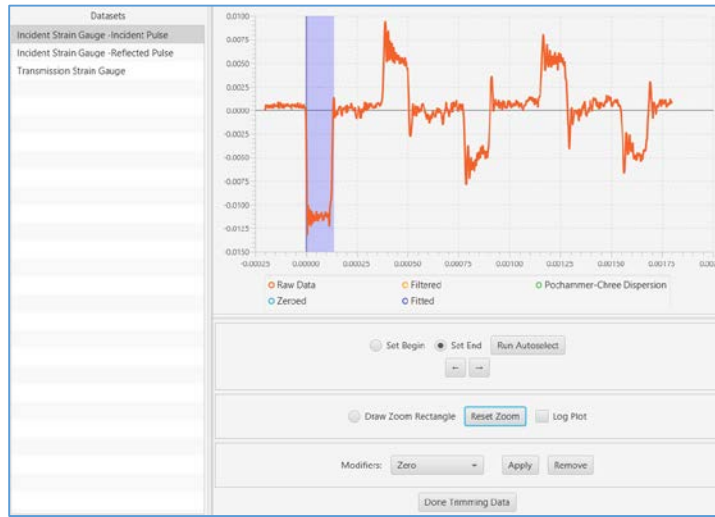
Click the “Trim Data” button on the “Trim Data” tab of the Create Sample page.



Select the data to be trimmed. To set the beginning of your selection click the “Begin” radio button. Then click on the graph where you would like the selection to start.

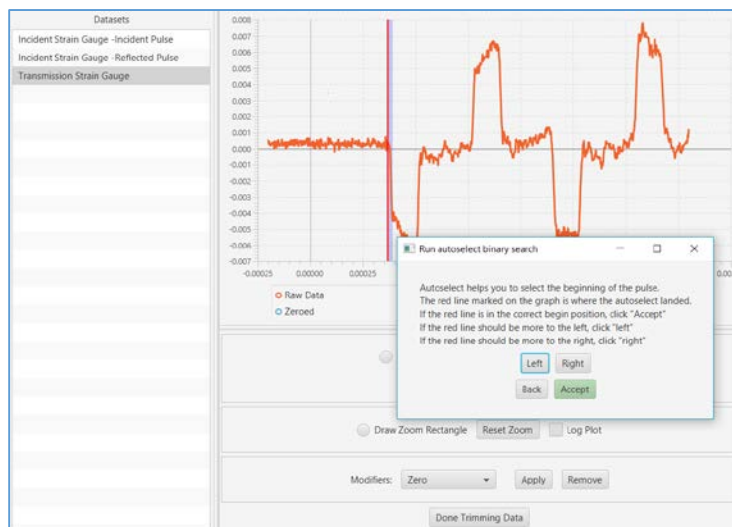


Repeat this process for the end of your selection. The selection will show up with a translucent purple background behind it.



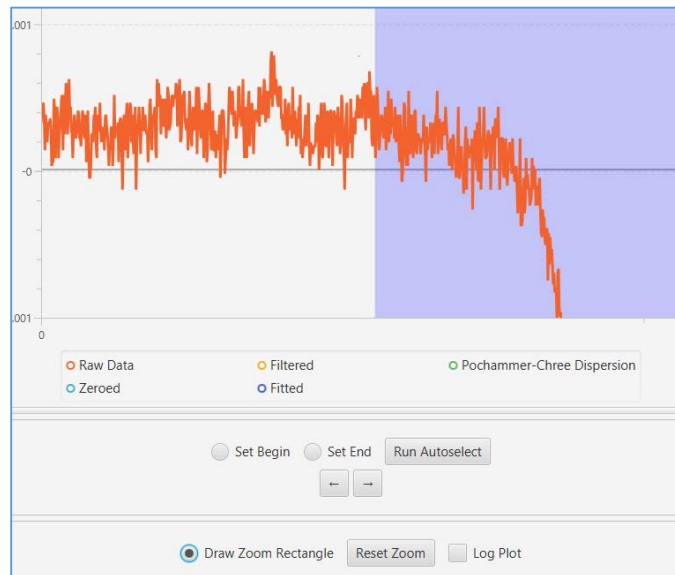
ii. Auto-Select

The Auto-Select tool allows you to easily, more accurately and consistently choose the beginning of your pulse. To run the Auto-Select, initially set your “Begin” to the start of your data. Then click the Auto-Select button, a red line will show up on the graph. Click the “Left/Right” buttons on the Auto-Select screen until you are satisfied with the “Begin” setting and click “Accept”. The “Left/Right” selection is using a change-point detection algorithm to consistently choose the start of an event. Use the zoom-in function to examine the selection. Zoom-In will be discussed in the next section.



iii. Zooming

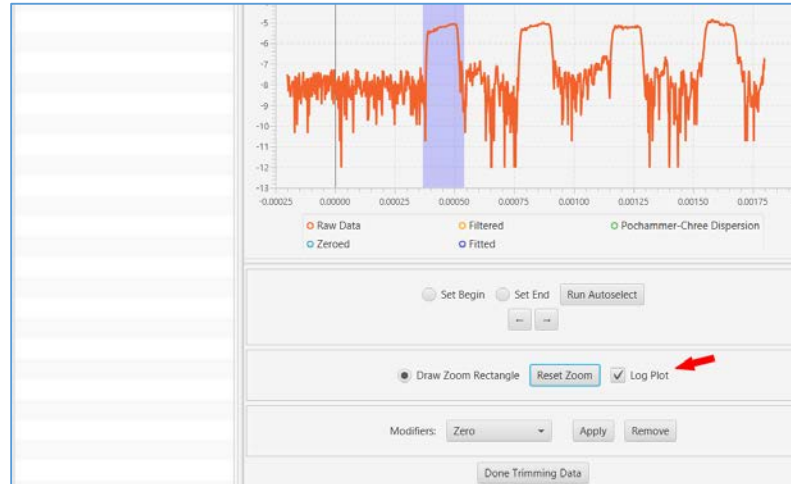
To zoom on the graph, click “Draw Zoom Rectangle” radio button. With the zoom feature, the user can click and drag a rectangle over the graph on the area of interest. Repeat this process as many times as needed to closely examine the data.



To reset the zoom click the “Reset Zoom” button.

iv. Log Plot

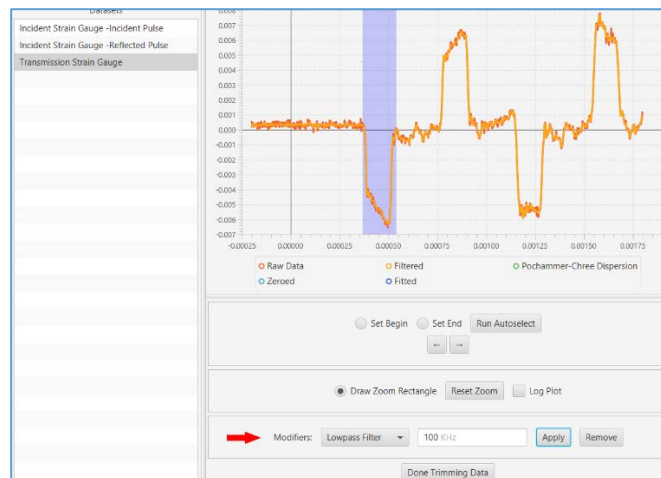
The “Log Plot” shows the log of the data on the graph. The “Log Plot” can be useful in determining the start of an event.



v. Modifiers

There are multiple modifiers that can be applied to data. The zero modifier, for example, allows you to zero out your data if there is a visible offset on the y-axis (typically a DC voltage offset). To apply a modifier, choose the modifier you would like to apply from the dropdown list and click the “Apply” button.

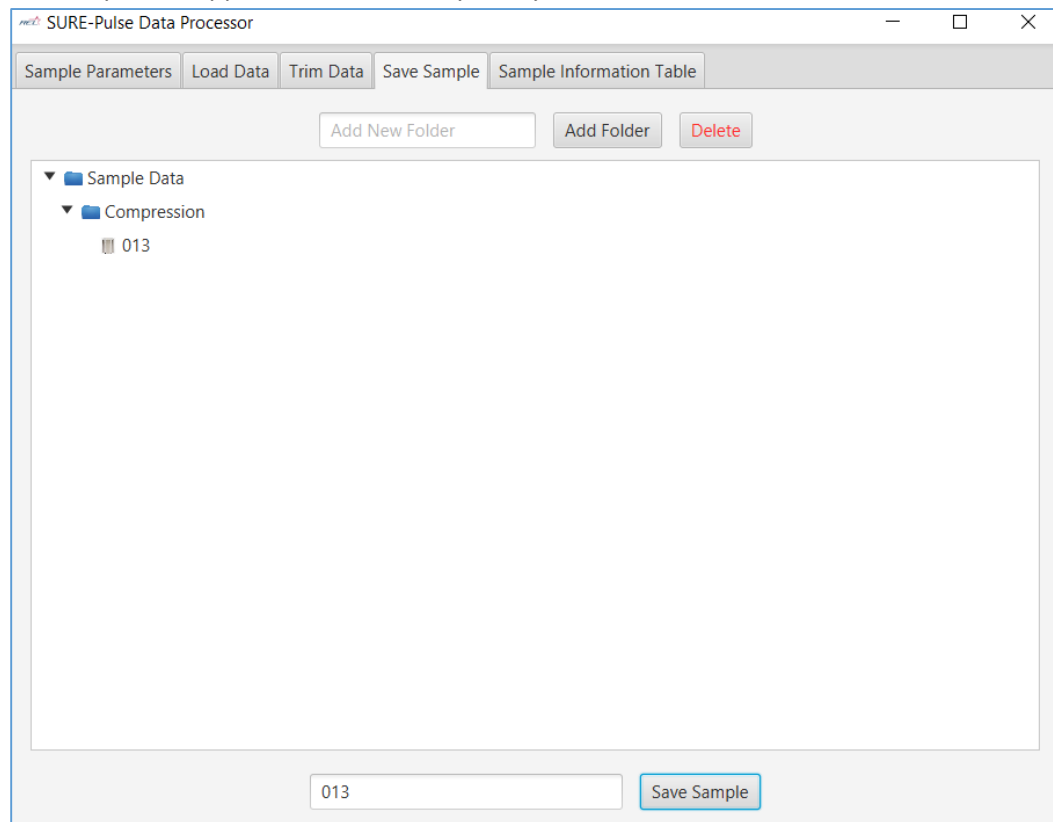
To remove a modifier, choose the modifier you would like to remove from the list and click the “Remove” button.



e. Save a Sample

When saving a sample the user is saving all of the parameters, notes and selections used in the data section/identification process. These saved samples will be located in the directory. In order to save a sample, click the “Save Sample” tab on the “New Sample” screen. Folder structures can be created in the same manner as in bar set-ups and strain gauge folders. Name the sample and click “Save”.

A confirmation dialog saying that the sample has been saved successfully will pop up and the sample will appear in the directory that you saved it into.



f. Sample Information Table

To show the sample information table click on the “Sample Information Table” tab and click the “Refresh” button at the top of the screen. The “Sample Information Table” will show a table of all of the samples in your workspace and their specific parameters.

The table can be exported to .csv by clicking the “Export Data to CSV” button next to the refresh button.

Sample Parameters   Load Data   Trim Data   Save Sample   <b>Sample Information Table</b>								
<input type="button" value="Refresh"/> <input type="button" value="Export To CSV"/>								
	A	B	C	D	E	F	G	H
1	Sample Name	Type	Density	Young's Modulus	Heat Capacity	Length	Diameter	Pulse Shaper
2	013	Compression Sample	0.102	10.0	0.2	0.249	0.249	No
<input type="button" value="← Back"/> <input type="button" value="Done"/> <input type="button" value="Analyze Results"/> <input type="button" value="Clear All"/> <input type="button" value="Create New Sample"/>								

g. Loading Previously Saved Samples

To load a previously saved sample click on the desired sample in the list on the right side of the “Sample Parameters” tab. Modify this information and save it as desired.

The screenshot shows the 'Sample Parameters' software interface. At the top, there are tabs: 'Sample Parameters', 'Load Data', 'Trim Data', 'Save Sample', and 'Sample Information Table'. The 'Sample Parameters' tab is active.

On the left side, there is a form for entering sample parameters:

- Units:  Metric
- Sample Type: Compression (dropdown)
- Name: 013
- Length: 0.2495 inches
- Diameter: 0.249 inches
- Density: 0.102 Lb/in<sup>3</sup>
- Young's Modulus: 10.0 psi\*10<sup>6</sup>
- Heat Capacity: 0.2 Btu/Lb/F

Below the form is a table with columns 'Parameter' and 'Value':

Parameter	Value
Pulse Shaper	No

At the bottom of the form are buttons: 'Clear Table', 'Delete Descriptor', 'Add Bar Setup', and 'Remove'. Below these buttons, it says 'Current Bar Setup: My Bar Setup'.

On the right side, there is a panel titled 'Load Previous Samples'. It contains a tree view with 'Sample Data' and 'Compression' folders. Under 'Compression', there is a list of samples, with '013' selected and highlighted in blue. A red arrow points to the '013' entry in this list.



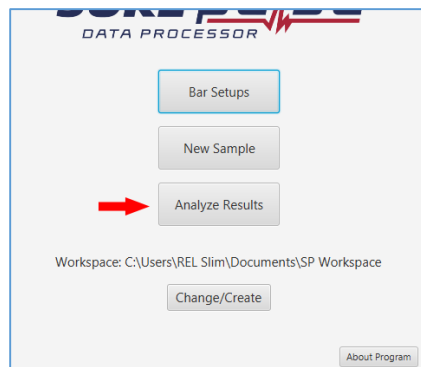
## SURE-Pulse™ Viewer

## 1. Viewing Results

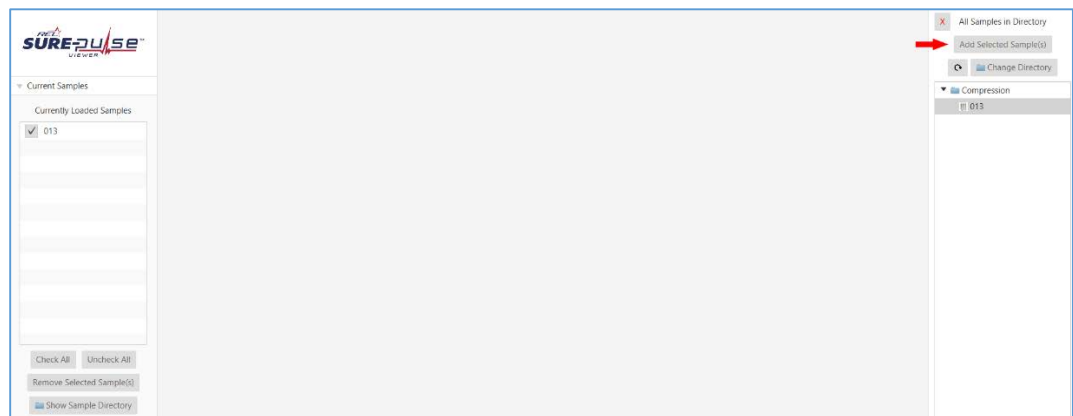
The *Data Viewer* portion of the software can be used independently of the *SURE-Pulse Data Processor*. If used as a sharing tool, the software should be downloaded and data can be shared by sharing directories. The selections, modifiers and notes will be shared with the directory as well. The sharing tool will help both parties understand set-ups and equipment used.

### a. Selecting Samples

Click the “Analyze Results” button on either the main screen or the “New Sample Screen” to launch the viewer screen.

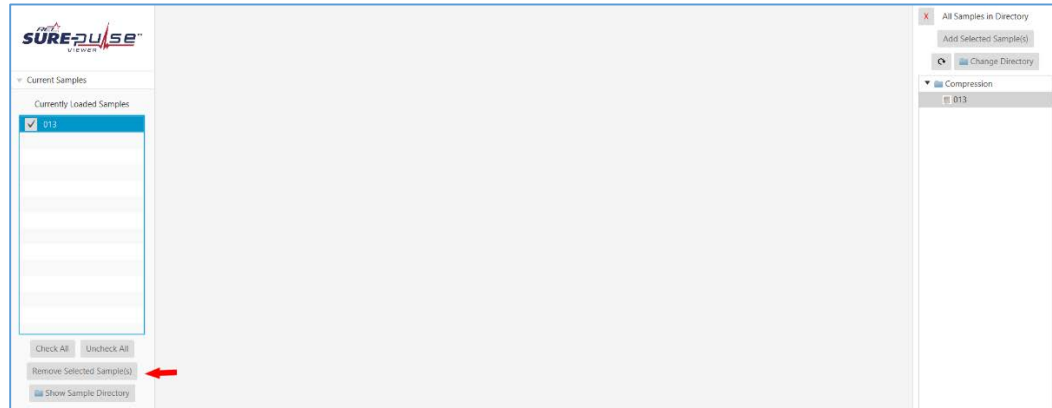


From the viewer screen, choose samples from the sample list on the right, to be analyzed. Click the “Add Selected Sample(s)” button. The samples will appear in the “Currently Loaded Samples” list on the left.



b. Removing Samples

To remove a sample from the “Currently Loaded Samples” list, click on the sample(s) desired to remove and click the “Remove Selected Sample(s)” button. Removing the sample will not delete the sample, it will keep them from showing up in the analyzation window.

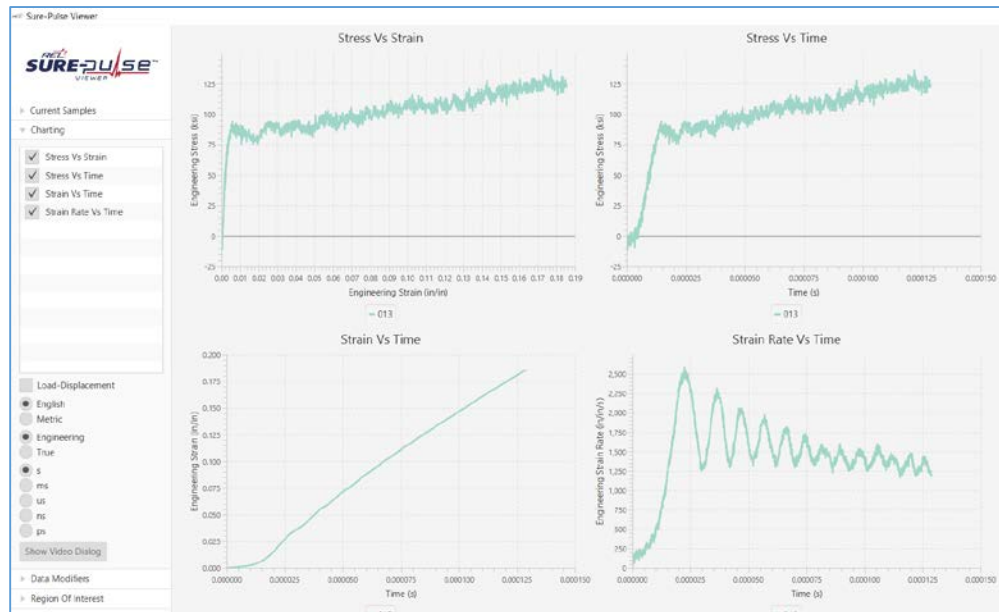


c. Charting

To show charts click on the “Charting Tab” on the left and select the charts of interest.

Charts populated with the data from your selected samples will appear.

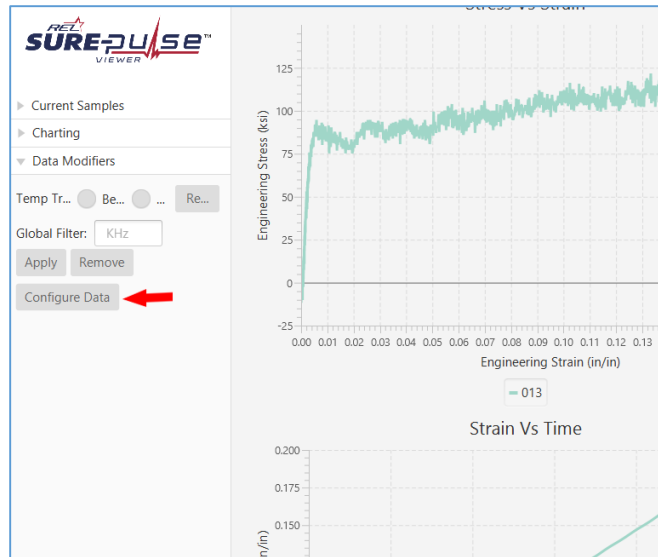
There are options provided in the Charting Window to change units and engineering/true. Choosing an option will automatically update the charts.



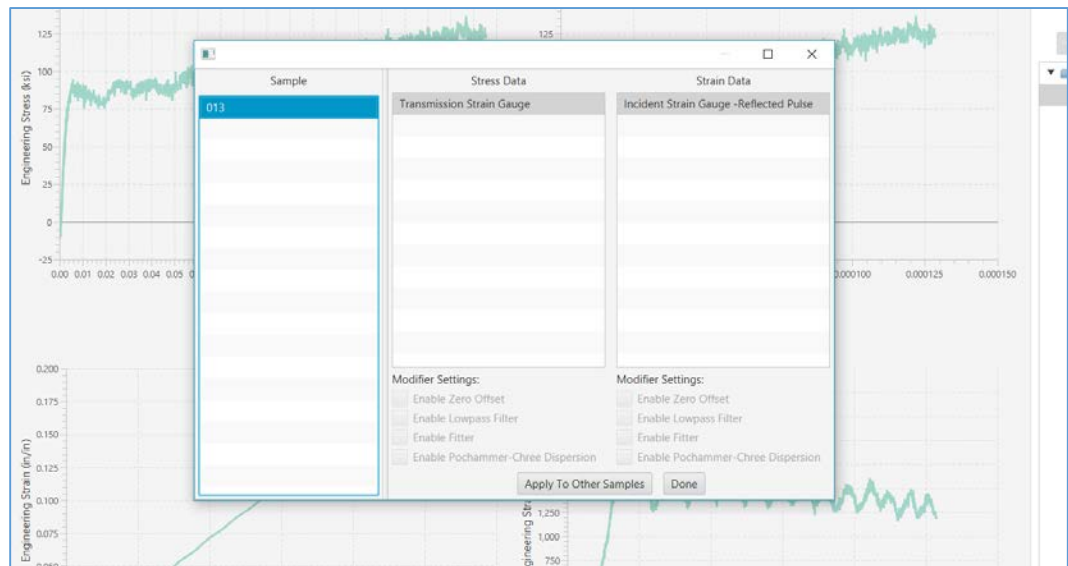
d. Data Modifiers

There are some data modification tools provided in the “Data Modifiers” tab.

If there are multiple strain data sources one will be selected by default. To plot other sources click the “Configure Data” button.

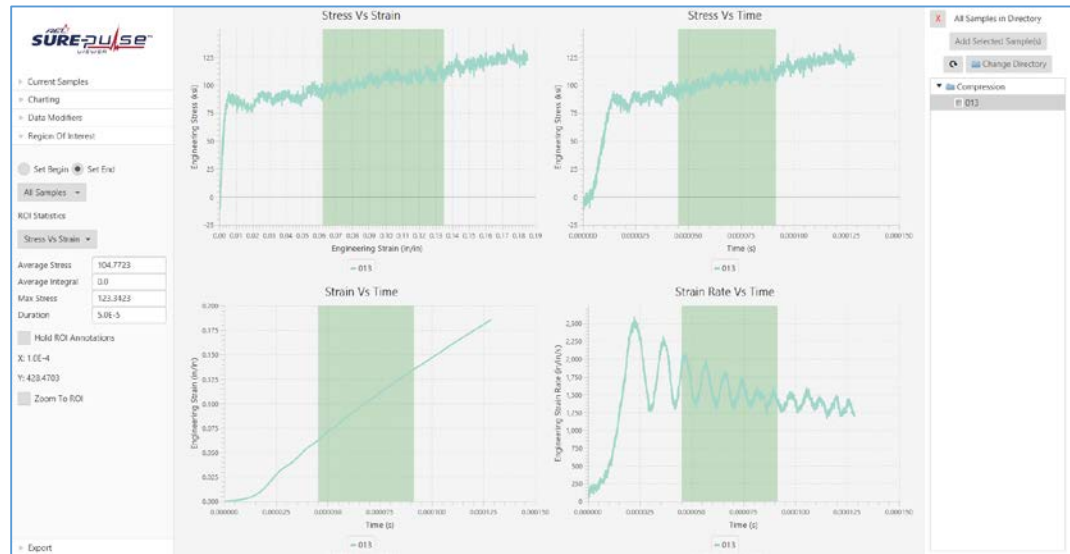


Once the Data Configuration window has launched, choose the data source of interest. Click the “Apply To Other Samples” button and then click the “Done” button. The other data source will now be plotted on the graph.



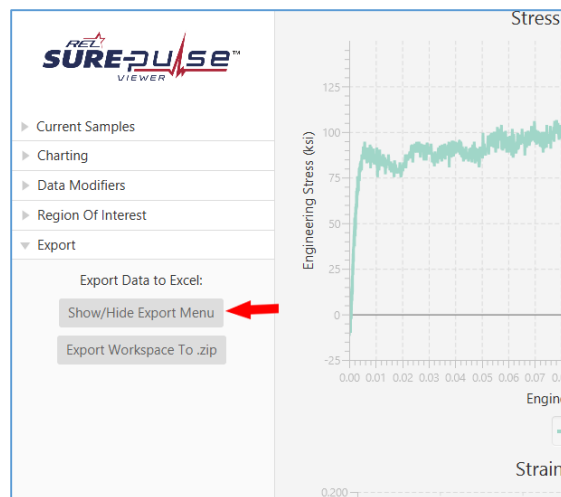
e. Region of Interest

Region of interest allows for quick calculations over a defined region. Set the “Begin” and “End” per trim data instructions in step 4.d.i. Calculations will show in the region of interest tab after a selection is made.

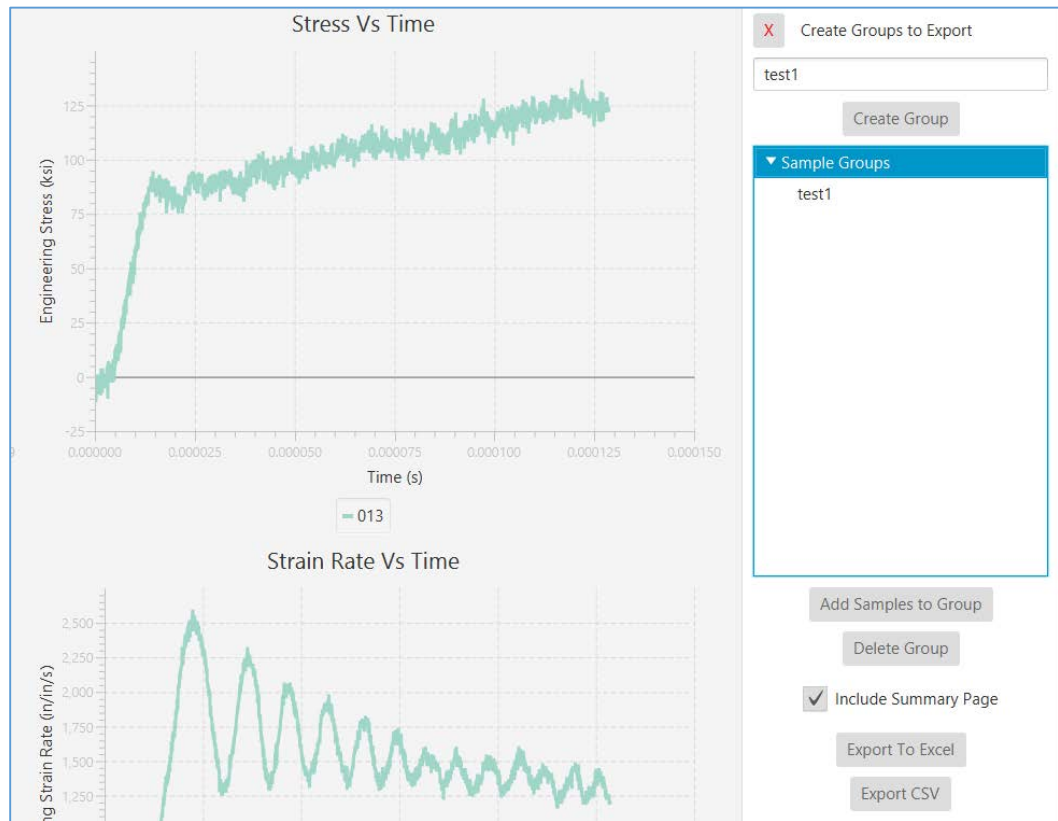


f. Exporting Data

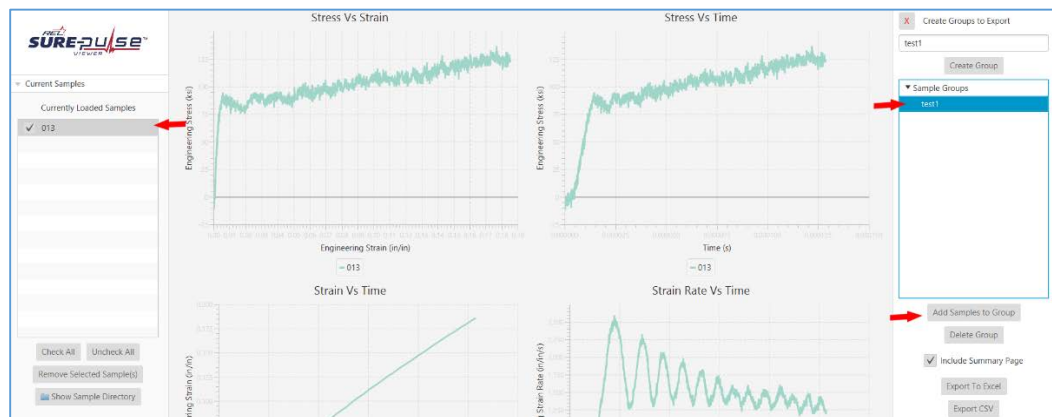
To export data, click the “Export Data” tab from the menu on the left and click the “Show/Hide Export Menu” button.



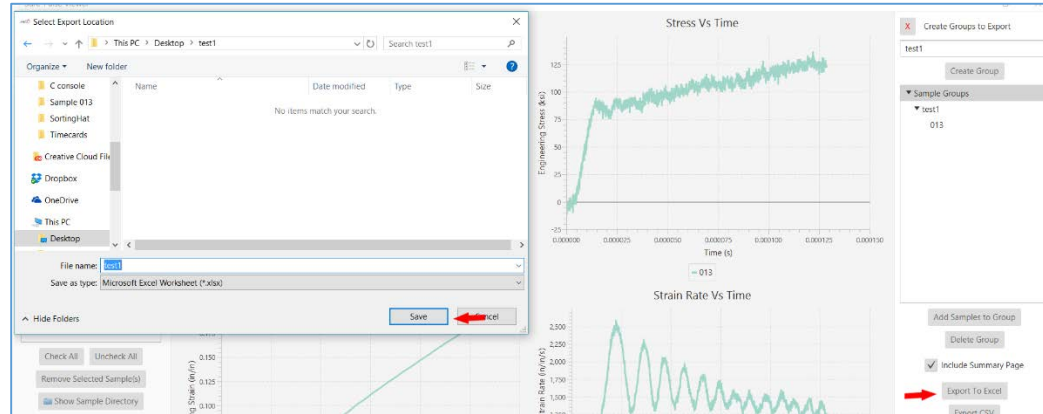
The selected data must be grouped for exporting. To do this, enter a group name in the export menu and click “Create Group”.



Add samples to the group by selecting samples of interest from the “Currently Loaded Samples” list on the left. Highlight the group you would like to add the samples to, and click “Add Samples To Group”. The selected samples will appear in the assigned group.

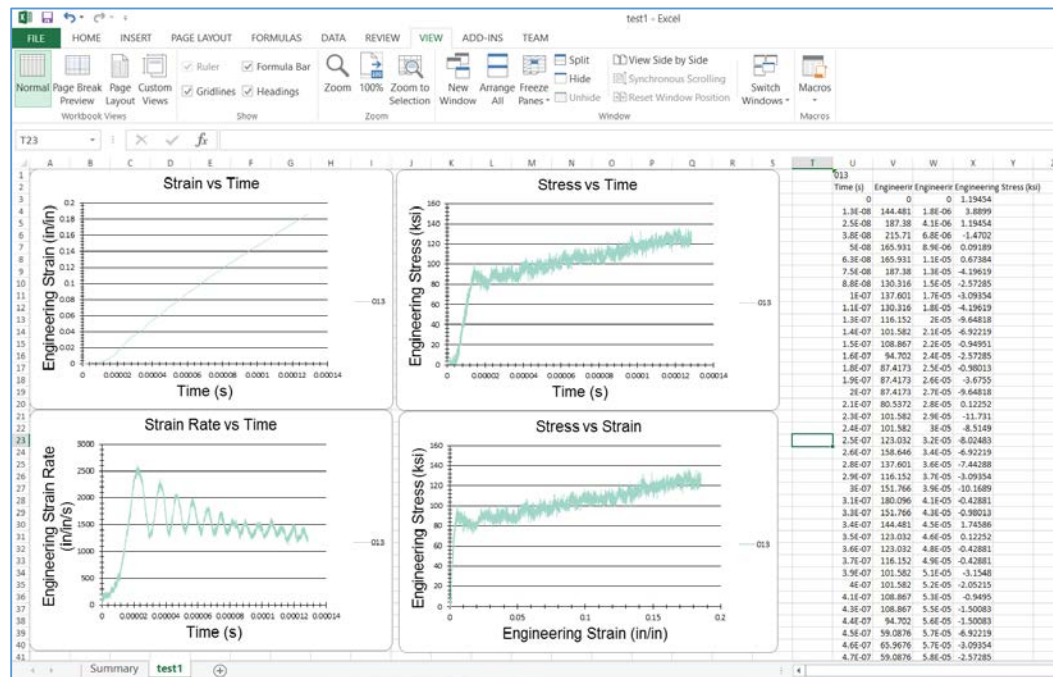


Windows users can select to export the sample to Excel. To export to Excel, click the “Export to Excel” button in the export menu. Choose a location and file name from the window that appears and click “Save”. “Export to CSV” follows the same steps but will export to CSV instead of an Excel file.



Find the exported file in its’ saved location and double click to open the data in Excel.

If the user choses to export a summary page, the first worksheet will display this page. Subsequent worksheets will contain sample groups, graphs, and your exported data.



# Theory, Techniques, and Calculations

## 1. Calculations

SURE-pulse uses several calculations in reaching its results.

### **Young's modulus of bar**

The Young's modulus of the bar is found from the wave speed and the density.

The wave speed is found in the bar calibration by using the distance between the strain gauges and the time between pulses.

$$\text{Wave speed} = \frac{\text{Distance between strain gauges}}{\text{Time Between Pulses}}$$

For example, if the pulse travels a distance of 1 m in 201  $\mu\text{s}$  in a steel bar, the wave speed can be found as follows.

$$\text{Wave speed} = \frac{1 \text{ m}}{201.2 \mu\text{s}} = 4970 \frac{\text{m}}{\text{s}}$$

The Young's modulus is found from the wave speed and density.

$$\text{Youngs Modulus} = \text{Wave Speed}^2 * \text{Density}$$

For example, if the same steel bar that was used above has a density of 8100  $\frac{\text{kg}}{\text{m}^3}$ , the Young's modulus can be found as follows.

$$E = \left(4970 \frac{\text{m}}{\text{s}}\right)^2 * 8100 \frac{\text{kg}}{\text{m}^3} = 200 \text{ GPa}$$

### **Strain calculation in bar**

The strain gauge readings in volts need to be converted into strain. This requires the resistance of the strain gauge, the resistance of a calibrating resistor, the gauge factor of the strain gauge, and the voltage to which system is calibrated. (Vishay Micro-Measurements, 2002) Please read the Vishay manual for further details on strain calculation.

$$\text{Strain} = \frac{\text{Voltage reading}}{\text{Gauge Resistance}} * \frac{1}{\text{Voltage Calibrated} * \text{Gauge Factor} * (\text{Gauge Resistance} + \text{Calibration Resistance})}$$

For example if the voltage reading on the strain gauge is 2V, the gauge resistance is 120  $\Omega$ , the voltage the gauge was calibrated at was 2V, the gauge factor is 2, and the calibrating resistor has a resistance of 59940  $\Omega$  the strain in the bar can be found as follows.

$$\text{Strain} = 2 \text{ V} * \frac{120 \Omega}{2 \text{ V} * 2 * (120 \Omega + 59940 \Omega)} = .001$$

### Sample Stress and Strain Calculations

Force on the sample is equal to the transmitted force in the pulse transmission bar if the sample is in equilibrium. To find the stress in the sample, the ratio of areas of the bar and the sample is multiplied by the stress in the bar.

$$\sigma_{sample}(t) = \frac{\text{Cross Sectional Area Of Bar}}{\text{Cross Sectional Area Of Sample}} E_{\tau} \varepsilon_{\tau}(t)$$

Where  $E_{\tau}$  is the elastic modulus of the transmission bar, and  $\varepsilon_{\tau}(t)$  is the strain in the transmission bar at time  $t$ .

For example, with the a 2 cm steel bar and a cylindrical sample with a diameter of .5 cm, for a strain of .001 in the transmission bar, the corresponding stress in the sample can be found as follows.

$$\sigma_{sample}(t) = \frac{.00314 \text{ m}^2}{.0000196 \text{ m}^2} * 200 \text{ GPa} * .001 = 800 \text{ MPa}$$

The strain rate of the sample  $\dot{\varepsilon}_{sample}(t)$  can be found using one dimensional wave theory and an assumption of equilibrium.

$$\dot{\varepsilon}_{sample}(t) = -2 \frac{\text{Wave Speed Incident Bar}}{\text{Length of Sample}} \varepsilon_r(t)$$

Where  $\varepsilon_r(t)$  is the strain of the reflected pulse in the incident bar at time ( $t$ ).

For example, with the above mentioned steel bar and a sample of 1 cm, for a strain of .001 in the reflected pulse in the incident bar, the corresponding strain in the sample can be found as follows.

$$\dot{\varepsilon}_1(t) = -2 \frac{4970 \frac{\text{m}}{\text{s}}}{.01 \text{ m}} .001 = 994 \frac{1}{\text{s}}$$

Sample strain can be easily found from strain rate using an integral.

$$\varepsilon_{sample}(t) = \int_{t_{begin}}^{t_{end}} \dot{\varepsilon}_{sample}(t) dt$$

Time is indexed from the beginning of the pulses, so the first strain gauge reading that is determined to be in each selected pulse is at  $t = 0$  and is considered to occur at the same time in the sample.

If you assume that the above mentioned strain rate is constant over  $6 \mu\text{s}$ , the sample strain can be found as follows.

$$\varepsilon_1(t) = \int_0^{6 \mu\text{s}} 994 \frac{1}{\text{s}} dt = .05964$$

## Dynamic Force

The force on the back face can be found from the transmitted strain  $\varepsilon_T(t)$

$$\begin{aligned} \text{Back Face Force} &= \text{Area Of Bar} * E_T \varepsilon_T(t) \quad \text{e.g. } .0003142 \text{ m}^2 * 200 \text{ GPa} * .001 \\ &= 62840 \text{ N} \end{aligned}$$

The force on the front face can be found from the difference in the strains of the incident  $\varepsilon_I(t)$  and reflected  $\varepsilon_R(t)$  pulses.

$$\text{Front Face Force} = \text{Area Of Bar} * E_I (\varepsilon_I(t) - \varepsilon_R(t))$$

For example, with a 2 cm steel bar with a Young's modulus of 200 GPa, a strain of .001 on the incident pulse, and a strain of .0009 on the reflected pulse the force on the front face of the sample can be found as follows.

$$.0003142 \text{ m}^2 * 200 \text{ GPa} * (.001 - .0009) = 6284 \text{ N}$$

## Noise Issues

Often the incident bar has a good deal of background noise due to the incident pulse having travelled through the bar. In order to minimize bias in the sample from noise, the voltage of the reflected pulse is adjusted down by the initial voltage.

$$\text{Voltage adjusted} = \text{Voltage Measured} - \text{Voltage baseline}$$

If noise is low (2.5% of signal or less), then the *Voltage baseline*  $\approx 0$  and the result is no adjustment.

## Energy Calculations

Bar alignment and shot quality can be evaluated using energy calculations. If the bars are closely aligned, the energy of the shot should stay level as it travels down the bar. Also, the energy from a non-trapped shot should closely match the energy from the striker bar.

There are two forms of energy in the bar, elastic and kinetic, and both are proportional to  $\varepsilon_B^2$ . More details on these numbers can be found in (Chen & Song, 2011) in the Conventional Bar section. The power travelling through the bar at any point in time can be found with the following equation.

$$\text{Power}(t) = \left( \frac{1}{2} \rho_B A_B C_B^3 + \frac{1}{2} A_B C_B E_B \right) \varepsilon_B^2(t)$$

For example, if you have a 2 cm steel bar that at some point in the pulse experiences a strain of .001, the power at that point can be found as follows.

$$\left( \frac{1}{2} * 8100 \frac{\text{kg}}{\text{m}^3} * .0003142 \text{ m}^2 * \left( 4970 \frac{\text{m}}{\text{s}} \right)^3 + \frac{1}{2} * .0003142 \text{ m}^2 * 4970 \frac{\text{m}}{\text{s}} * 200 \text{ GPa} \right) * (.001)^2 = 312375 \text{ watts}$$

Where  $\rho_B$  is the density of the bar,  $A_B$  is the area of the bar,  $C_B$  is the wave speed of the bar,  $E_B$  is the Young's modulus of the bar, and  $\varepsilon_B$  is the strain in the bar.

**To find the energy of a pulse,** Integrate power over the whole pulse

$$Pulse\ Energy = \int_0^{end\ of\ pulse} Power(t)dt$$

For example, a pulse in the steel bar with a strain of .001 over 60  $\mu s$  can be found as follows using the power calculated above.

$$Pulse\ Energy = \int_0^{60\ \mu s} 312375\ watts\ dt = 18.74\ joules$$

### Number of Reflections

The above equations assume that the sample is in equilibrium, it has been shown (Ravichandran & Subhash, 1994) that 4 reflections of the wave in the sample are necessary to reach equilibrium. The number of reflections in a sample are calculated as follows.

$$Number\ of\ Reflections = \frac{1}{2} \frac{Duration\ of\ Pulse}{l_s/C_s}$$

$$e.g.\ Number\ of\ Reflections = \frac{1}{2} \frac{60\ \mu s}{.01\ m/6420\ \frac{m}{s}(Aluminum)} = 19.3$$

Where the duration of the pulse is the duration of the transmitted pulse,  $l_s$  is the length of the sample, and  $C_s$  is the wave speed of the sample.

### References:

Chen, W., & Song, B. (2011). *Split Hopkinson (Kolsky) Bar*. Springer Science.

Ravichandran, G., & Subhash, G. (1994). Critical Appraisal of Limiting Strain Rates for Compression Testing of Ceramics in a Split Hopkinson Bar. *Journal of American Ceramics*, 263-267.

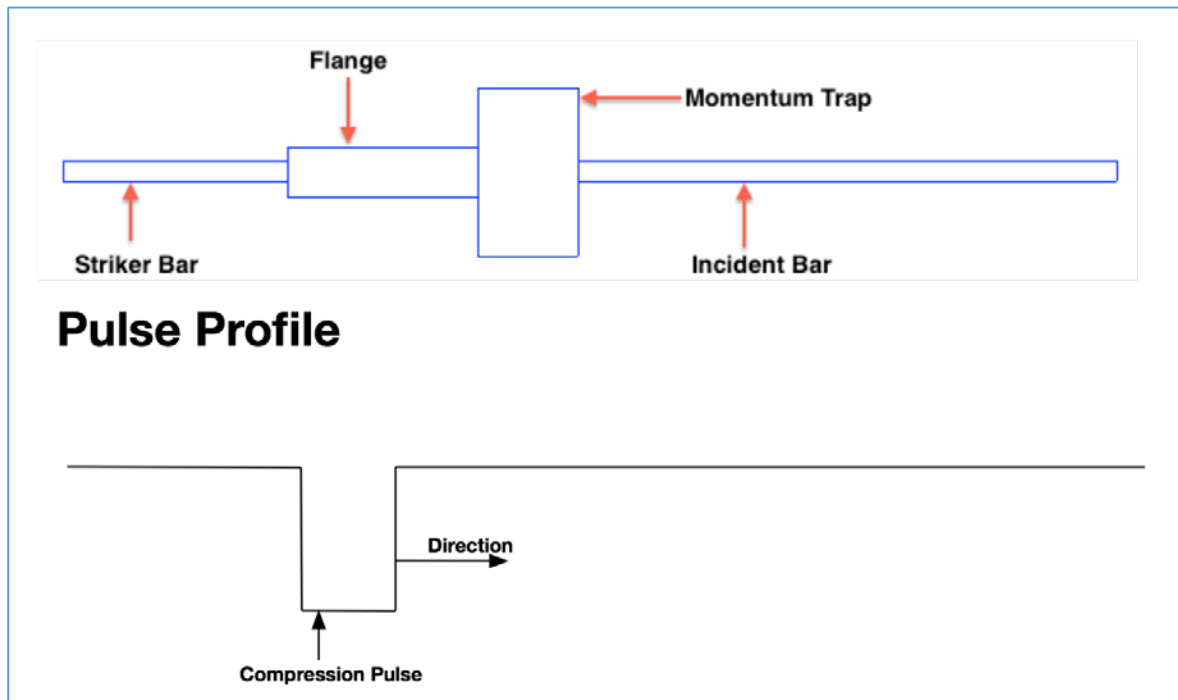
Vishay Micro-Measurements. (2002). *2300 System Signal Conditioning Amplifier 2311 Instruction Manual*. Raleigh: Vishay.

## 2. Momentum Trapping

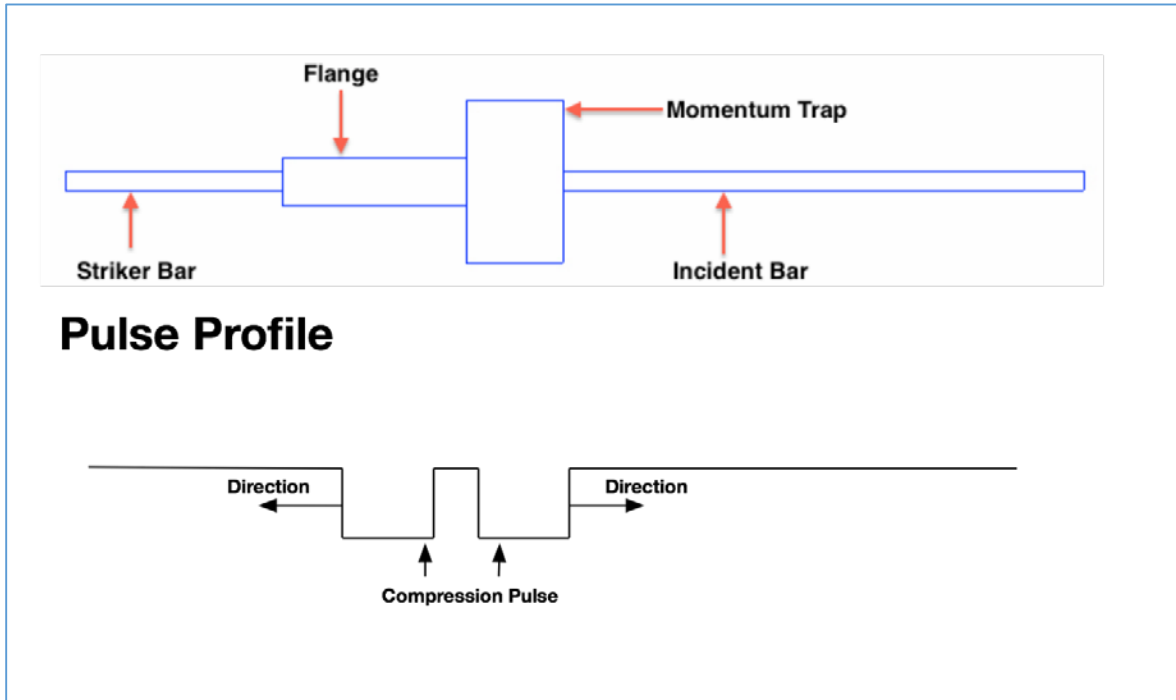
Typically in an untrapped Split Hopkinson Pressure Bar shot, a sample is struck many times by the incident bar, as the energy is transferred from the incident bar into the transmission bar. This crushes the sample beyond the initial deformation. If it is desired to measure the real deformation of the sample after a shot, it is necessary to trap the pulse.

Pulse trapping causes a tension wave to follow the main compression pulse down the bar. This causes the bar to pull away from the sample allowing the sample to only be struck once.

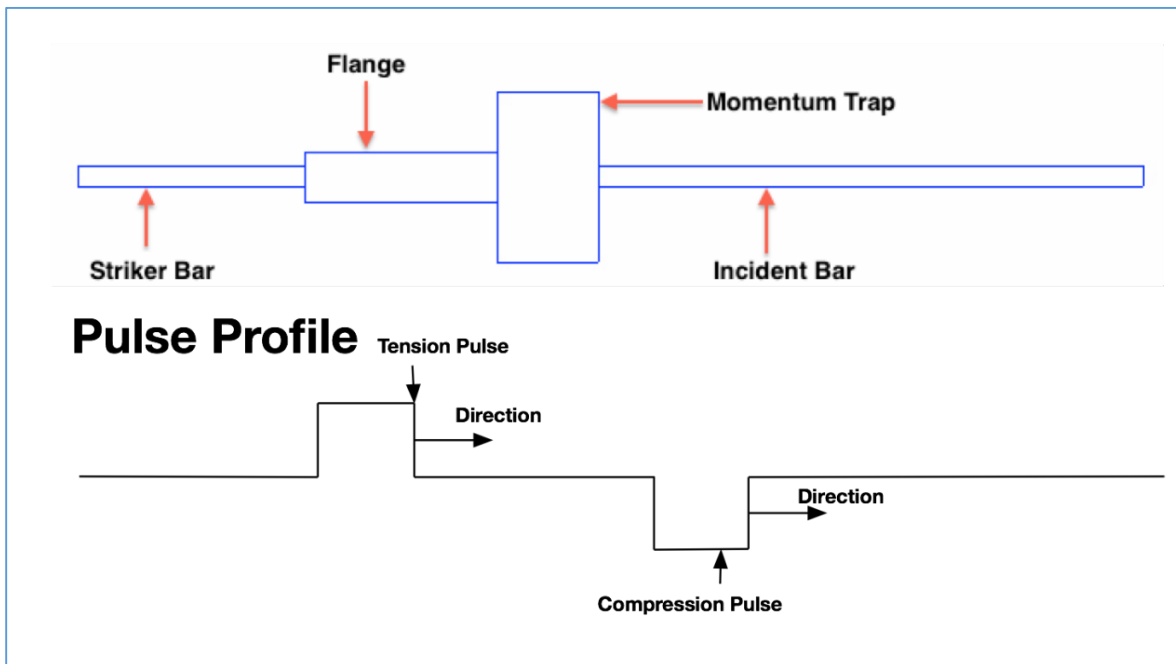
The pulse is split by the following mechanism. First, as seen below, the striker bar hits the flange, causing a compression pulse to travel through the flange



Half of the compression pulse strikes the rigid body of the momentum trap and reflects back as compression. The other half of the pulse travels unimpeded down the bar.

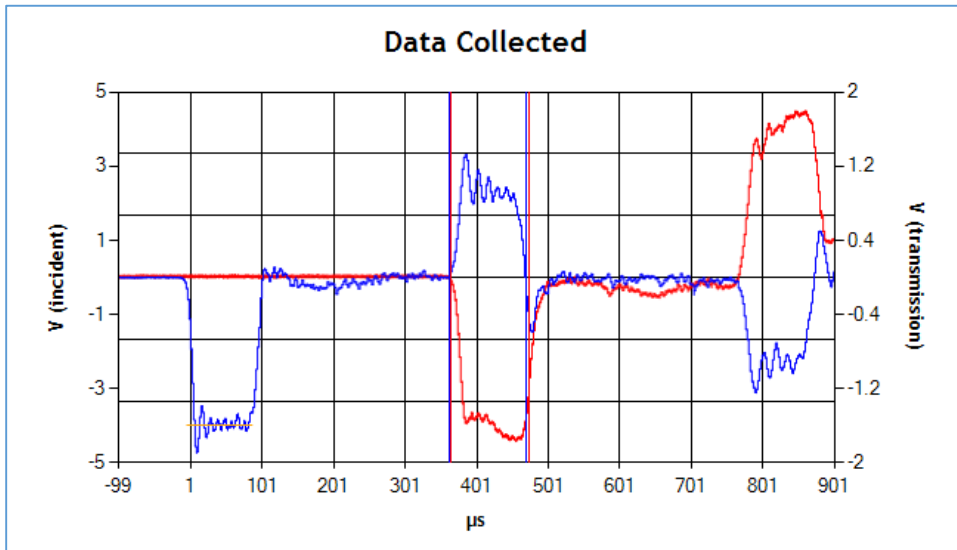


The compression pulse that was reflected by the momentum trap the hits the free face of the striker end of the transmission bar, reflecting back as tension.



This tension pulse follows the compression pulse down the bar. The leading compression pulse strikes the sample deforming the sample and reflecting a tension pulse back toward the strain gauge. This pulse represents the sample strain rate. The tension pulse then hits the end of the bar, pulling the bar back from sample.

Below is an example of an untrapped pulse displayed in the SURE-pulse interface. Notice that the expected pulse (orange line) closely matches the actual pulse, and there is no pulse between the incident pulse and the reflected pulse.



Below is an example of a trapped pulse displayed in the SURE-pulse interface. Notice that the expected pulse (orange line) is about  $1.4 (\sqrt{2})$  times the height of the incident pulse. This indicates that the pulse was split in half by the momentum trap. Also, notice the second tension pulse before the reflected tension pulse. This is the pulse that pulls the bar off of the sample.

