# TXF Users Manual 2011

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## Variable Definition

F = ma
F = Force (hammer)
m = mass (calibration mass 1 kg plus mass of the accelerometer)
a = acceleration (accelerometer)

## *1.0 Introduction*

TXF is MLI's specialized frequency analyzer package that is tailored for FAST measurement of machine tool dynamics. This program primarily collects data from two types of sensors, an accelerometer and an impact hammer to record the frequency response function of the machine-holder-tool combination being measured. The frequency response function of the structure can be experimentally determined using an impact test. The relationship between the vibration and displacement, X, and the excitation force, F is defined as the frequency response function (FRF), X/F. The results from the measurement are displayed graphically as the real and imaginary components of the FRF. The real part of the frequency response function is a one to one mapping into the lobes of the stability lobe diagram. The stability lobe diagram shows the relationship between the spindle speed and the stable depth of cut for a given measured system.

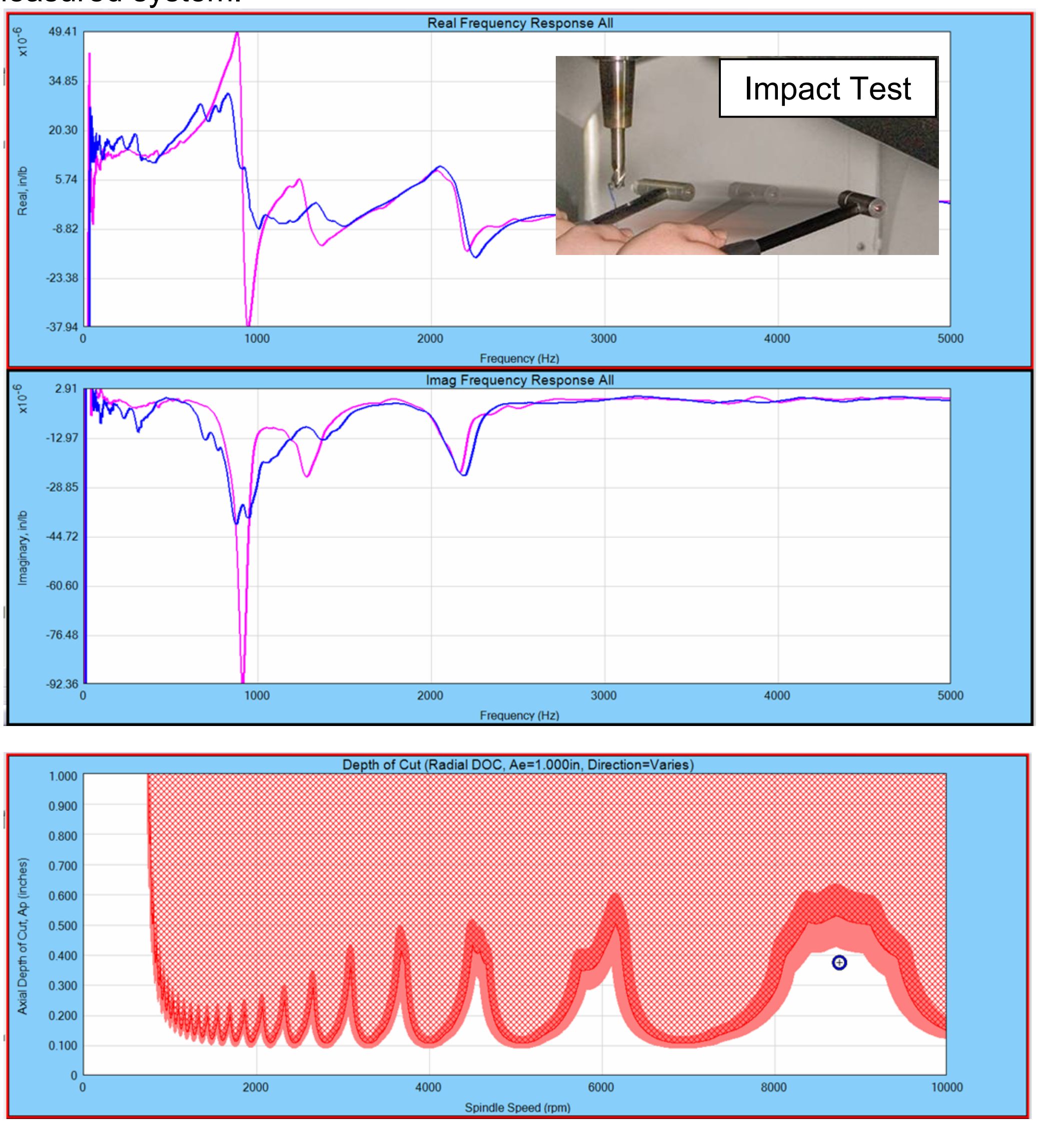


Figure 1: Impact Test to determine the FRF, Resulting Real and Imaginary plots, and the corresponding Stability Lobe Diagram

## 1.1 Starting TXF

To start TXF both the data acquisition card and the dongle must be on the computer before booting up the computer and accessing the software. Figure 2 shows the measurement hardware connection scheme.

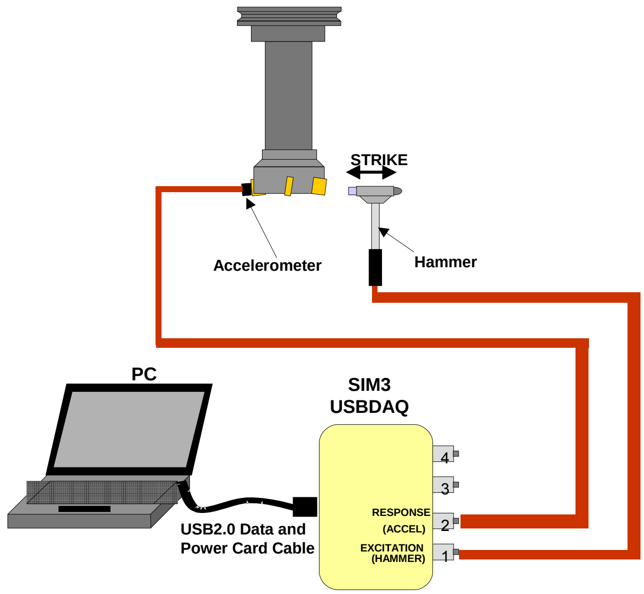


Figure 2: Connection Scheme for METALMAX Measurement set up

### *Startup Instructions for Data Acquisition*

If you have hardware including a National Instruments Card

- Insert the NI-Daq card into the PCMCIA slot
- Attach the NI-Daq and Power cables to the SIM2 Module
- Attach the USB dongle to the computer
- Start the computer
- Open TXF

If you have the Photon+ or NI-4431 USB

- Plug the Photon data acquisition into the desired USB port
- Attach the USB dongle to the computer
- Start the computer
- Open TXF

Other DAQ systems are compatible. Contact MLI for specific installation instructions for alternate DAQ systems.

### *Startup Instructions to Review or Analyze Existing Data and ReSave Files*

National Instruments Card or the Photon+ DAQ does NOT need to be attached for this function. USB dongle can be inserted with computer already on.

- Attach the USB dongle to the computer
- Open TXF

***Startup Instructions for Reviewing Data Only***

No Dongle is necessary to review or manipulate the data. Simply start the computer and open TXF. However if you desire to save edits to the data or setting and then resave the file you will need the Dongle (see above).

## 1.2 Data Acquisition

This section describes the series of steps necessary to properly setup TXF and prepare for data acquisition. The main default screen for TXF is shown in Figure 3 below. There are three sets of accessible Menus in TXF

When beginning to use the software, the user should follow the menus at the right of the screen in the order they are displayed from top to bottom.

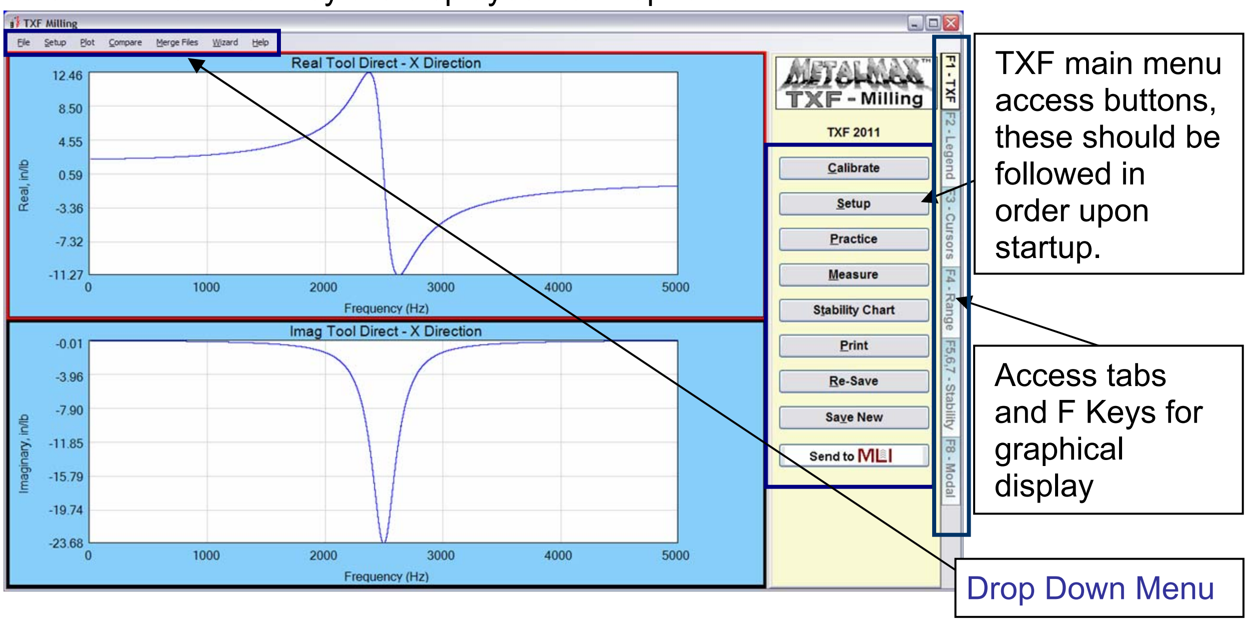


Figure 3: TXF Main User Interface Screen

***Calibrate***

Immediately after opening TXF, the user should calibrate the system, using the calibrate button at the top right of the screen.

Calibration takes approximately 30 seconds. It resets the internal electronics and makes sure the sensors have settled close to 0. The purpose is to verify proper operation and connectivity and check that the channels have settled and to allow the user to review Voltage levels before collecting data.

Next the user should access the Setup Menu using the Setup button. This is the most important Tab.

### *Setup Menu*

The Setup Menu has 7 tabs, Project Tab, the Measurement Tab, the Sensors Tab, the Cut Data Tab, the Stability Tab, the Machine Limits Tab, and the Plot Range Tab. Again the user should enter the necessary data or make the appropriate selection on each tab, following the tabs in order. The TXF Menus are very similar to those in the other MetalMax products.

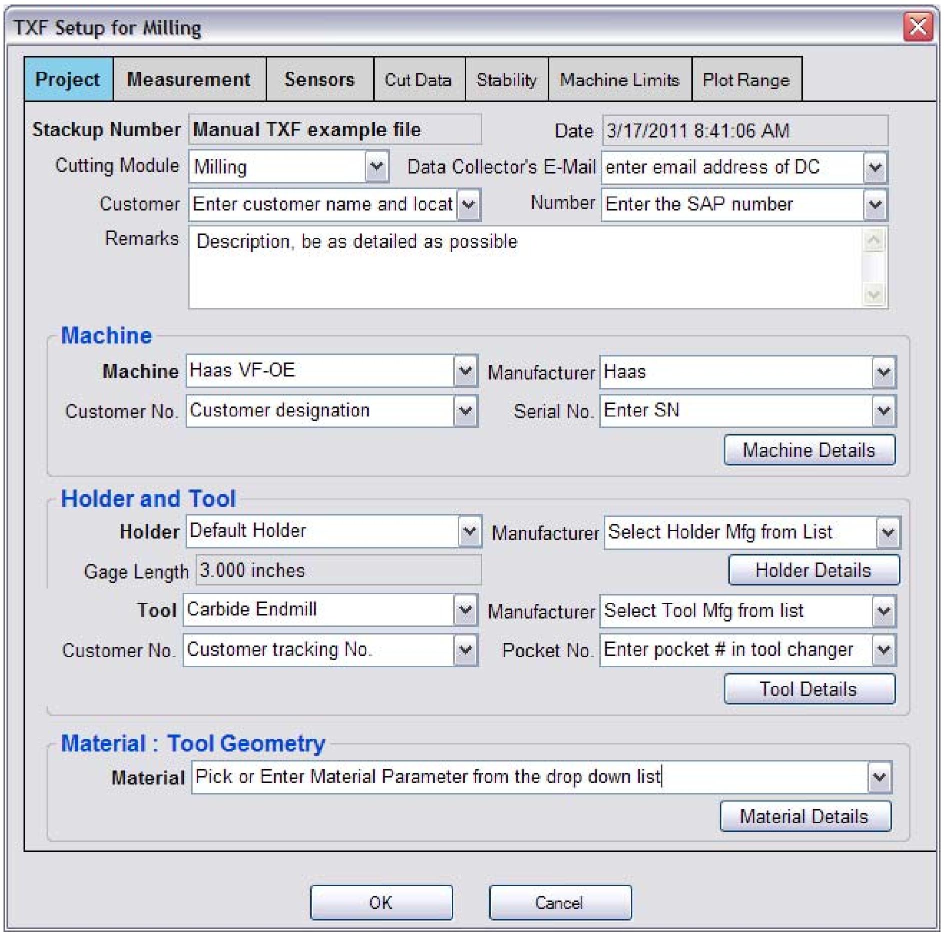


Figure 4: TXF Setup Menus

**<u>Project Tab</u>**

Stackup Number and Date will fill in automatically once the file is saved.

Cutting Module: There are currently 6 choices for Modules, Milling, Small Tool Milling Helical Milling, Milling RCSA, Boring, and Turning. The remainder of this document will outline the setup and user parameters for the standard Milling Module.

Data collector's email: enter the email address of the data collector. This person maybe different from the person analyzing the data and will be helpful for communication if there are any questions regarding the measurement.

Customer: Enter the customer name and facility location

Number: Enter the SAP number

Remarks: Enter an appropriate project description in the designated box. Always include as much detail as possible.

Choose your machine, holder, and tool information from the drop down lists. If the item you desire is not in the list use the appropriate database button to create your machine, holder, or tool and save it to the database.

*Machine Details*

The Machine Details button is used to create a new machine definition and to save this machine definition by adding it to the database. To achieve this enter the appropriate information in to the cell of the dialog box shown in Figure 5. Items in bold are essential information needed to fully complete the calculations and should not be left blank. You must click ADD to save your machine to the database. If you click OK before click ADD TXF will ask 'Do you want to ADD it to the database now?' If you answer NO the information will be local to this file only but will not be stored in a database.

If the machine definition has already been saved to a database, then the ADD button will change to UPDATE, allowing the user to update the existing machine definition in the database.

Cancel: At any time you may click cancel to exit the dialog box without saving any of the changes.

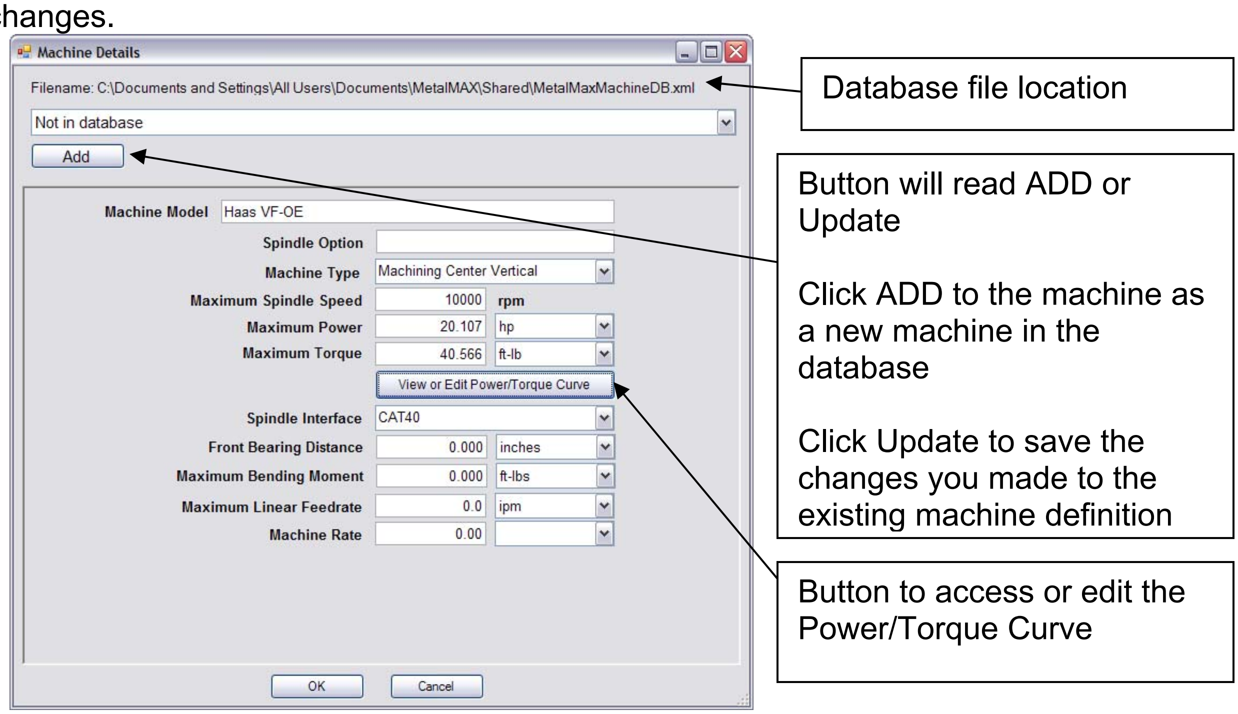

Figure 5: Update Machine Database from the Machine Details

*<u>Interface and Spindle Bearing Limit</u>*

By indicating the Spindle Interface the user will enable the Interface Limit (F2: Legend and Figure 29) to be displayed on the Stability Lobe diagram.

By indicating the Front Bearing Distance and Maximum Bending Moment the user will enable the Spindle bearing Limit to be displayed on the Stability Lobe diagram (F2: Legend and Figure 29)

*Edit Torque/Power Curve*

Every machine has a Power curve associated with its performance.  This information will be provided by the machine manufacturer.  If you have this information, enter it in the appropriate cells.  The values entered into the cells are point pairs on the graph of either spindle speed and torque or spindle speed and power. The graph on the right will show the Power in red and the Torque in blue. CAREFUL to select the correct units. Click OK when complete. By entering the Power curve the user will enable the Power Limit to be displayed on the Stability Lobe diagram (F2: Legend and Figure 26)

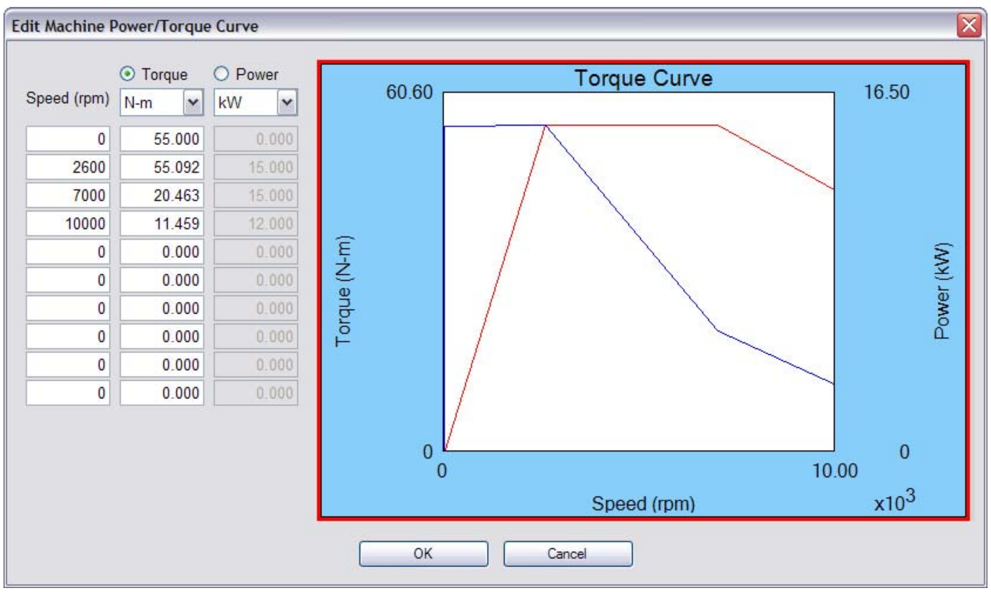

Figure 6: Edit Machine Torque/Power Curve

*Holder Details*

The Holder Details button is used to edit or create a new holder definition and to save this holder definition to by adding it to the database.  To achieve this enter the appropriate information in to the cells of the dialog box shown in Figure 7.

Items in bold are essential information needed to fully complete the calculations and should not be left blank.  All items in this dialog box are essential, except for the holder number. If you do not know the Max RPM for the holder then enter the max RPM for the machine.

You must click ADD to save your holder to the database. If you click OK before click ADD TXF will ask 'Do you want to ADD it to the database now?' If you answer NO the information will be local to this file only but will not be stored in a database.

If the holder definition has already been saved to a database, then the ADD button will change to UPDATE, allowing the user to update the existing holder definition in the database.

Holder Graphics: When the user chooses different holder types from the drop down menu the display for the holder graphics will change. The display of the holder graphics can also be changed using the options to the right of the display window.

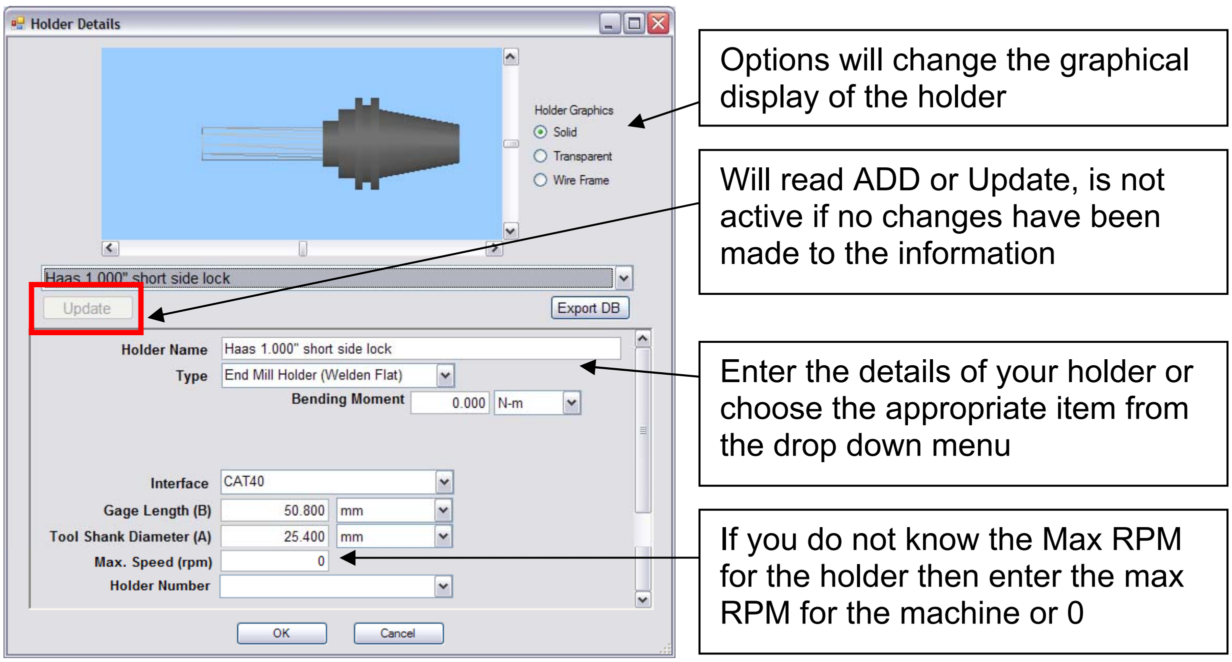


Figure 7: Edit Holder Details

*Tool Details*

The Tool Details button is used to create a new tool definition and to save this tool definition to by adding it to the database. To achieve this enter the appropriate information in to the cells of the dialog box shown in Figure 8.

Items in bold are essential information needed to fully complete the calculations and should not be left blank.

You must click ADD to save your tool to the database. If you click OK before click ADD TXF will ask 'Do you want to ADD it to the database now?' If you answer NO the information will be local to this file only but will not be stored in a database.

If the tool definition has already been saved to a database, then the ADD button will change to UPDATE, allowing the user to update the existing tool definition in the database.

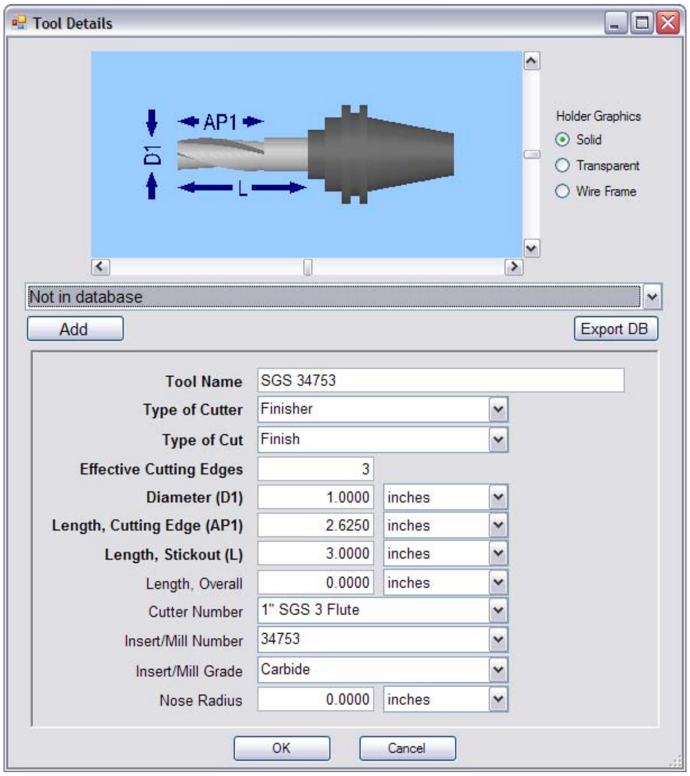


Figure 8: Edit Tool Details

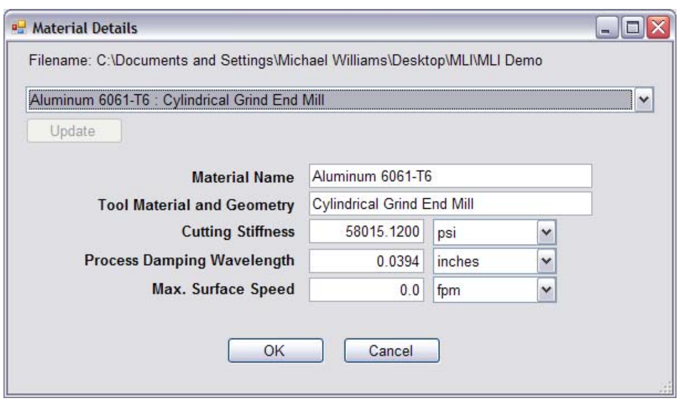


Figure 9: Material Details

*Material Details*

The Material Details button is used to create a new material definition or to edit and existing material definition. To achieve this enter the appropriate information in to the cells of the dialog box shown in Figure 9.

You must click ADD to save your material to the database. If you click OK before click ADD TXF will ask 'Do you want to ADD it to the database now?' If you answer NO the information will be local to this file only but will not be stored in a database.

If the material definition has already been saved to a database, then the ADD button will change to UPDATE, allowing the user to update the existing tool definition in the database.

The parameters in the Material Details are critical for correct calculation of the stability lobe diagram. TXF includes approximate values for the cutting force coefficient (Cutting Stiffness) and Process damping wavelength for a wide variety of common cutting materials in the database.

These values are often sufficient to get you "in the ballpark" for process predictions. While it is possible to determine more precise parameters for a particular set up, it is often not necessary. These coefficients are like other material properties such as Young's modulus or fatigue life which can have substantial variability. If you are a practitioner, you want to stay away from the edges of stability, because at the edges you are sensitive to all of the variables, many of which are not in your robust control. The user should choose the material that best represents the material they will be cutting. If the user wants or needs more precise values for the cutting stiffness and process damping refer to the Procedure for Obtaining Material/Tooling Parameters.

**Measurement Tab**

The Measurement Menu allows the user to set up the Measurement Configuration including the direction of the impact and the sensitive direction of the response accelerometer. The user can also indicate if they are making a Tool Direct FRF, a Workpiece Direct FRF, or a Tool-Workpiece FRF.

Measurement Bandwidth: Only one measurement bandwidth can be applied to a set of measurements. First the user should indicate the desired measurement bandwidth. If you are uncertain,

- set this parameter to a high value,
- make a measurement, and then
- reduce the measurement bandwidth down as low as possible to still capture the relevant frequencies, and then
- remake the measurement.

Next indicate what measurements you will be making using the enable boxes. A green check mark represents that the measurement is enabled. Next set the active measurement. This means the first measurement that you will be making.

The display shows the active measurement setup, including the accelerometer location and impact location. For each measurement that will be made, make the measurement active, and then use the + buttons to indicate the appropriate stimulus and response directions for the measurement setup.

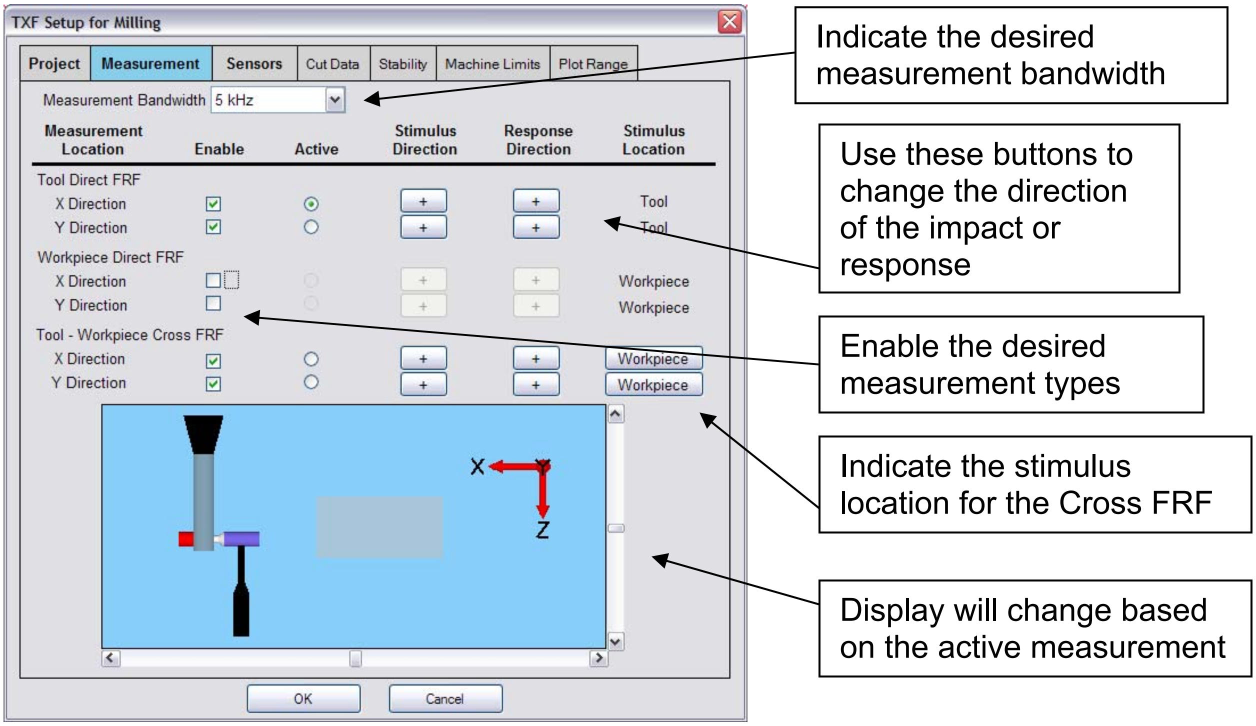


Figure 10: Measurement Tab

The column labeled Stimulus Location will indicate where the impact should occur. For the Tool-Workpiece Cross FRF the user can indicate where the impact is occurring.

When making a measurement it is best to always start with the X direction active and make a corresponding X direction measurement. In this case the software will automatically prompt the user to continue to the next measurement (i.e. the Y direction and then any other enabled measurements). Otherwise, the user will have to manually indicate the active measurement between each set of impacts.

## Sensors Tab

The Sensors Tab is where the user indicates what type of sensor is being used and its configuration information such as sensitivity and range.

Measurement configuration: Choose the measurement configuration for which you are setting the Sensor information. You can choose a set of sensors and then Apply the setting to ALL measurement configurations using the appropriate button.

Sensor Name: For each channel the user must choose a sensor from the database or supply the appropriate information and add their sensor to the database
Integration: The desired response type is displacement. Integration changes the measured signal into different units.

Choose none if the response sensor is a displacement sensor.
Choose single if the response sensor is a vibrometer.
Choose double if the response sensor is an accelerometer.

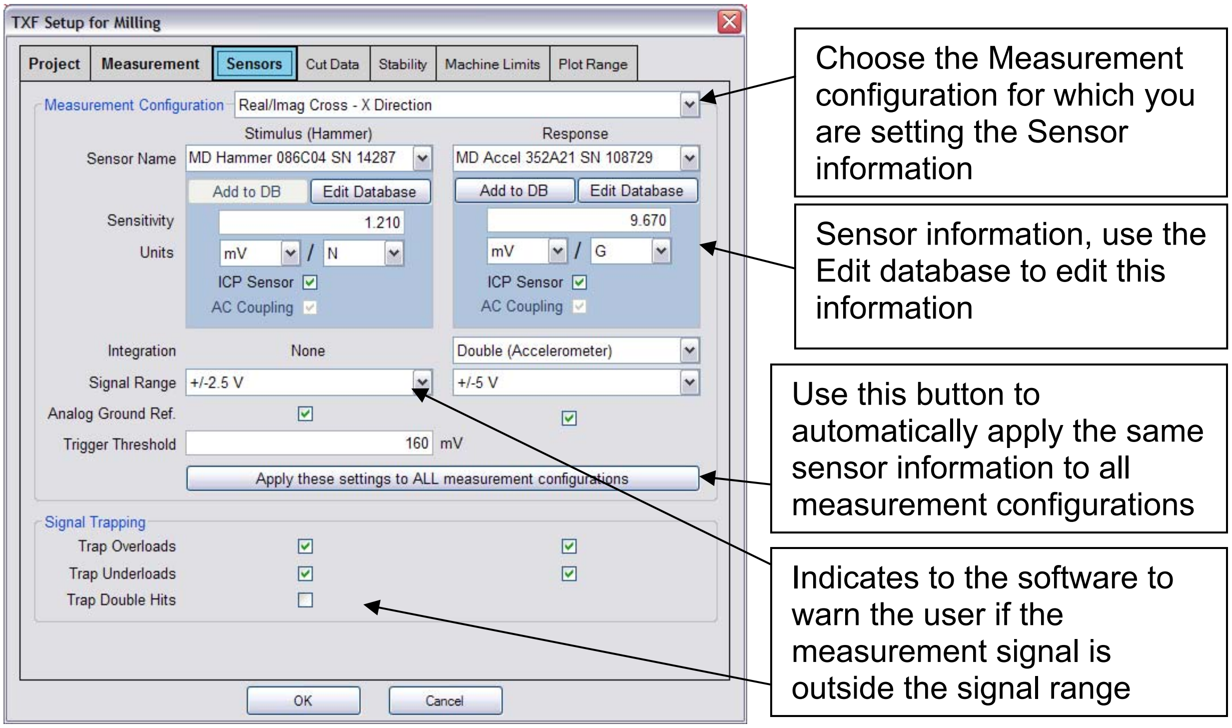


Figure 11: Sensors Tab

Signal Range: This setting is not linked to the database. The Signal Range can be set by the software using the Practice option in the Drop Down Menu or the user can indicate the signal range by choosing the desired value from the drop down menu. For the best signal to noise ratio the range should be set just above the peak signal. So for example if the maximum signal is 0.8 volts, the range should be set to ±1V. If the user is unsure what values to use, it is recommended to set the range high, ±10V, and make a measurement. Once the user is able to determine what range the sensor is detecting, this value can be reduced and the measurement repeated.

Analog Ground Ref: This setting ties the ground reference in the measurement to the computer's power supply. This could be the battery or the wall outlet AC power supply. It is recommended that data is collected with the laptop unplugged to eliminate any grounding issues with the AC power. Ungrounded AC power supplies can cause major DC shifts.

If grounding problems persist, uncheck this option to float the ground which will allow the ground of the target to be the ground reference in the measurement. This sometimes is necessary when the object being measured (e.g. the cutting tool or machine) is poorly grounded.

Trigger Threshold: This value indicates to the software what level signal is considered a measurement. It should be set high enough such that if the user moves the hammer around, or sets it down on a table to rest, the software does not trigger a measurement.

*Signal Trapping:*

While making a measurement, TXF will warn the user if any signal levels exceed the range set in the Signal Range box. The default setting is for all of these warnings to be active. The Signal Range can be set manually or TXF can set this value automatically using the Practice Option in the Drop Down Menu.

Trap Overloads: Will signal the user if the impact force level or the response of the accelerometer is above the voltage in set in the Signal Range box, see Figure 23.

Trap Underloads: Will signal the user if the impact force level or the response of the accelerometer is below the voltage in set in the Signal Range box, see Figure 23.

Trap Double Hits: Will signal the user if the software detects two impacts within the measurement window.

*Sensor Database*

To edit a sensor in the database or add a sensor to the database click on the Edit Database button, the menu in Figure 12 will appear.

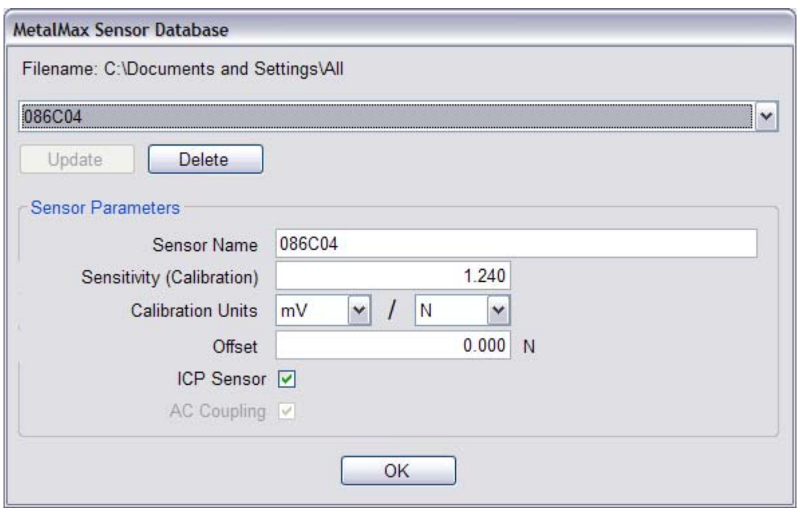

Figure 12: MetalMax Sensor Database

Enter the sensor name, sensitivity with the correct units, and indicate if it is an ICP Sensor and if it requires AC Coupling. Careful to indicate the correct Calibration Units. Then click Add to add the sensor to the database. You will know the sensor is added to the database because the drop down menu will now display your new sensor name.

ICP Sensor: ICP is a type of sensor that requires a power amplifier. The PCB sensors in MetalMax kit are all ICP sensors. An ICP sensor should always be AC coupled. As a result if ICP is indicated, then the option for AC Coupling will automatically be indicated and will not be a setting the user can change.

AC Coupling: Eliminates DC shifts away from ground reference, so data decays to 0 for the mean signal. This setting will become active when the ICP option is NOT indicated.

**Cut Data Tab**

The Cut Data Tab allows the user to set up the specifics of the Target Cutting Parameters and the Tool Properties.

*Target Cutting Parameters*

The target cutting parameters are the desired spindle speed and depth of cut. The numbers entered here will be displayed on the stability lobe diagram using the blue target symbol.

Spindle Speed: Enter the current spindle speed and/or a desired spindle speed

Depth of cut: Enter the axial depth of cut

Limit Depth of Cut: Enter the limiting depth of cut, this is commonly the tool flute length, but may be any limiting value that the user desires to input.

Feedrate/Feed per Tooth: Enter either the feedrate or the feed per tooth. If feedrate is entered TXF will calculate the corresponding feed per tooth based on the tool properties. Conversely, if feed per tooth is entered TXF will calculate the feedrate.

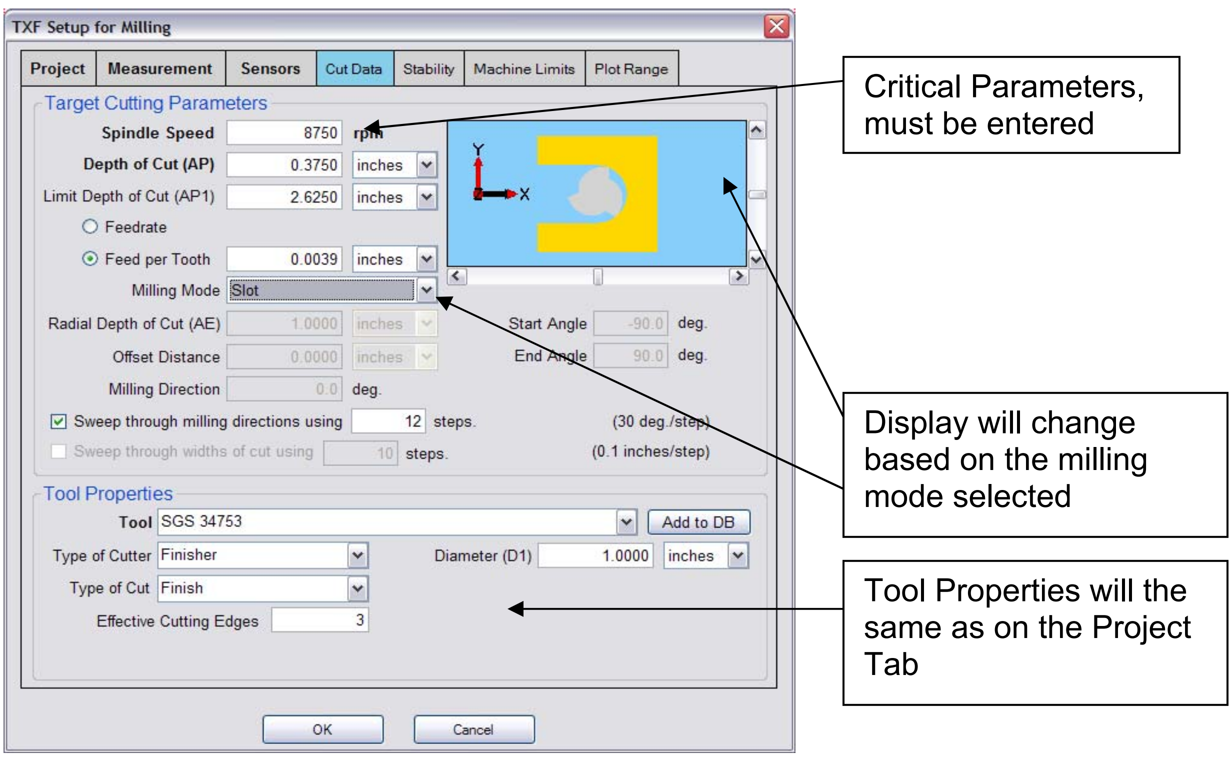


Figure 13: Cut Data Tab

*Milling Mode*

The stability lobe diagram can be calculated for full immersion cuts (slot), partial immersion cuts (convention and climb milling), and/or face milling.

The user should select the desired milling mode for which the stability lobes should be calculated. Based on the milling mode selected different parameters will become active or grayed out.

*Slot Milling*

A full slot cut represents the 'worst case scenario.' This means that if the stability lobes are generated for this mode, then all partial immersion cuts will also be stable if the boundaries for a full slot are respected.

Milling Direction and Sweep through milling direction: If the X direction and Y direction FRFs are not similar then the stable cutting regions will differ depending on the milling direction, see Figure 14. Therefore, the stability lobes can be calculated for a specific milling direction or as an envelope including all milling directions.

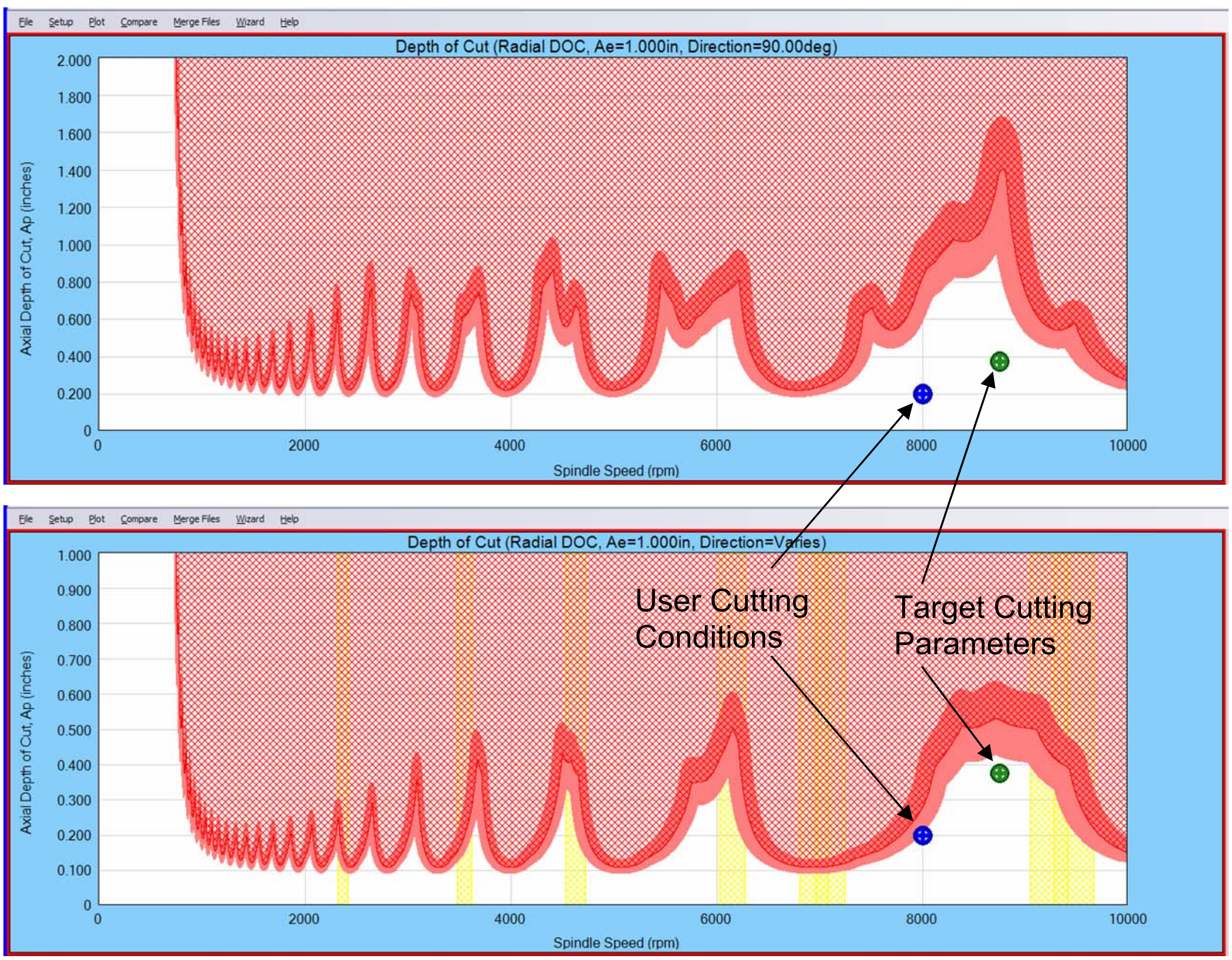


Figure 14: Stability lobe diagram for a full slot (top) for Milling Direction 90 (bottom) Sweep through milling directions using 12 steps.

To calculate the stability lobe diagram for a specific milling direction indicate the by deselecting 'Sweep through milling direction' which will cause the Milling Direction input box to become active. The +X direction corresponds to 0° and the +Y direction corresponds to 90°.  The graph located at the top right of the Cut Data Tab will change to correspond to the value that the user inputs for Milling Direction.

*Sweep through milling direction*

This option allows the user to calculate the stability lobe diagram as an envelope including all milling directions.  Select 'Sweep through milling direction' which will cause the Milling Direction input box to become inactive. Indicate the number of steps to use when sweeping through the milling directions.  Sweep through widths of cut is not a valid selection for slot milling and is therefore not accessible.

*Sweep through all widths of Cut*

This option allows the user to calculate the stability lobe diagram as an envelope including the widths of cut.  Select a partial immersion cut, conventional or climb milling, which will activate the 'Sweep through width of cut' selection. Activate 'Sweep through widths', and indicate the milling direction.

*Partial Radial Immersion Milling*

The stability lobe diagram can be calculated for a specific partial radial immersion milling condition.  The following combinations of cutting conditions are possible for generating the stability lobe diagram.

- Partial Radial immersion at a set radial depth of cut and a set milling direction

For this case choose the appropriate milling module, conventional or climb milling. This will cause the Radial Depth of Cut field to become active.  Indicate the desired radial depth of cut in the appropriate text box. Deselect 'Sweep through milling direction' which will cause the Milling Direction input box to become active. Indicate the desired milling direction in the appropriate text box.

- Partial Radial immersion at a set radial depth of cut and sweep through milling directions

For this case choose the appropriate milling module, conventional or climb milling. This will cause the Radial Depth of Cut field to become active.  Indicate the desired radial depth of cut in the appropriate text box. Select 'Sweep through milling direction' which will cause the Milling Direction input box to become inactive. Indicate the number of steps to use when sweeping through the milling directions.

- Partial Radial immersion at a set milling direction with sweep through widths of cut

For this case choose the appropriate milling module, conventional or climb milling. Select 'Sweep through widths of cut' which will cause the radial Depth of Cut input box to become inactive. Indicate the number of steps to use when sweeping through the widths of cut. Deselect 'Sweep through milling direction' which will cause the Milling Direction input box to become active. Indicate the desired milling direction in the appropriate text box.

- Partial Radial immersion with sweep through milling directions and sweep through widths of cut

For this case choose the appropriate milling module, conventional or climb milling. Select 'Sweep through milling direction' which will cause the Milling Direction input box to become inactive. Indicate the number of steps to use when sweeping through the milling directions. Select 'Sweep through widths of cut' which will cause the radial Depth of Cut input box to become inactive. Indicate the number of steps to use when sweeping through the widths of cut. In this case TXF will increment the Milling direction and then 'Sweep through width of cut' for that milling direction and then increment the milling direction again. Therefore, for the selections, Sweep through milling direction using 12 steps and Sweep through width of cut using 10 steps, TXF will calculate 120 combinations and provide the combined stability lobe diagram.

*Face Milling*

The stability lobe diagram can be calculated for a face milling application which is a special case of a partial immersion milling because the point in which the face milling cutter engages the workpiece (i.e. the start angle) and disengages the workpiece (the end angle) can differ for the same value of radial immersion, as shown in Figure 16. When calculating a specific case stability lobe diagram, there can be significant difference in the stable depth of cut for a given spindle speed, depending in the start and end angle of the cut.

- Face milling with 'Sweep through widths of cut'

For this case choose the appropriate milling module, face milling. Select 'Sweep through widths of cut.' Indicate the desired Radial Depth of Cut, start angle, and end angle. Indicate the number of steps to use when sweeping through the widths of cut. Deselect 'Sweep through milling direction' which will cause the Milling Direction input box to become active. Indicate the desired milling direction in the appropriate text box. For example, Figure 15 shows the graphics for Sweep through width of cut for Face Milling using 3 steps and half radial immersion.

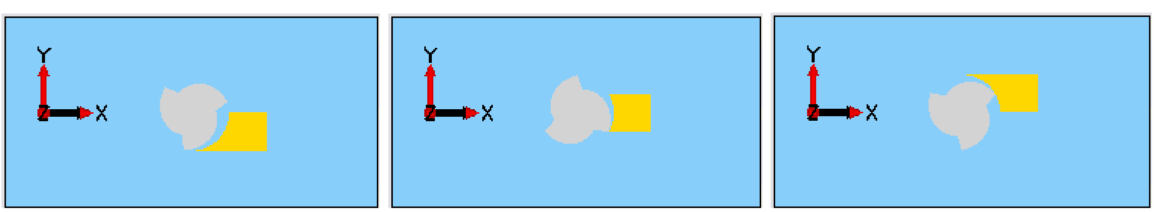

Figure 15: Sweep through width of cut for Face Milling using 3 steps and half radial immersion

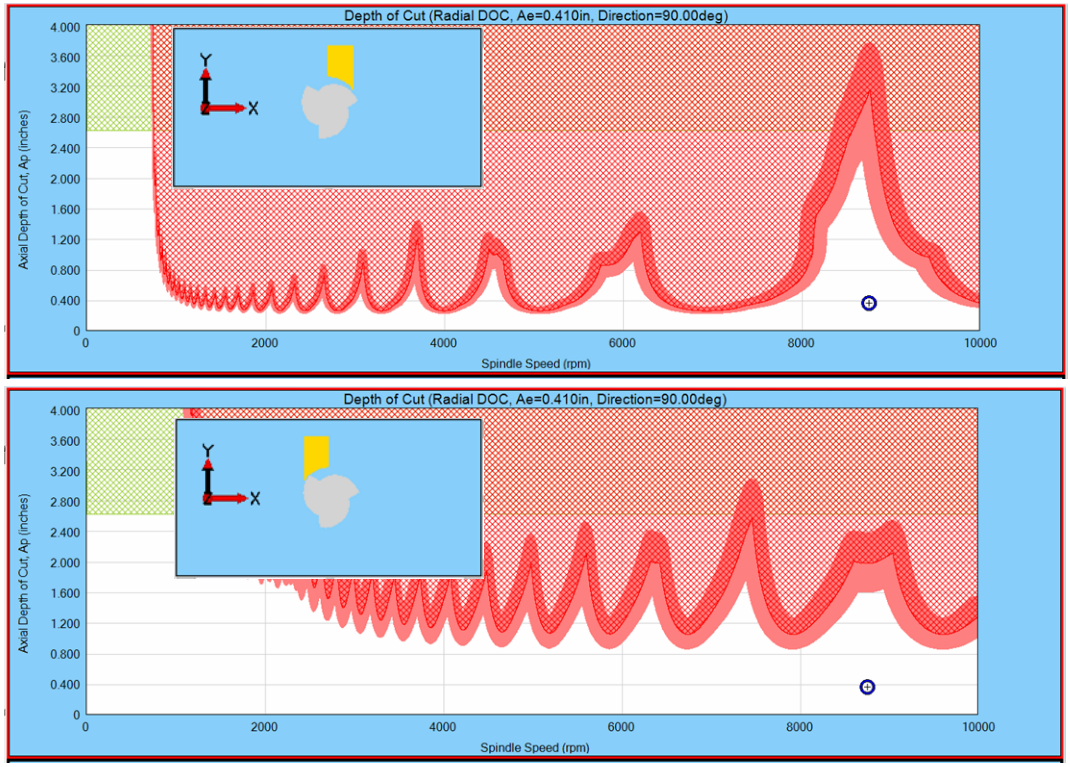


Figure 16: Face Milling Mode Stability lobe diagrams showing the same radial depth of cut with different stand and end angles

*Tool Properties*

The Tool properties section of the Cut Data Tab will display the tool specifications set up on the Project Tab. If the information displayed is not correct choose or enter the correct information. If Information is edited or changed in the Tool Properties, Tool section on the Project Tab update accordingly. However, the new information will NOT update the database unless the Add to DB button is clicked.

For example, if the number of cutting edges is increased from 2 to 3, the both the Tool Details and the Tool Database Button on the Project Tab will also display 3 as the number of cutting edges. However this setting will be specific to this file only, unless the new information is added to the tool database by updating the database.

## Stability Tab

The Stability Tab allows the user to set parameters specific to the generation and display of the stability lobe diagram. The input cells for the Measurement locations will be gray or active based on settings from the Measurement Tab and/or the Cutting Module set on the Project Tab.

Traditional stability lobes are generated from the Tool Direct Measurement. The user should indicated if the stability lobes should be generated

- using the X direction Measurement only (indicated with a green check in the X column)
- the Y direction measurement only (indicated with a green check in the Y column)
- or both the X and Y direction measurements (indicated with a green check in both the X and Y columns)

For each active measurement the user should indicate the minimum and maximum frequency range that will be used to generate the stability lobe diagrams. All data outside the indicated range will be ignored.

Similarly, stability lobes can also be generated from workpiece and/or Tool-Workpiece Cross FRFs by indicating the desired measurements with a green check mark and indicating the desired frequency range.

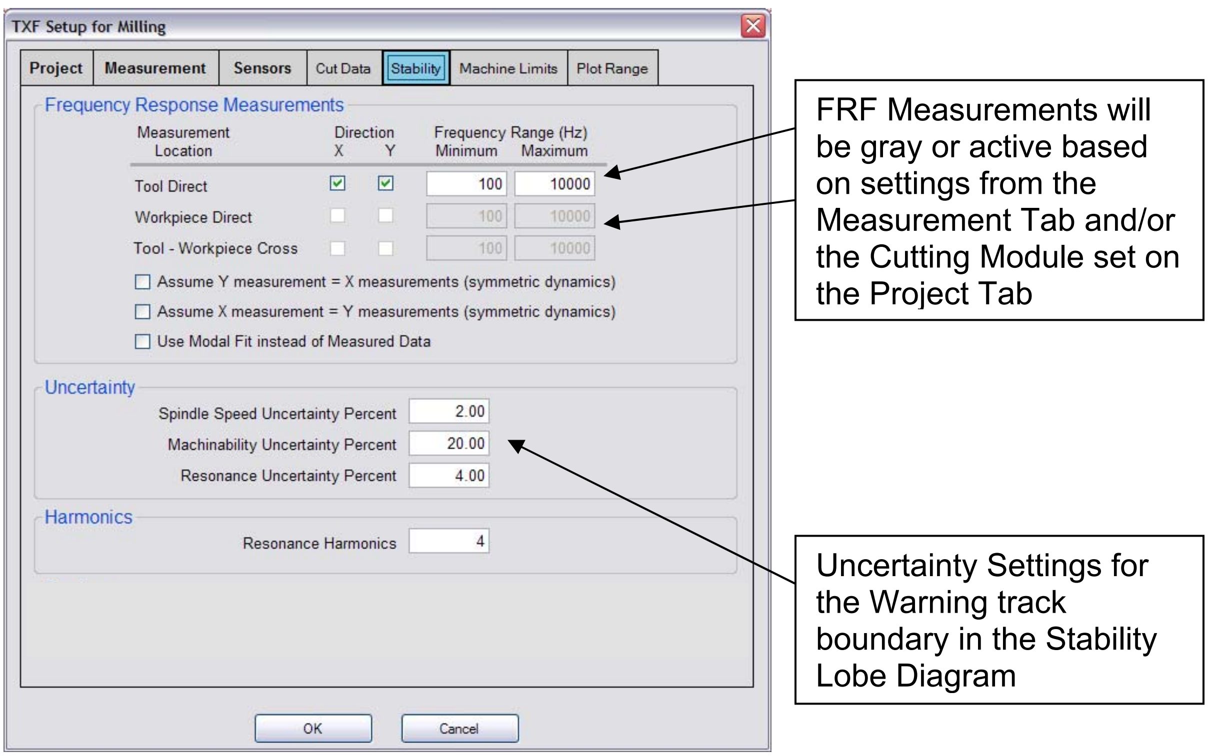


Figure 17: TXF Setup for Milling

*Assume symmetric dynamics*

Often the X direction and Y direction tool tip FRF will be very similar. In this case, to shorten the measurement time the user can make only one FRF, and then indicated that the software should assume that the X and Y direction FRFs are identical. Depending on the active measurement, TXF will let the user indicate symmetry by either choosing Assume X measurement = Y measurement or Assume Y measurement = X measurement.

If the user records a Y direction measurement only then the Assume X measurement = Y measurement should be indicated for symmetrical dynamics.  In this case the Assume Y = X option will be grayed out since it is not a valid choice.

If the user records an X direction measurement only then the Assume Y measurement = X measurement should be indicated for symmetrical dynamics. In this case the Assume X = Y option will be grayed out since it is not a valid choice.

Several examples are given below to guide the user.  These examples do not include all possible cases, but are meant to help the user understand the parameter selections.

Sequence 1:
For example
- if the user only makes an X direction FRF and
- does NOT indicate Assume Y measurement = X measurements (symmetric dynamics),
- but chooses sweep through milling direction using 12 steps

The user will be prompted “Do you want to apply Y=X symmetry for the stability calculation?”  Choose OK to apply Y=X symmetry, and the corresponding stability lobes will be calculated.  If CANCEL is chosen, NO stability lobe diagram will be calculated and the graph will default back to the FRF display.

Sequence 2:
For example
- if the user only makes an X direction FRF and
- DOES indicate Assume Y measurement = X measurements (symmetric dynamics), and
- chooses sweep through milling direction using 12 steps

The stability lobe diagram will a combined stability lobe diagram taking into account X and Y measurements that are the same.

Sequence 3:
For example
- If the user only makes an X direction FRF and
- DOES indicate Assume Y measurement = X measurements (symmetric dynamics), and
- chooses milling direction = 90 degrees  (which should be a Y cut)

The stability lobe diagram for the Y direction cut will be the same as for the X direction cut.

Sequence 4:
For example
- If the user only makes an X direction FRF and
- DOES NOT indicate Assume Y measurement = X measurements (symmetric dynamics), and
- chooses milling direction = 90 degrees  (which should be a Y cut)

The user will be prompted “Do you want to apply Y=X symmetry for the stability calculation?” Choose OK to apply Y=X symmetry, and the corresponding stability lobes will be calculated. If CANCEL is chosen, NO stability lobe diagram will be calculated and the graph will default back to the FRF display.

*Use Modal Fit instead of Measured Data*

The Stability Lobe Diagram can be generated using a modal fit to the data instead of the actual data. This might be desirable when the measurement data is very noisy which can sometimes be the case when measuring very small diameter tools. Also the modal fit option can be used to create a custom FRF and see how this would affect the stability lobe diagram. For instance the user can say if “I lengthen my tool it will shift the natural frequency of the primary mode down”. This can be simulated by adjusting the modal fit parameters and then generating the stability lobe diagram to see how this will change the stability lobe diagram.

The modal fit to the data is created using F8 Modal or from the Plot drop down menu at the top of the screen. When the Use Modal Fit instead of Measured Data box has a green check mark, then TXF will use the fit data to generate the stability lobe diagram instead of the actual data.

*Uncertainty*

Uncertainty is a quantity that represents the limit on the accuracy with which certain measurement can be made. Uncertainty can result from a wide variety of causes including the measurement procedure, the sensors, lack of knowledge of process information (such as the material properties). As a result when generating the stability lobe diagrams in TXF, a warning track is included in the display, to represent a band of uncertainty around the calculated parameter. The shape of the band is controlled by the two parameters located on the Stability Tab, under the heading Uncertainty.

Spindle speed uncertainty percent – will cause the stability lobe pocket to narrow by increasing the thickness of the warning track along the axial depth of cut axis. This parameter indicates uncertainty in the operating spindle speed. 2-5% is a typical value for this parameter.

Lobe uncertainty percent – will cause the stability lobe pocket to indicate a smaller stable depth of cut by increasing the thickness of the warning track along the axial depth of cut axis. This parameter indicates uncertainty in the depth of cut, which is primarily affected by material properties such as the cutting stiffness. The default value for the lobe uncertainty is 20%.

*Harmonics*

When displaying the stability lobe diagram, the user can choose to have the spindle speed bands that correspond to the resonance of the system highlighted in yellow.
When displaying the stability lobe diagram, the user can choose to have the spindle speed bands that correspond to the resonance of the system highlighted in yellow.

Cutting at or near a resonance can lead to larger vibration levels, although much less than what would be obtained in chatter.

Two setting will affect how the resonance bands are displayed, the Number of Resonant Harmonics and the Resonance uncertainty percent

Number of Resonant Harmonics: The number of harmonics will dictate how many bands are displayed. So if the Number of Resonance Harmonics is 4, then bands would occur at the primary spindle speed (N), 2N, ½N and ⅓ N.

Resonance uncertainty percent: The resonance uncertainty percent will dictate the thickness of each resonance band on the stability lobe diagram.

**Machine Limits Tab**

The active machine as set on the
Project Tab will be displayed on the Machine Limits Tab. The Machine Limits Tab displays the machine parameters that are used in generating the stability lobe diagram and/or limits displayed on the stability lobe diagram. All the values show on this tab are critical for calculating the stability lobe diagram therefore a value should be entered for each parameter.

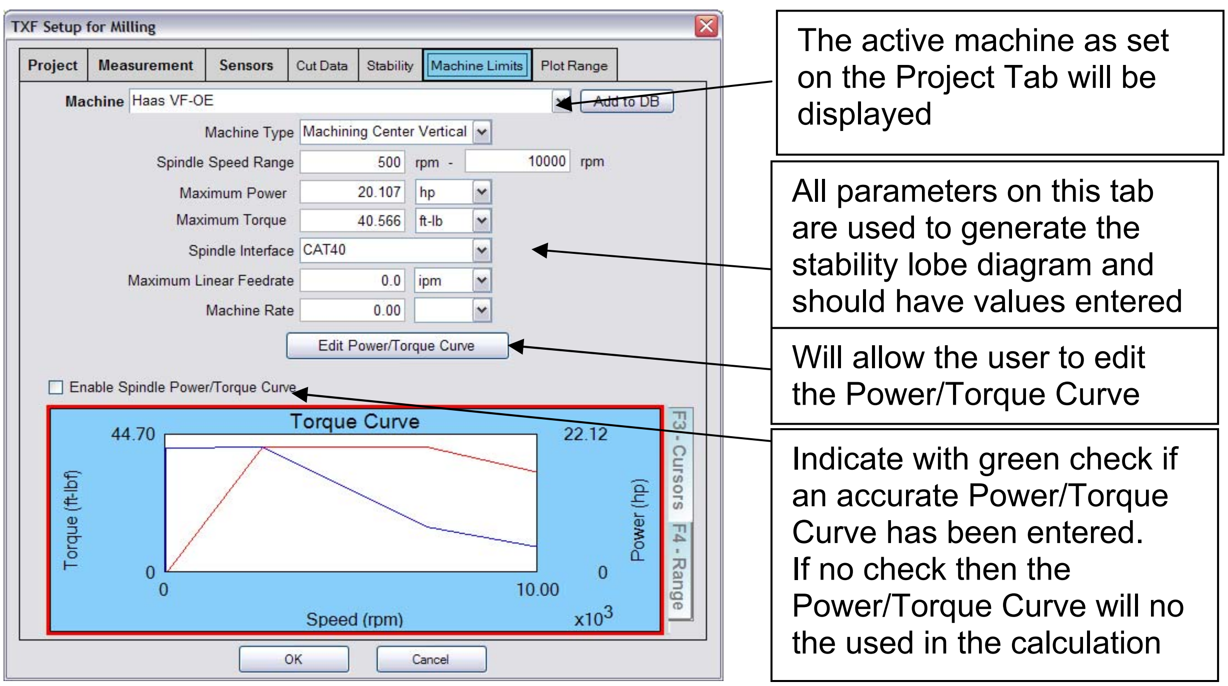

Figure 18: Machine Limits

The graph at the bottom of the screen shows the Machine Power/Torque Curve. This information is required if the user desires certain limits to be available on the stability lobe diagram. For example, an indicator line showing the machine power limit can be displayed on the stability lobe diagram (See F2: Legend). However, this option will not be available if the Enable Spindle Power/Torque Curve is not enabled.

To edit the Power/Torque Curve Values click the appropriate button in the center of the screen and the window shown in Figure 19 will open. The Power/Torque curve is created by entering spindle speed and torque or spindle speed and power point pairs into the appropriate columns.  CAREFUL to indicated the correct units for the values entered.  The graph at the right of the screen will update as new point pairs are entered or edited.  Click OK to save the changes.

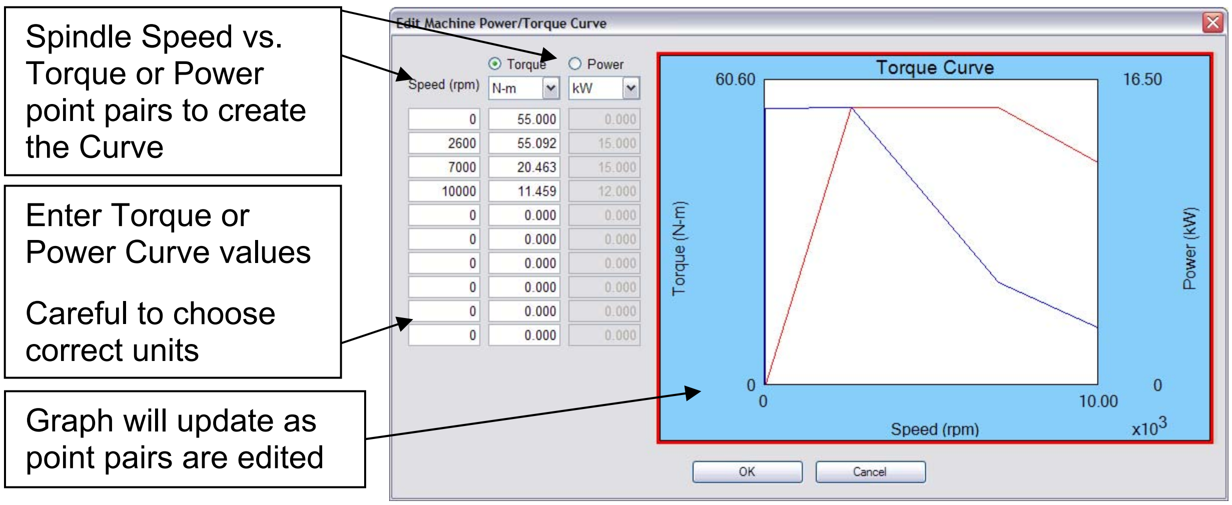


Figure 19: Edit Machine Power/Torque Curve

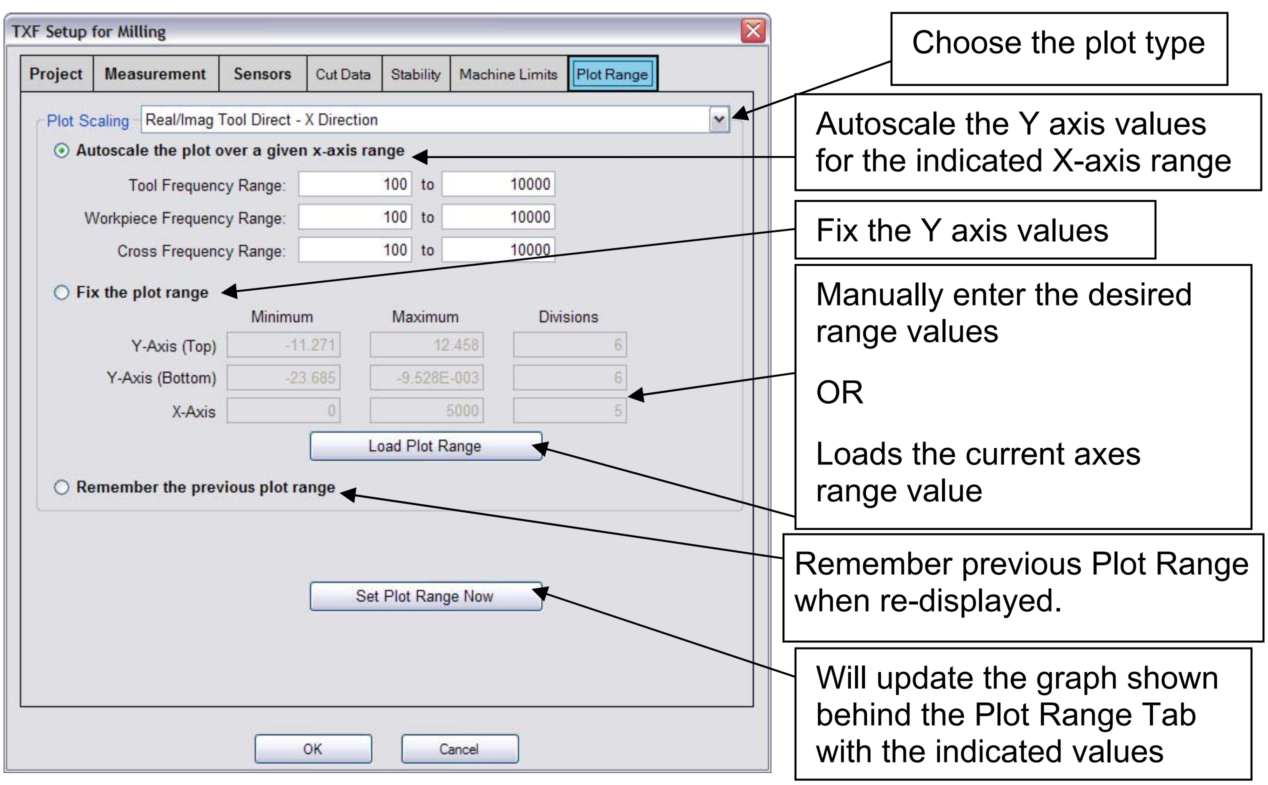


Figure 20: Plot Range Menu

**Plot Range Tab**

The Plot Range menu lets the user set the plot ranges for each type of plot (eg. The Real/Img FRF or the Stability Lobe Diagram)

Autoscale the plot over a given x-axis range: This option allow the user to autoscale the Y axis values for the indicated X-axis frequency range. The frequency ranges are set for each individual type of FRF recorded, Tool, Workpiece, or Cross.

Fix the plot range: This option allow the user to manually set the X and Y axis values.

Load Plot Range Button: this button will load the current plot values into the appropriate cells in the Fix the plot range section.

Set the Plot Range Now Button: This button will set the plot range values indicated by the user active on the graph. When clicking this option the user will see the graph behind the Plot Range window update.

Remember the Previous Plot Range: This setting preserves the most recent plot range used whenever the plot is returned to. For instance, if you zoom in on the X-direction plot and go to the Y-direction plot, when you return to the X-direction it will return to your prior zoomed range instead of any preset or auto-range (scaled) setting.

***Practice***

The practice button will not be accessible unless the hardware and hardware lock are appropriately setup, see Figure 2. The practice section serves 3 primary purposes

- To make sure that the sensors are working. During the practice hits, the user can see the hammer plot (top) and the accelerometer plot (bottom), as shown in Figure 21. This provides visual feedback that everything is working.

- Allow you to practice hitting so that you get comfortable with your setup.

- Practice can also "Autorange" the voltage input range on your sensors if you are using the NI6062E Data acquisition card. Each time you hit, the range will update until the program has selected the smallest possible voltage range that doesn't saturate. The "Autorange" feature doesn't help much with the newer 24-bit DAC cards because they are always set to use the full +/- 10Volt range.

Auto Spectrum shows the frequency range and force magnitude that is created by the impact, as shown in Figure 22.

In Figure 22, the frequency range that was sufficiently excited by the impact was 0-1600 Hz. If frequencies greater than 1600 Hz appear in the magnitude plot, then they should be disregarded, or a different hammer and accelerometer combination should be used to sufficiently excite the desired frequency range. The user can also use this information to change the measurement bandwidth (see Figure 10).

***Measure***

The measure button brings the user to the screen which will allow the user to record the FRF's. If the user selects Measure without selecting Practice, TXF will automatically go to the Practice Screen before proceeding with the Measure Screen.

If Show all Hits is selected the plot window will be subdivided such that all recorded hits will be displayed. If this option is not selected only the most current hit will be displayed. This option only applies to the Time Domain plots.

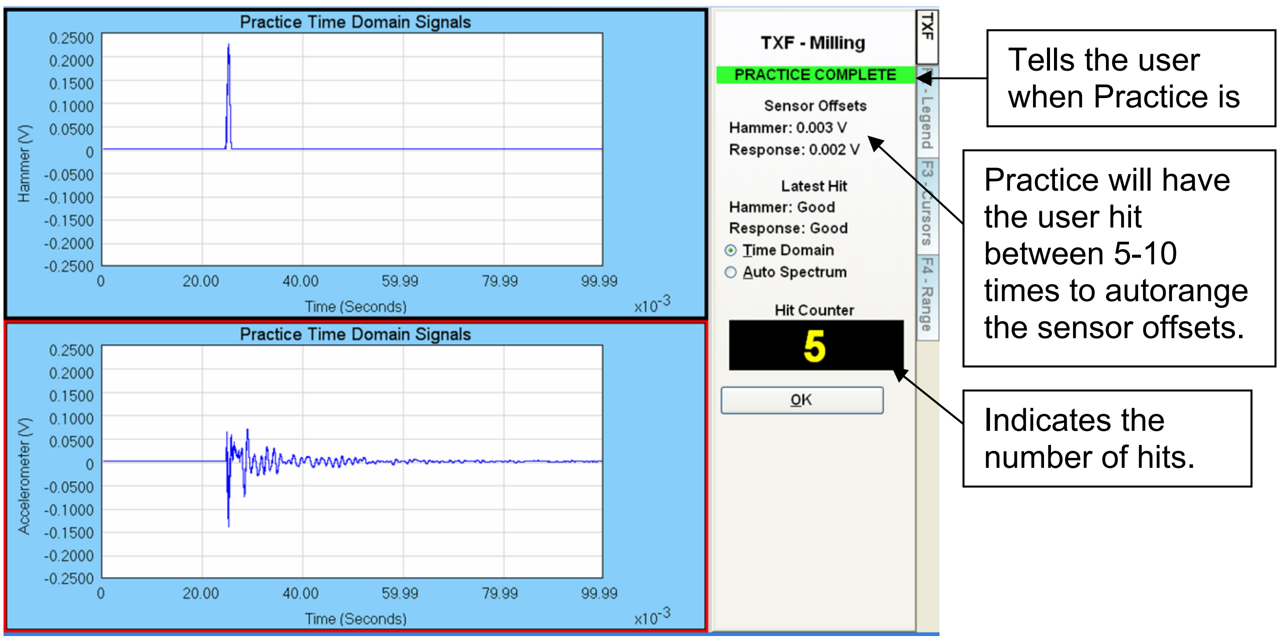


Figure 21: Practice

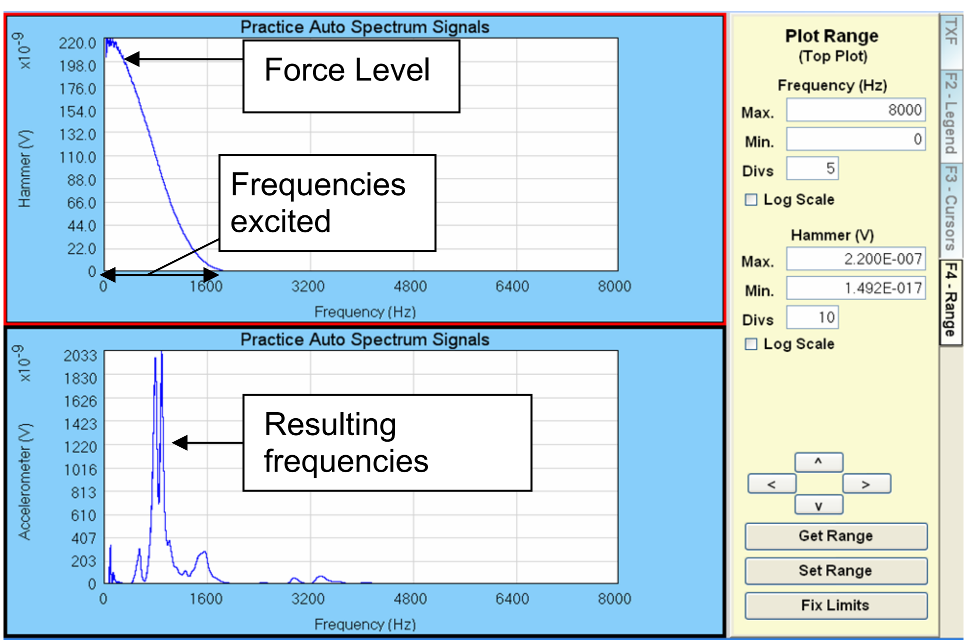


Figure 22: Auto Spectrum Option in the Practice Section

Reject: this button will allow the user to reject the most recent hit.  To reject a hit previous prior to the most recent hit, the user can simply click on the hit that should be deleted.  TXF will indicate that this hit is no longer valid with a large red X.  This hit can be re-included in the measurement by clicking on the red X causing the X to be removed and making the hit active.

Plot Types:  There are 5 different types of plots that may be viewed during the measurement process. The different plot types allow the user to ensure the impact level and frequency and other setting are appropriate for the system and to view the resulting FRF as well as coherence of the measurement.

Frequency Spectrum: Plots the stimulus magnitude and response magnitude versus frequency.

Auto Spectrum: Plots the stimulus magnitude squared and response magnitude squared versus frequency. Is also called the power spectrum, see Figure 22.

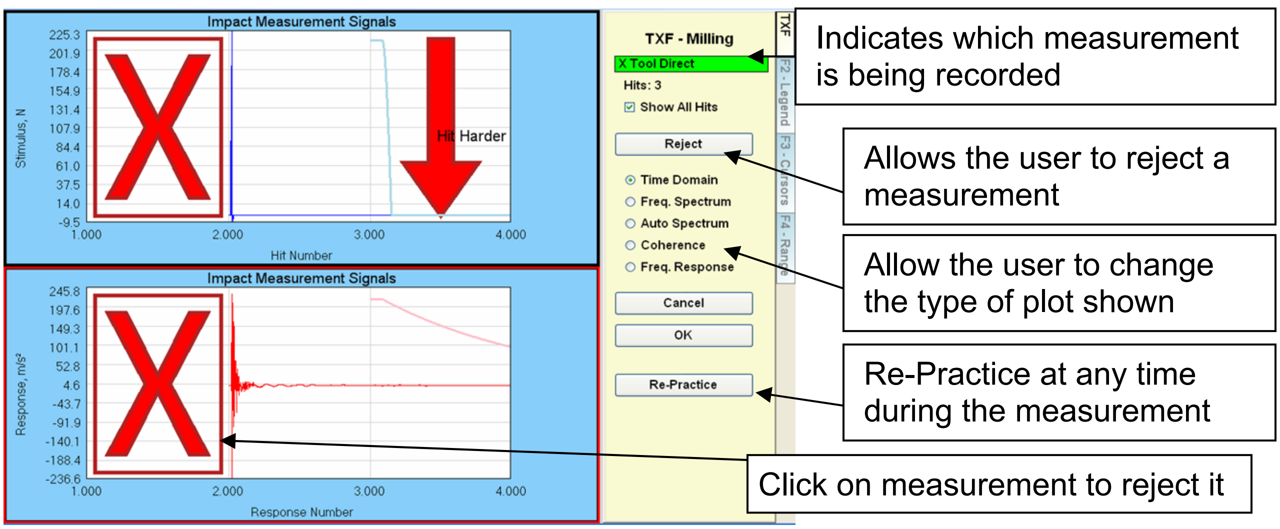

Figure 23: Measure

Coherence: Coherence is a data quality assessment which identifies how much of the system response is related to the input force, see Figure 50 and Figure 60.

Frequency Response: the Real and Imaginary FRF for the current measurement.

Re-Practice: If during the measurement process too many errors (Hit Harder, or Hit Softer) are experienced, the use can go back to the Practice screen to practice hitting again and/or to reset the autorange values for the sensors.

Cancel: will cancel the measurement and NOT record any of the data.

OK: Use this button when you are satisfied with the number of hits recorded and to see the final FRF.

Upon completion of the Measure option the main TXF Screen will display the resulting FRF recorded during the Measure exercise.

### *Stability Chart*

The Stability Chart button will generate the stability lobe diagram based on the FRF measurement and the settings in the Setup Menu. As shown below in Figure 20, a stability lobe diagram is spindle speed vs. axial depth of cut. The RED line is the boundary between stable and chatter (red hatched area). So when reading the graph any region below the red line is stable. The user should pick a combination of spindle speed and axial depth of cut that is stable as the desired cutting parameters. The blue bulls eye indicates the spindle speed and depth of cut combination entered in the Cut Data Tab as the Target Cutting Parameters.

The Chatter Frequency Graph (lower plot) shows the chatter frequencies that correspond to a given portion of the stability Lobe Diagram (top plot). So, as shown with the cursor, for a spindle speed of 7500 rpm, the chatter boundary occurs at 0.149 inch depth of cut, and at these parameters chatter will occur at 967 Hz.

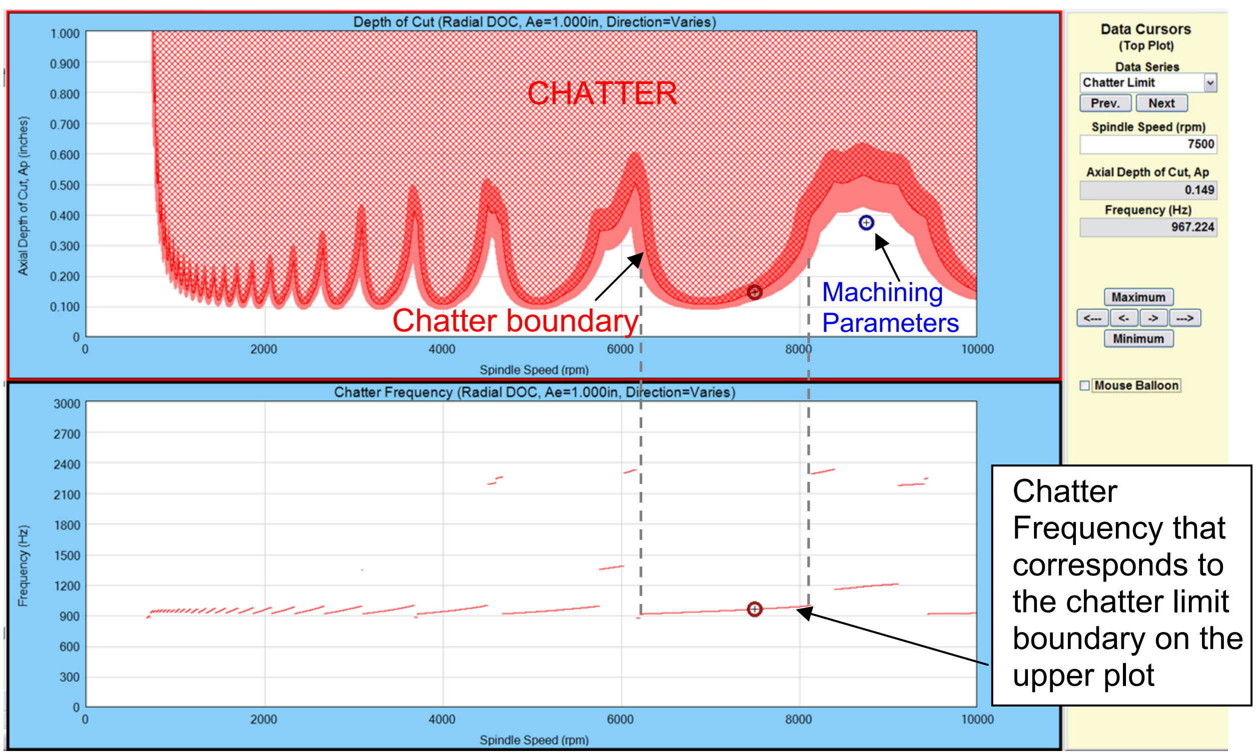

Figure 24: (top) Stability Lobe Diagram and (bottom) Chatter Frequency Diagram

**Process Damping Region**:
Process damping is a phenomenon where there is a very strong stabilizing effect at low spindle speeds that leads to a significant increase in the depth of cut. This effect is

essentially added damping to the system which is based on the wavelength of the wavy surface a vibrating cutter will leave on the surface of the part and the tool geometry. The increase in the damping is larger for shorter wavelengths. The parameter in TXF that effect the calculation and display of this region is the Process Damping Wavelength located on the
Project Tab under Material Details.

This phenomenon is very important when machining materials, which because of their properties, cannot be machined at high speeds. Often, although low cutting speeds must be used, large depths of cuts are possible without experiencing chatter. This can lead to productive metal removal rates, even for materials which are known to be difficult to machine.

***Re-Save***

The Re-Save Data option saves the data with the existing file name and writes over the old file.

***Save New***

Depending on the F12: Preferences, File Naming Conventions the save new data option will either

1. Open a new file dialog box and allow the user to name a new file to save the data,
2. Automatically save and rename the file to the data directory set in the F12: Preferences Menu, using the File Naming Conventions, also set on this menu.

***Send to MLI***

The Send to MLI button provides the user a way to send a measurement or set of measurements directly to MLI. The MLI site and MLI Folder are options that must be specified when using the Send to MLI button on the main screen. Please refer to the Preferences section for description of these settings. When using the send to MLI Option the correct MLI folder must be specified or the data will not be sent. Contact you MLI representative to get the correct setup information.

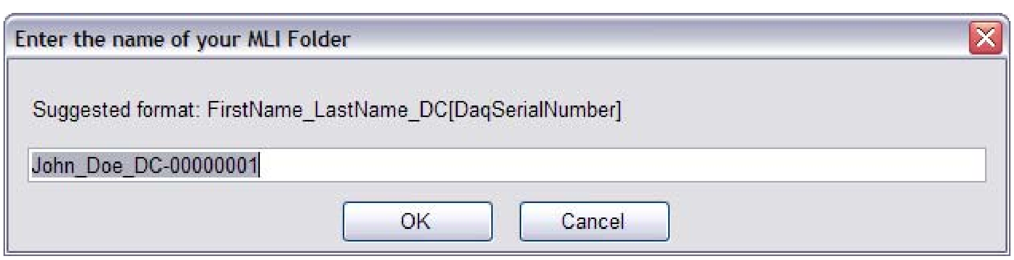

Figure 25: Send to MLI

## 1.3 Data Plotting and Analysis

This section describes the setting for changing the visual display of the data as well as the Stability Lobe Diagram settings and analysis.

### *F Keys for Graphical Display Properties*

The menus for the changing the setting for the plots and the stability lobe analysis are accessible along the right side of the main screen or by using the F keys.

F1 or Esc: Main TXF Screen
F2: Legend
F3: Cursors
F4: Range
F5,6,7: Stability Lobes

- F5- Stability lobe diagram Depth of Cut (DOC) Lobes
- F6- Stability lobe diagram MRR Lobes
- F7- Stability lobe diagram Power Lobes

F8: Modal
F12: Preferences

#### F1 or Esc: Main TXF Screen

This function, F1 or ESC, returns the user to the main TXF Screen.

#### F2: Legend

This tab allows the user to turn on and off the limits for each plot and to change the properties (color and line width) of each data set. To access the properties menu for each data series, point the cursor at the desired data series and right click.

At the right under the Legend heading the active plot will be displayed, shown as Top Plot in Figure 26. This means the legend displayed below is relative to this plot. To activate the setting for the other plot, simply move your cursor over the desired plot, and the legend will be relevant to the indicated plot. The active plot is outlined in red and displayed in the heading under the Plot Range Title. To turn on or off the data displayed in the plot click the colored box to the right of the label name.

If the user has fully set up all the other machining information including the machine, tool, holder, and material details located in the
Project Tab, then there are 9 other limit boundaries that can be displayed on the stability lobe diagram.

Machining Parameters: The green cursor displays the target cutting parameters entered on the Cut Data Tab by the user.

Current Conditions: The blue cursor displays the users current conditions entered on the Current Conditions by the user.

Power Limit: The Power limit shows a boundary line as the maximum allowable depth of cut based on the Machine Power Curve. The Enable Spindle Power/Torque Curve must be enabled for this limit to be available.

Tool Length Line: The tool length line shows the maximum allowable depth of cut based on the flute length or cutting edge length of the tool.  If the user does not enter a valid number for the cutting edge length in the
Project Tab, Tool Details, this limit will not be available for display.

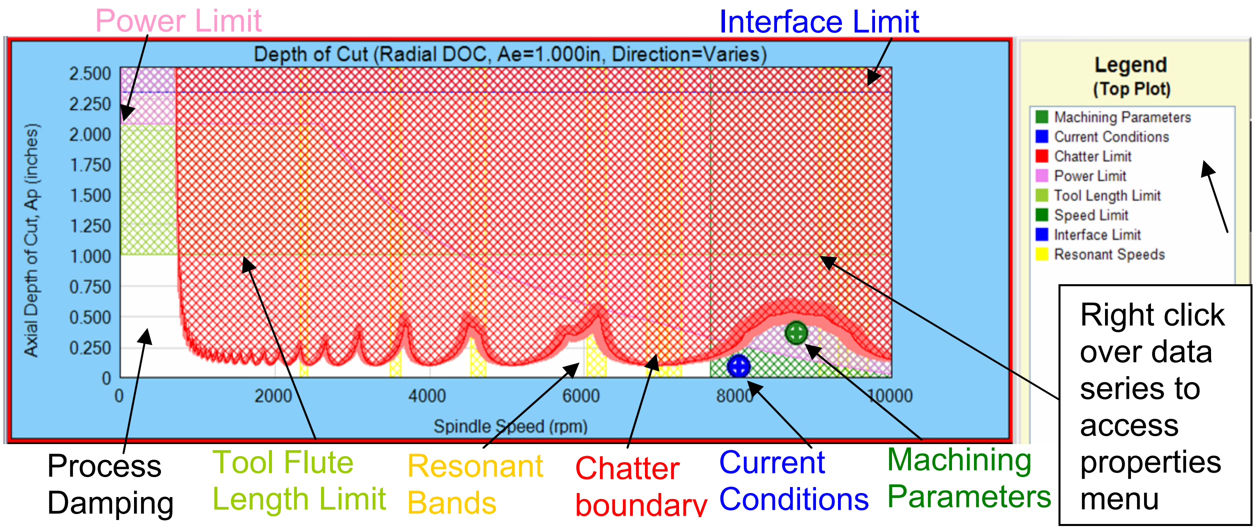

Figure 26: Stability Chart with Limits displayed

Speed Limit: the speed limit line is the maximum allow spindle speed based on the maximum surface speed value entered in the
Project Tab under Material Details. If a valid number for this parameter is not entered, this limit will not be available for display.

Resonant Speeds: The resonant speeds are spindle speed bands that correspond to the dominant natural frequencies of the system.  Theoretically resonant bands occur where the TPF harmonics crosses the chatter frequency bands as shown in Figure 30. The number of harmonics setting under the Stability Tab will dictate how many bands are displayed. So if the Number of Resonance Harmonics is 4, then bands would occur at the primary spindle speed (N), 2N, ½N and ⅓ N.

Interface limit: The interface limit is based on the machine interface that is selected for the file on the Machine Details Tab, Interface and Spindle Bearing Limit settings.

Spindle Bending Limit – The spindle bending limit is based on the front bearing distance and bending moment limit set on the Machine Details Tab, Interface and Spindle Bearing Limit. If the user leaves these cells blank or enters 0, no limit will be displayed.

Holder bending limit – The holder bending limit is controlled from the Holder Details Menu Figure 7.  For all tools and holder combinations other than shrink fit, the user must specify a maximum bending moment on the Holder Details Menu, Figure 28 (top). If the user leaves these cells blank or enters 0, no limit will be displayed.
Tool Pullout Limit – The Tool bending limit is controlled from the Holder Details Menu Figure 7 and is specific to shrink fit tools.  For shrink fit tool holders the user must specify the contact length between the tool and holder, the interference between the

tool diameter and holder diameter, and the Holder outer diameter. If the user leaves these cells blank or enters 0, no limit will be displayed.

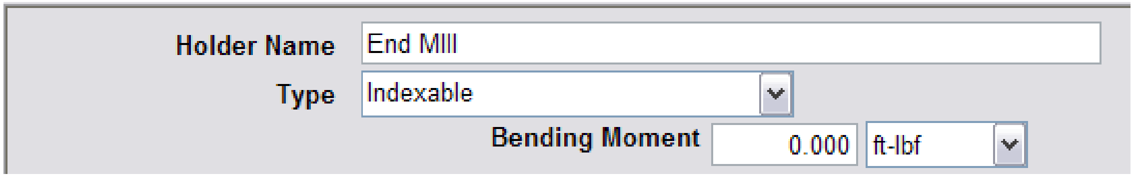


Figure 27: Holder Details Menu showing Holder Bending Limit controls

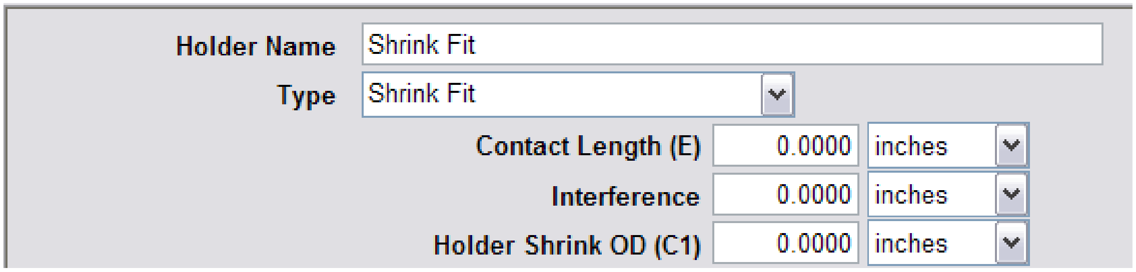


Figure 28: Holder Details Menu showing Tool pullout controls

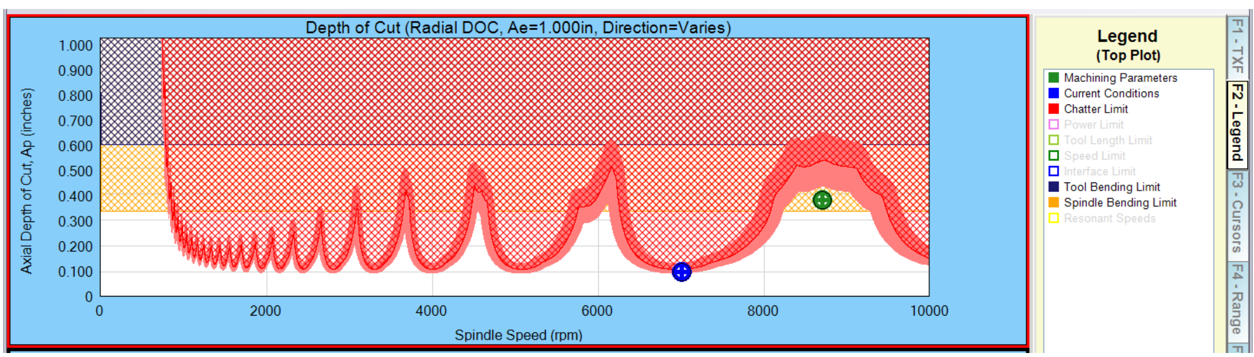


Figure 29: Spindle Bending Limit and Tool Bending Limit

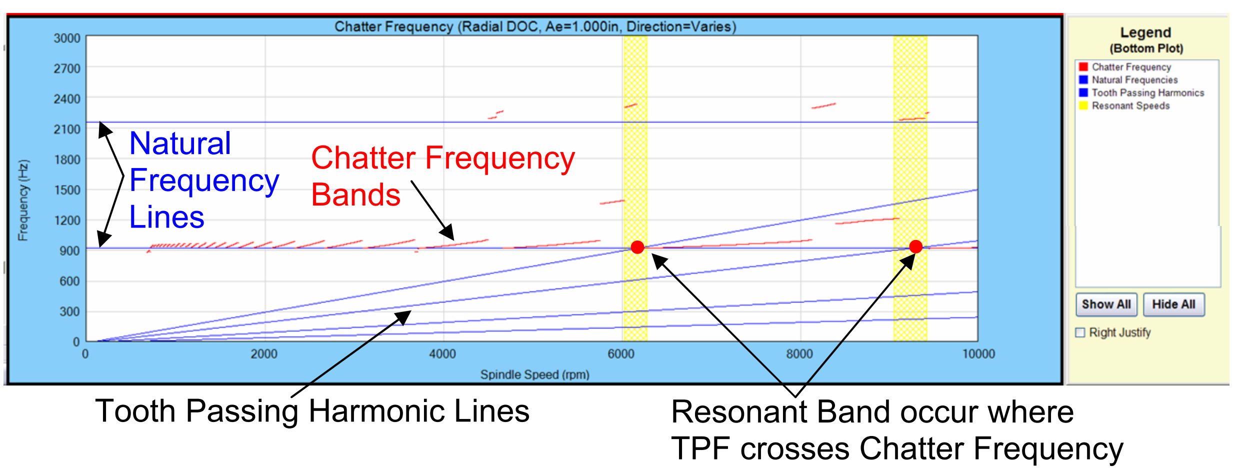


Figure 30: Chatter Frequency with Limits displayed

## F3: Cursors

This tab lets the user apply a cursor to a given data set and acquire the values of the data at the cursor location. The cursor will be relative to the data chosen in the Data Series drop down menu.

In the example shown in Figure 31, the data cursor displays the Power Limit value. The spindle speed and axial depth of cut are relative to the top plot, while the frequency displayed is the chatter frequency from the lower plot. When the chatter frequency data series is displayed the Axial Depth of Cut and Frequency readouts will not be valid. In this case they will read 0 or the last active value.

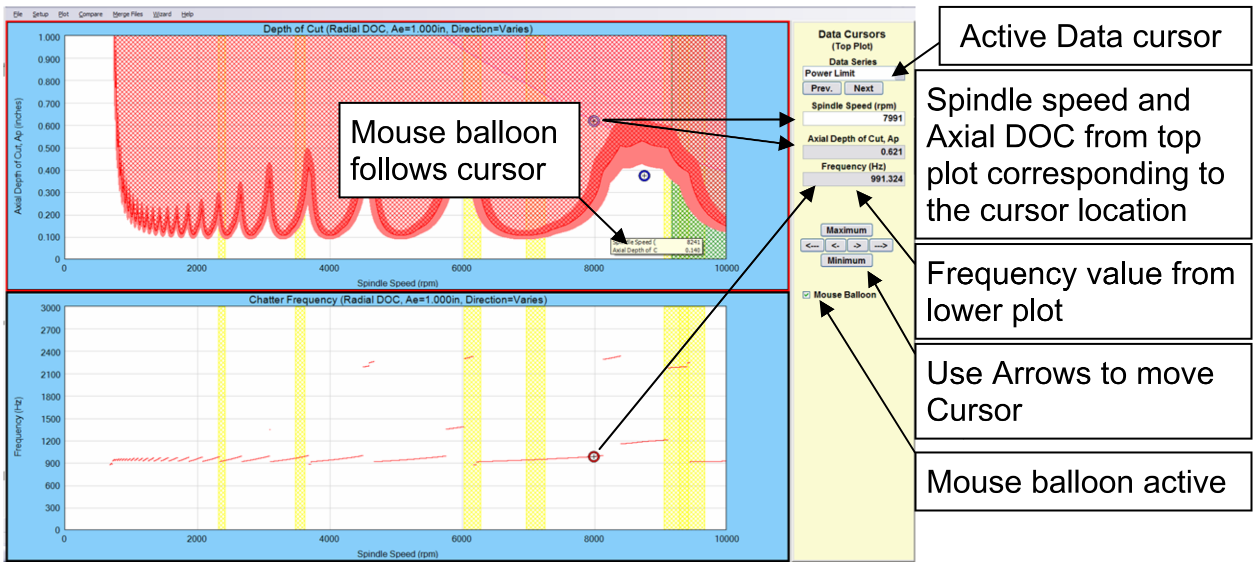


Figure 31: Data Cursors

## F4: Range

This tab allows the user to adjust the X and Y axis Range setting for each of the plots shown. Again the settings displayed at the right are relevant to the plot selected (by positioning the mouse over the desired plot). The active plot is outlined in red and displayed in the heading under the Plot Range Title.

Get Range: Will load the current range values (as displayed on the active plot) into the control cells.

Set Range: Will set the plot range values to the values the user enters into the control cells.

Fix Range: Will set the default range settings found in the Setup Menu under the Plot Range Tab to the current plot axes range. This will deactivate the Autorange option and set fixed range values.

## F5,6,7: Stability Lobes

F5 access the traditional stability Lobe diagram, showing Depth of Cut vs. Spindle speed. The controls to the right of the diagram allow the user to change 3 types of settings.

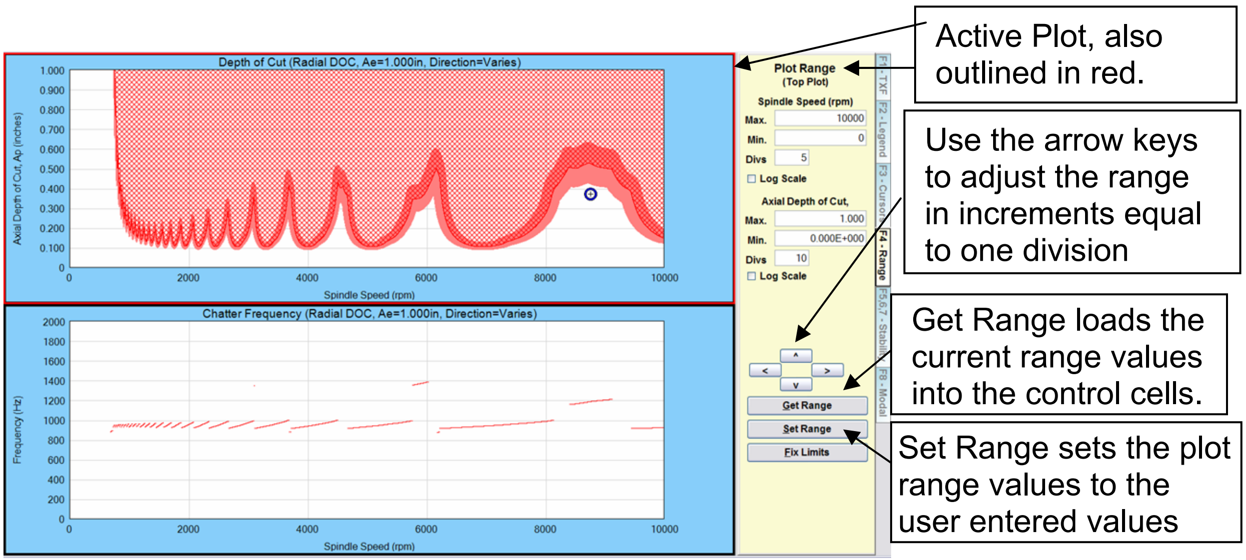


Figure 32: F4 Range

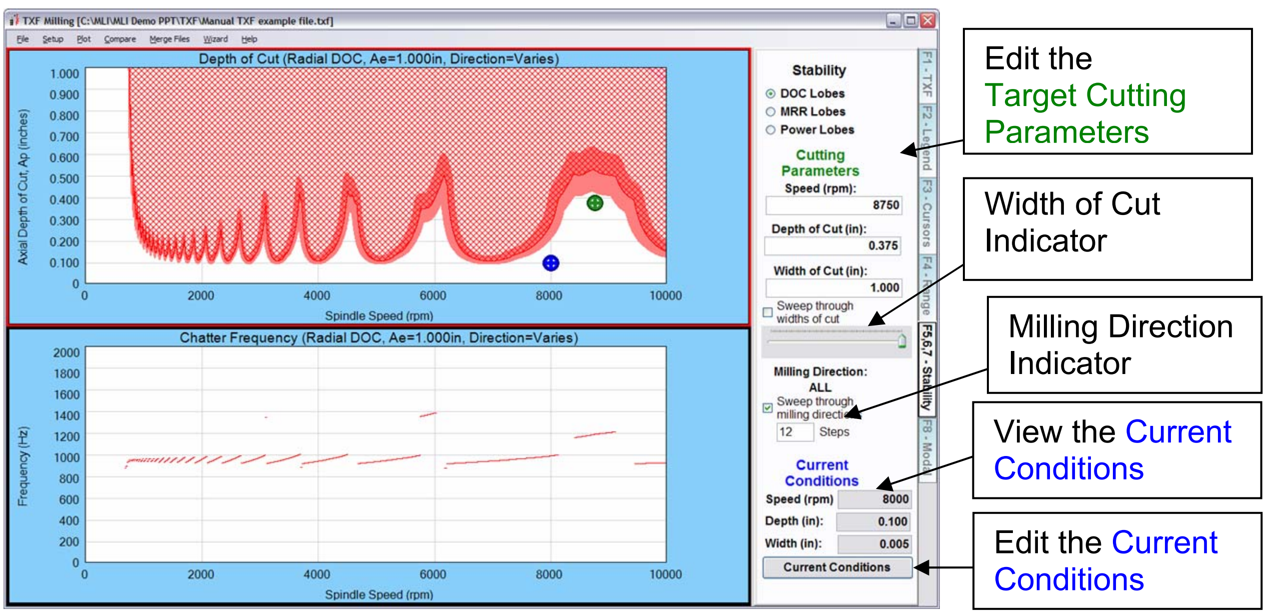


Figure 33: F5 DOC Stability Lobes

First is the type of Lobing diagram that will be displayed, Depth of cut (DOC), Metal Removal Rate (MRR), and Power Lobes. Figure 33 and Figure 34 show each type of Lobing diagram.

The second two options, Width of cut and Milling direction, are the same features available on the Setup-Cut Data Tab. The initial values displayed for Width of cut and

Milling direction will be the user selected values from the Cut Data Tab. These options provide a user friendly way to see how changing the milling direction or width of cut will affect the Lobing diagrams.

Finally, this tab allows the user to view and edit both the Target Cutting Parameters and the Current Conditions

To edit the Target Cutting Parameters type new values into the control cell. When editing the Target Cutting Parameters the stability lobes will regenerate displaying a new position for the green target.

To edit the Current Conditions click the current conditions button which will open the Current Conditions dialog box, Figure 39.

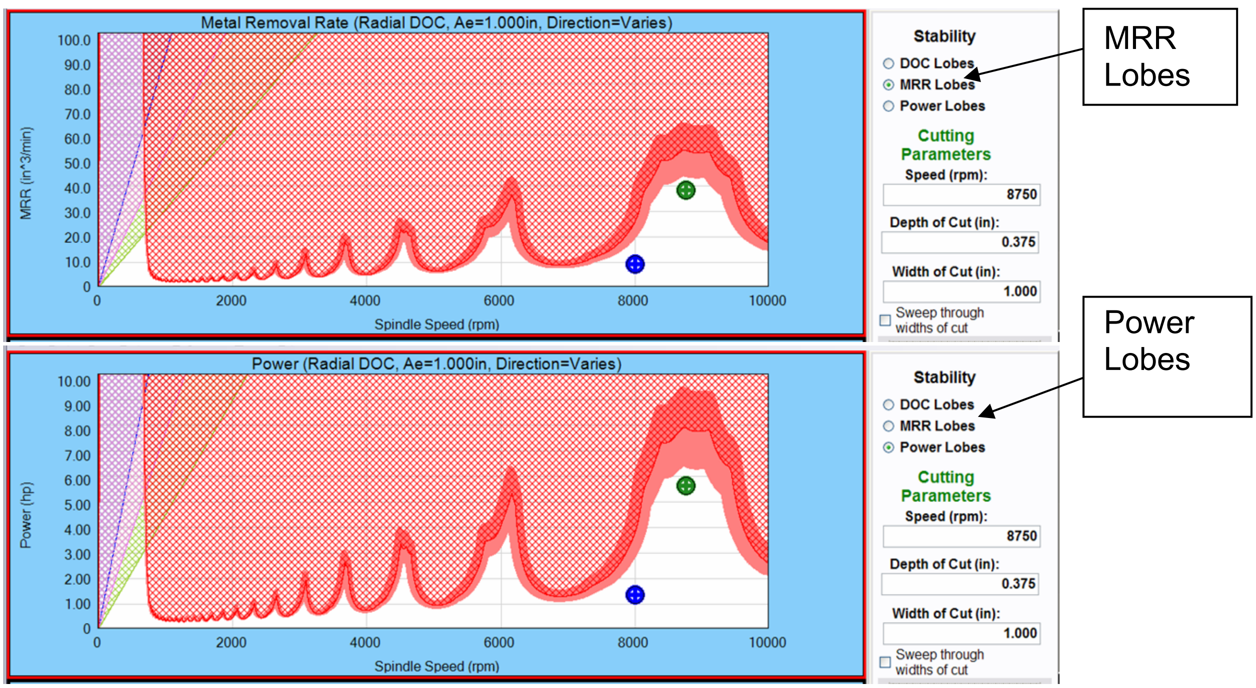

Figure 34: (top) F6 MRR Lobes and (bottom) F7 Power Lobes

**F8: Modal**

The F8 Tab allows the user to do a mode fit to the measured data, as shown in Figure 35. The modal fit can serve several purposes including

- Plotting the stability lobe diagram using the modal fit of the data instead of the actual data, see the section titled Use Modal Fit instead of Measured Data.
- Plotting the mode shape(s) of the data, see section Mode Shapes
- Identifying the modal fit parameters

To complete the modal fit follow the steps below:

- Click Add, and a box representing the bracketing frequencies will appear on the screen

- The user can click on one edge of the box, holding down the mouse key and drag the bracketing frequencies to the desired positions
- Alternatively the user can click Edit and manually enter the desired bracketing frequencies.
- TXF software will automatically estimate the Frequency, Stiffness, and Damping and display (in red) a best fit curve to the measured FRF

If the user desires to edit the modal fit parameters, click the Edit button to access the Modal Fit Parameter Pop up window. The default is for TXF software to automatically estimate the frequency, stiffness, and damping. Deselect this option to allow the modal fit parameters to become active. Edit the values as desired. The modal fit will not change until OK is selected. If Automatically estimate the Frequency, Stiffness, and Damping is reselected any edits to the modal fit parameters will be lost.

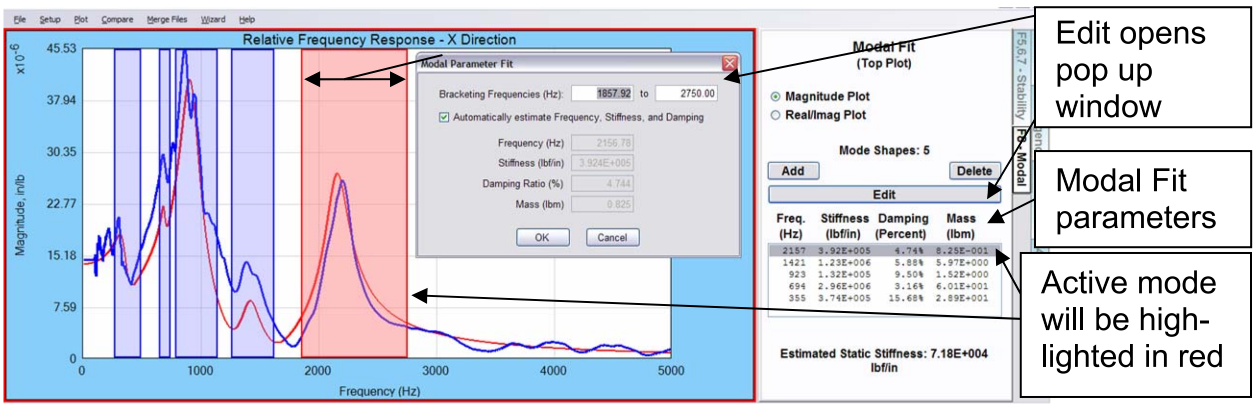


Figure 35: Modal Fit Parameters TXF

***Right Click and Zoom options***

A menu is accessible by Right Clicking in any plot window. This menu provides zooming options as well as a fast way to change the plot being displayed. This menu is shown in Figure 36.

To zoom into a specific region on the plot, hold the left mouse button down and drag a box around the region that you desire to zoom into.

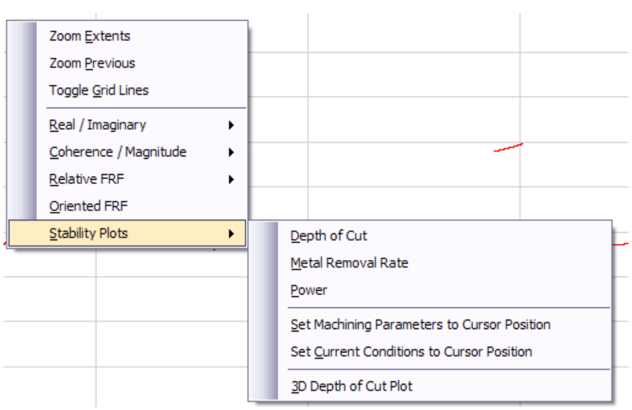


Figure 36: Right Click Menu

Zoom Extents: This option will reset the axes range to the extents based on the active setting on the Plot Range Tab.

Zoom Previous: This option will reset the axes range to the last plot selected using the zoom window.

Toggle Grid Lines: Will turn the grid lines on/off.

Real / Imaginary: Allows the users to choose display the Real and Imaginary plots for each measurement made.

Coherence / Magnitude: Allows the users to choose display the Coherence and Magnitude plots for each measurement made.

Relative FRF: The relative FRF combines the all the FRFs in the file (tool, workpiece, and/or cross) into a single FRF for each direction X or Y. The user can display the X Relative FRF, the Y Relative FRF, or both using this menu.

Oriented FRF: The Oriented FRF combines both directions X and Y and all measurements into one combined FRF. This is the final FRF for the stability lobes.

Stability Plots: As shown in Figure 36, there are 4 plot features that can be accessed from this menu, Depth of Cut Lobing diagram, Metal Removal Lobing Diagram, Power Lobing Diagram, and the 3D Depth of Cut Plot. For more details on these options, see the section titled The Plot Menu (page 49).

**Set machining parameters to cursor position**

This option will set the target machining parameters on the Cut Data Tab to the current cursor position.

**Set current conditions to cursor position**

This option will set the current conditions on the Setup Drop Down Menu, Current Conditions to the current cursor position.

## 1.4 Drop Down Menu

The Drop Down Menus are another way to access all of the features described above. In addition there are other menu options available in the Drop Down Menu that cannot be accessed any other way.

### *The File Menu*

The file menu allow the user to create a new file, open and existing file, re-save the data, save the data with a new file name, import data and export data, and print options.

New: opens new file

Clear Data: Will clear all measurement data from the file.

Open: opens an existing file Re-Save (Save): saves file using the existing file name, this writes over the existing file and will save any changes made to the document.
Save New (Save As): saves file with a new name

Send to MLI: The Send to MLI button provides the user a way to send a measurement or set of measurements directly to MLI, see Figure 25 and the corresponding explanation.

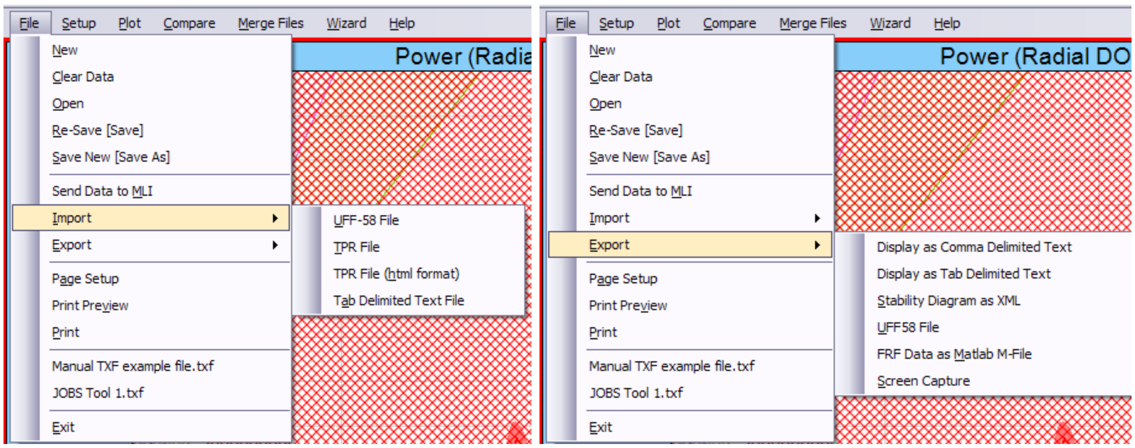

Figure 37: File Menu, Import and Export Menus

Import: There are 4 file formats that can be imported into TXF.

- UFF-58 File - Universal file format 58 (UFF58) is a common standards in experimental dynamics, especially in the area of modal and structural analysis
- TPR File - The tpr file extension stands for portable binary run input file.
- TPR File (html format)
- Tab delimited text

Each must be in the appropriate format for correct import.  More details are available if needed.

Export: There are 6 formats that can be exported from TXF.

- Comma delimited text
- Tab delimited text
- Stability Diagram as XML
- UFF58 File
- FRF Data as Matlab M-file
- Screen Capture – NOTE, The screen capture export won't work properly if Windows is set up to fade the windows in and out.  The save dialog box might not fully fade away before the screen capture happens.  You can turn the fade effect off in the Control Panel.

Page Setup: Allows the user to change the page setup parameters before printing.

Print Preview: Gives the user a preview of the page(s) to be printed

Print: Allows the user to print the file

File Names: Shows most recent files

Exit: exits program

***Setup Drop Down Menu***

The Setup Menu allow the user to access the same features as in the panel at the right of the main TXF Screen,
Project Tab, Measurement, Sensors, Cut Data Tab, Stability, Machine Limits Tab, and Plot Range.

## Cutting Module:

Allow the users a quick way to change the cutting module. This option is located under the
Project Tab, and explained in full detail under this section in the manual above.

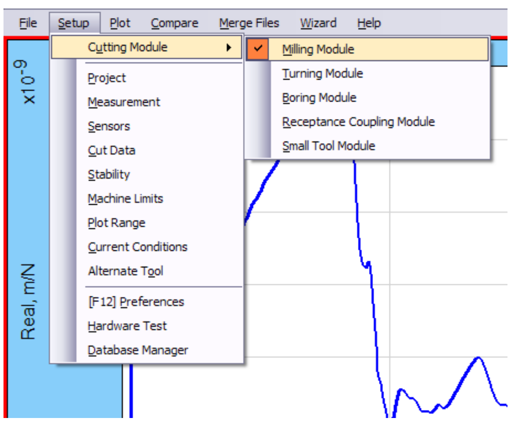


Figure 38: Setup Menu

## Current Conditions

This is an advanced feature and may not be assessable to all users. The primary purpose of this option is to provide a place to record the user's current cutting conditions and any notes regarding the stability or desires of the user, see Figure 39.

## Alternate Tool

This is an advanced feature and may not be assessable to all users. The primary purpose of this option is to provide a place to record the details of an alternate tool selection for the same operation, see Figure 39.

## F12: Preferences

This is an important settings menu that allows the user to indicate a variety of preference related to topic such as database locations, units, and the DAQ type.

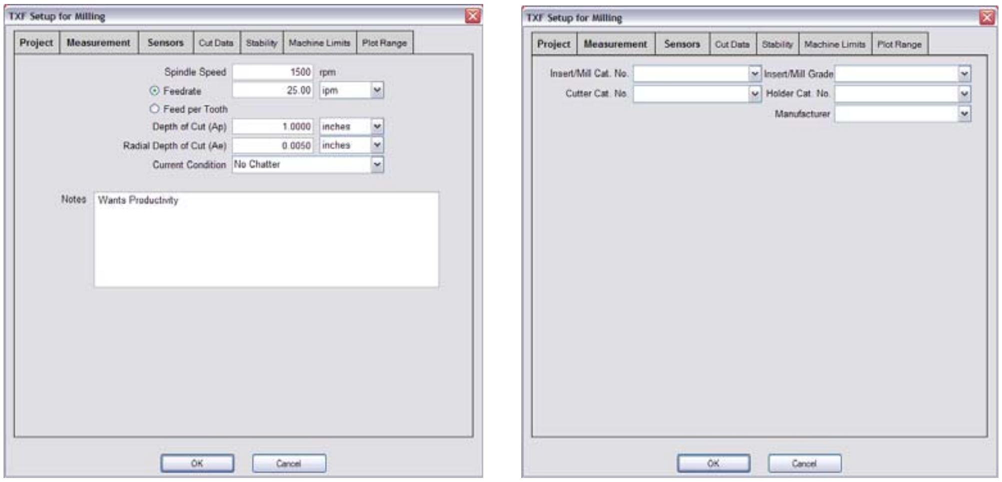


Figure 39: (left) User Current Conditions Menu (right) Alternate Tool Menu

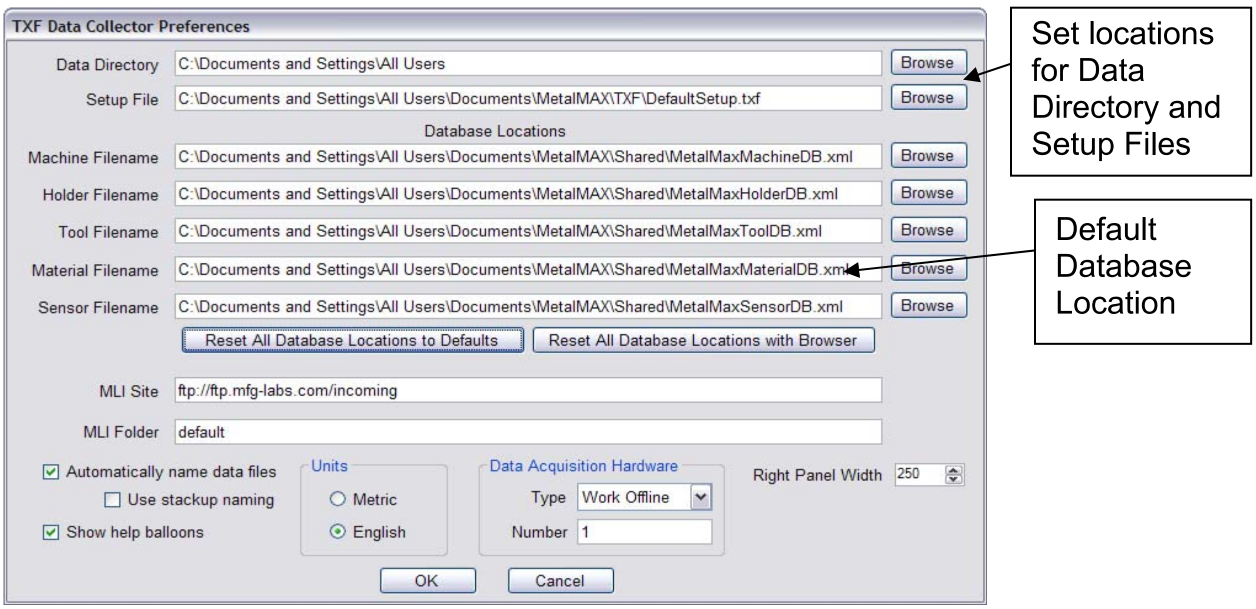


Figure 40: F12: Preferences

Data Directory: The data directory location allows the user to set the default location for the databases.
Setup File: The Setup File location allows the user to set the default location for the setup file.

The MLI site and MLI Folder are options that must be specified when using the Send to MLI button on the F1 or Esc: Main TXF Screen. When using the Send to MLI option the correct MLI folder must be specified. Contact your MLI representative to get the correct setup information.

*Reset all Database Locations to Defaults*

The 'Reset all Database Locations to Defaults' will set the Database Locations to the default path names shown in Figure 40.

*Reset all Database Locations with Brower*

When using the 'Reset all Database Locations with Brower', the data directory location will be the default. Additionally, the data directory location will be the location for files saved using the Save New option

*File Naming Conventions*

If Automatically name data files is selected, TXF will save the data file to the directory indicated in Data Directory without asking the user what directory and with the following naming convention:
Month-day-year-time-6_digit_random_number.txf

If Use Stack up Naming and Automatically name data files is selected TXF will save the data file to the directory indicated in data Directory without asking the user what directory and with the following naming convention:
Tool-Machine-Holder.txf

If ONLY Use Stack up Naming is selected TXF will save the data file with the following naming convention Tool-Machine-Holder.txf and TXF will ask the user to indicate which directory to save the data file.

If NO option is selected the user must specify both the data file name and the directory.

*Help Balloon*

If the user clicks on a field a help balloon will appear giving simple instructions regarding the type of data to be entered, see Figure 41. If the user does not want the help balloons to appear then the deselect Show help balloons, see Figure 41.

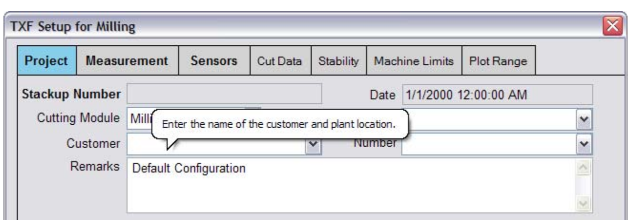

Figure 41: Help Balloon

The size and font of the Help Balloon can be edited in Windows by right clicking on the Desktop and select Properties then Appearances tab. Then click on the Advanced button (bottom of window on right). In the Advanced Appearance window, click on the Item pull down arrow and select ToolTip.

*Units*

The user should specify if their measurement are in Metric or English Units.

*DAQ type*

The user should indicate which data acquisition system was provided when they purchased the MetalMax hardware and software. Choices are as follows.

Work Offline

- NI-6062E Card (Standard MetalMax SIM2 from 2000-2008)
- NI-9234 Card (New USB 50kHz base option for 2009)
- Photon Plus (New USB 100kHz High End option for 2009)
- NI4431
- DT9837

The NI device number can also be specified.

*Right Panel Width*

This setting allows the user to change the size of the right panel column where buttons Calibrate, Setup Menu, Save Data, Print, and Trigger are located.

## Hardware Test

This menu gives the user a graphical display of the calibrations process.  It check for approximately 30 seconds to see if the channels have settled and displays Calibration Successful at the top and shows which channels settled at the bottom of the screen It also allows user to review Voltage levels before collecting data.

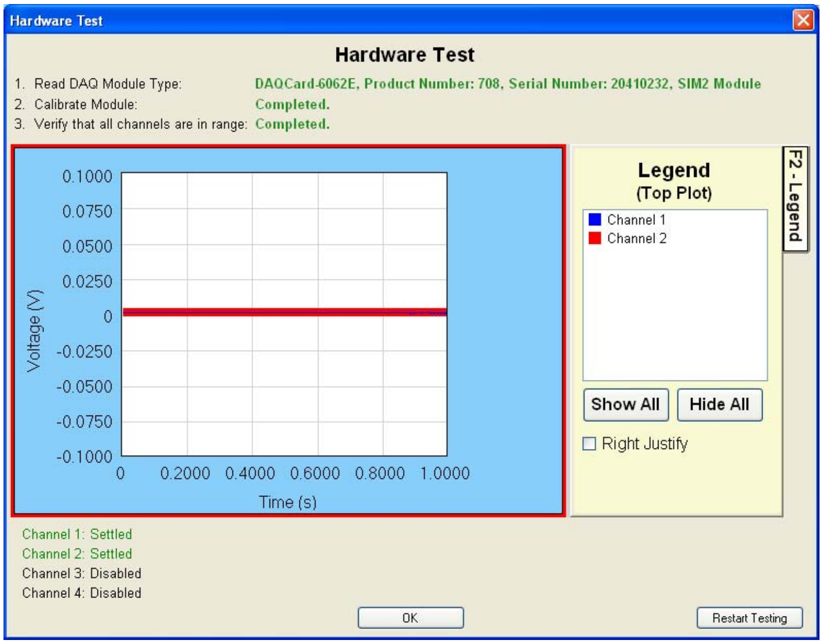


Figure 42: Hardware Test

## Database Manager

The Database Manger is accessed from the Setup Drop Down Menu.  The Database Manager allows the user to manage the databases by adding, editing, or deleting definitions from each database.  The database information is very similar to the information located under the Details Button.  However, the Details Button show the minimum required information whereas the Database allows the user to record additional information not included in the Details Button.

NOTE: If edits have been made in under the Details Button, but have not been added to the database by clicking ADD, the information located in the database may be different than the information local to the TXF file.

The default database location will correspond to the databases indicated in the preference menu.

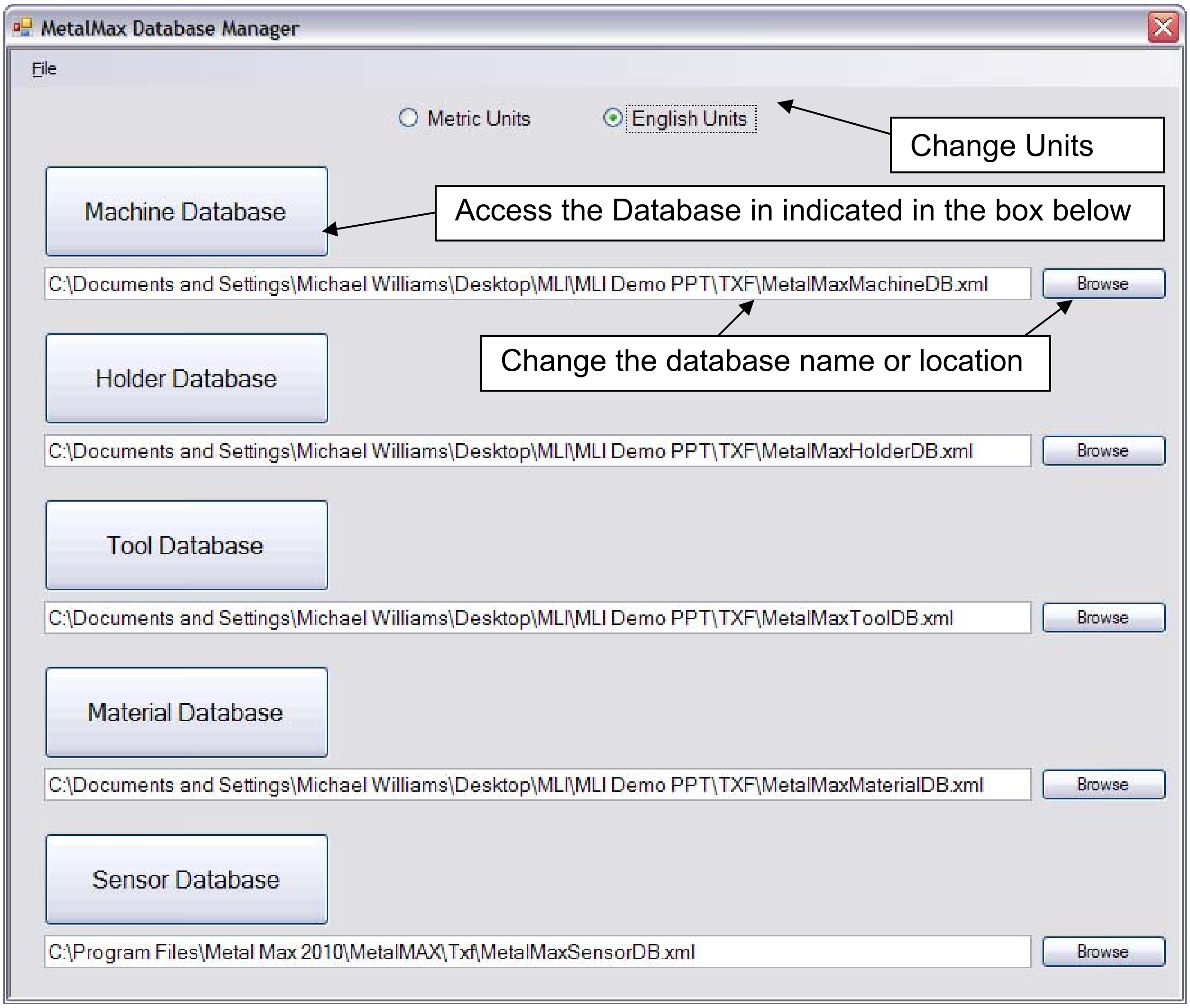

Figure 43: Database Manager

File: The File menu allows the user to export each individual database or all the databases.

*To create a new definition in the database*

To create a new machine in the database start with the default setup by choosing not in database from the drop down menu. Enter all the known information, paying specific attention to items in bold. When all the relevant information is entered, click ADD to add the machine definition to the database. Follow the same sequence to create new definitions for other databases.

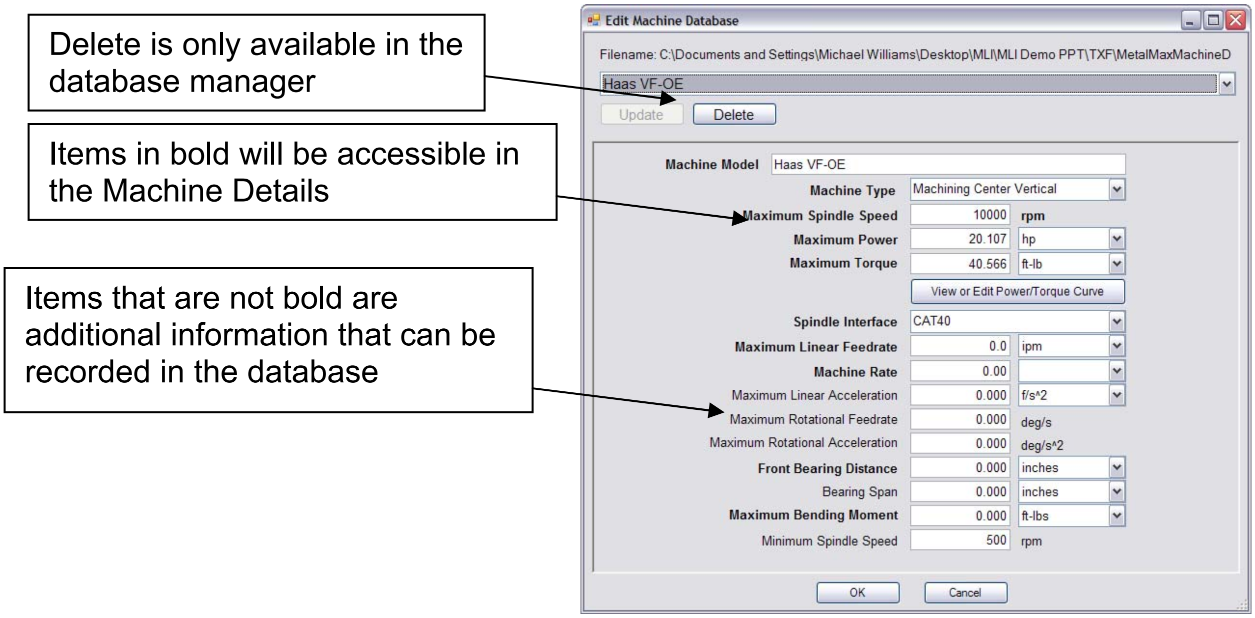


Figure 44: Edit Machine Database

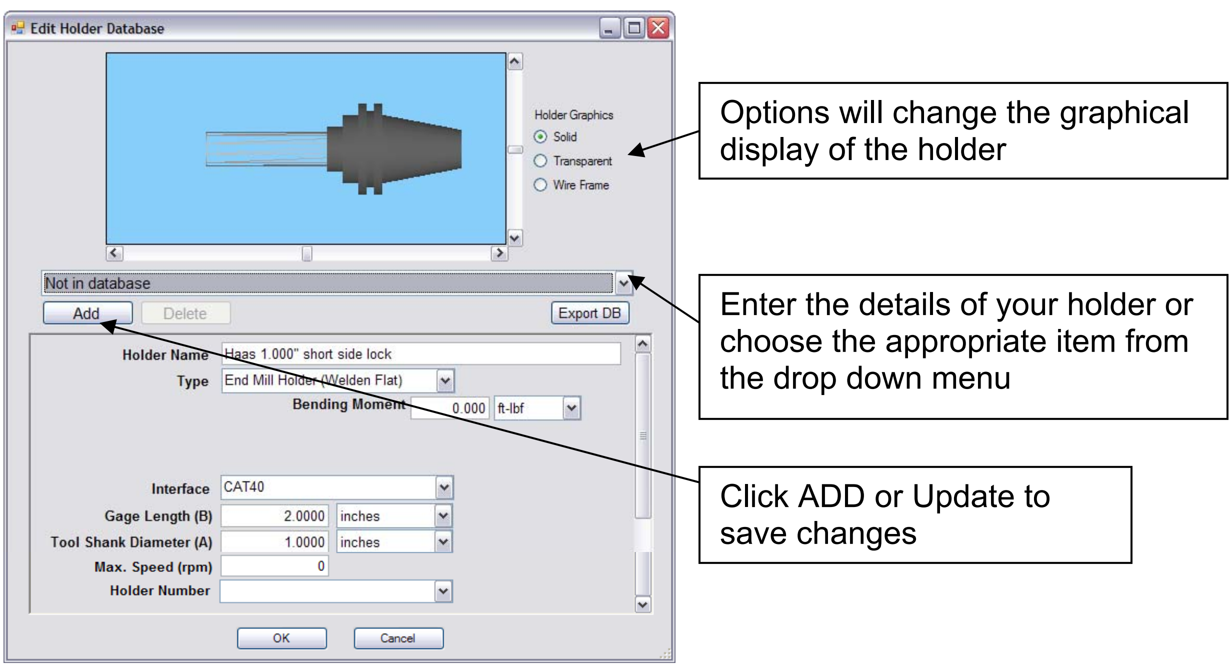


Figure 45: Edit Holder Database

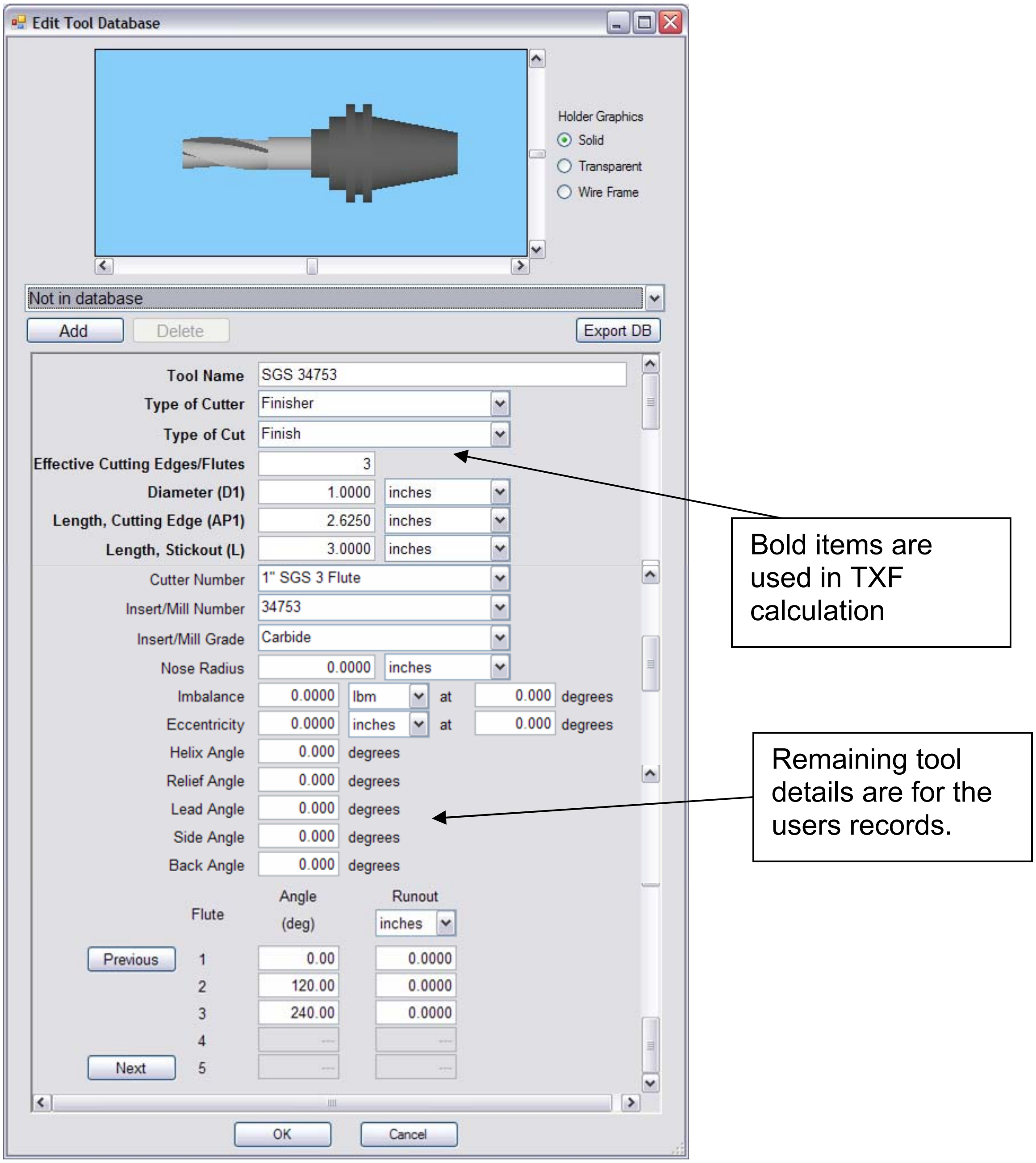

Figure 46: Edit Tool Database

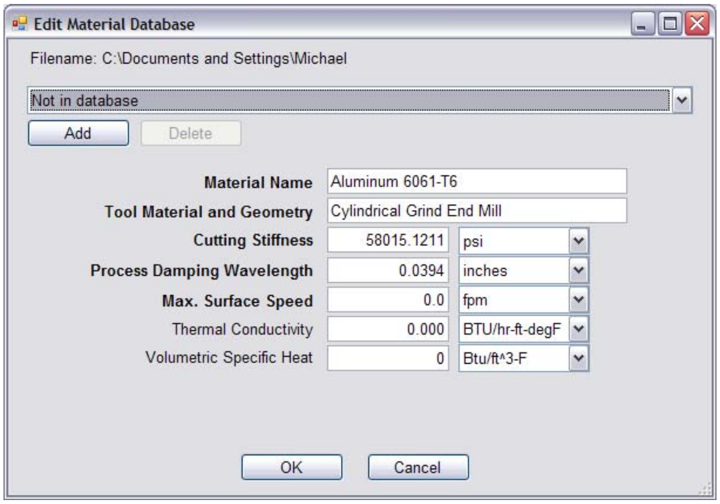

Figure 47: Edit Material Database

### *The Plot Menu*

The Plot Menu allow the user to access the same menus seen in the tabs along the right side of the TXF Screen, F1 or Esc: Main TXF Screen, F2: Legend, F3: Cursors, F4: Range, F5,6,7: Stability Lobes, F8: Modal, see Figure 48.

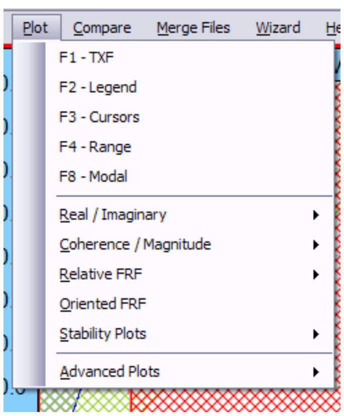

Figure 48: Plot Menu

## __Real / Imaginary:__

Allows the users to choose which Real and Imaginary FRF Plots to display. This menu will change based on the active measurements set in the Measurement Tab, as shown in Figure 49.

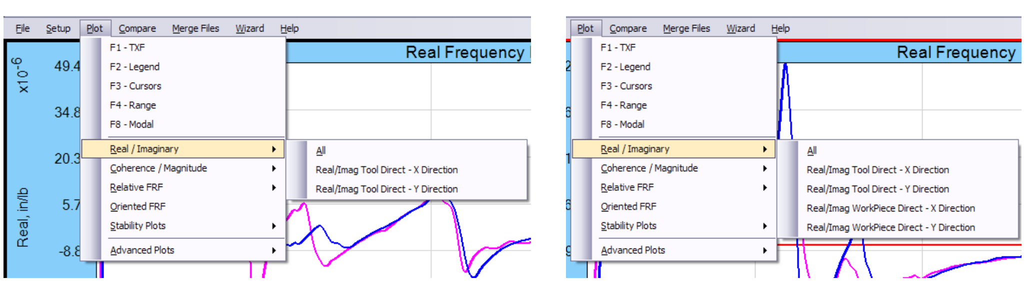

Figure 49: Plot Menu: Real and Imaginary

### Coherence / Magnitude:

Allows the users to choose display the Coherence and Magnitude plots for each measurement made. Coherence is a data quality assessment which identifies how much of the system response is related to the input force. The options available in this menu will change based on the active measurements set in the Measurement Tab.

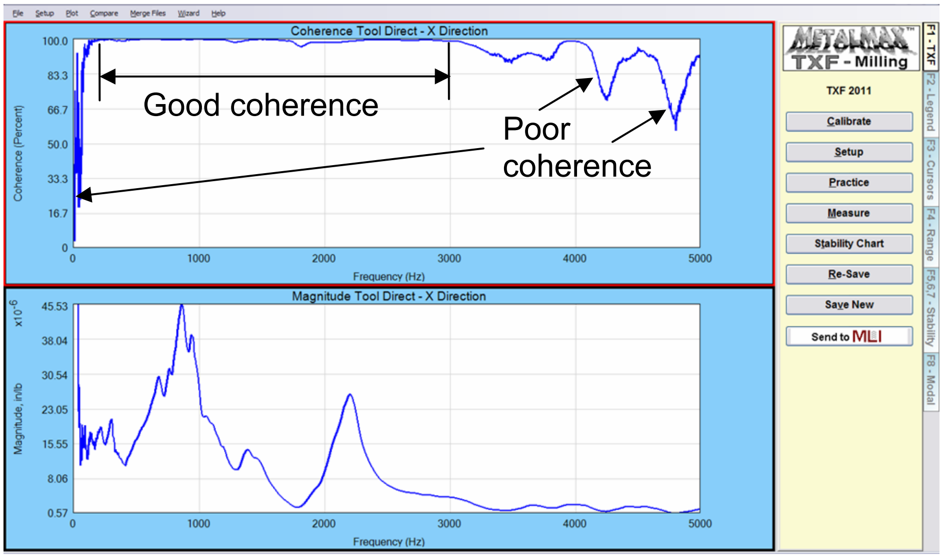


Figure 50: Coherence and Magnitude

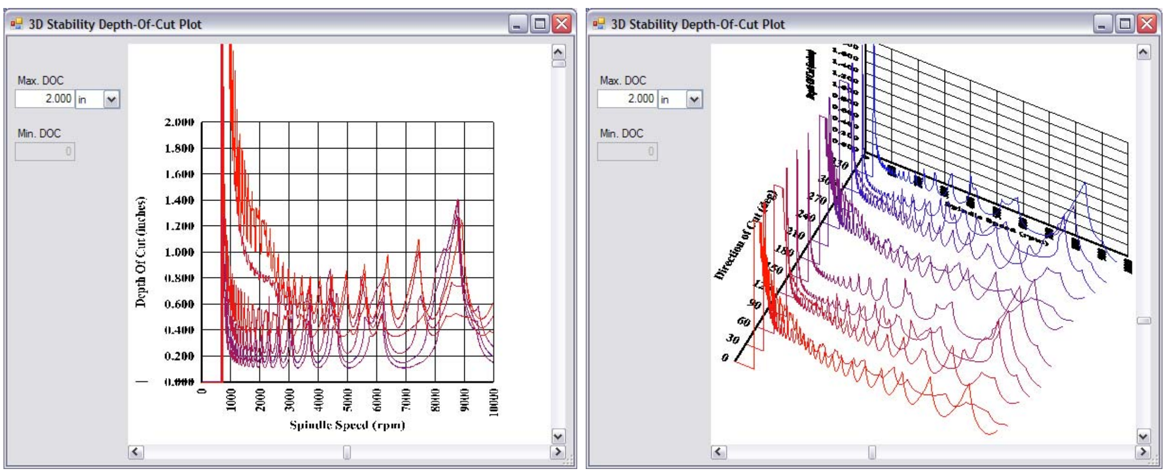


Figure 51: 3D Stability Lobes

### Relative FRF:

The relative FRF combines the all the FRFs in the file (tool, workpiece, and/or cross) into a single FRF for each direction X or Y. The user can display the X Relative FRF, the Y Relative FRF, or both using this menu.

### Oriented FRF:

The Oriented FRF combines both directions X and Y and all measurements into one combined FRF. This is the final FRF that creates the stability lobes.

## Stability Plots:

The Stability Plots menu allows the user to access the same plot functions as F5 Depth of Cut Lobes, F6 Metal Removal Rate Lobes, and F7 Power Lobes. In addition, this menu provides one additional plot, the 3D Stability Lobes.

## Advanced Plots:

The options available in this menu will change based on the active measurements set in the Measurement Tab. This menu will allow the users to view advanced plots including

The flexibility of the Tool or Workpiece (X or Y direction)
The phase of the Tool (X or Y direction)
Stiffness of the Tool (X or Y direction) which is the inverse of flexibility

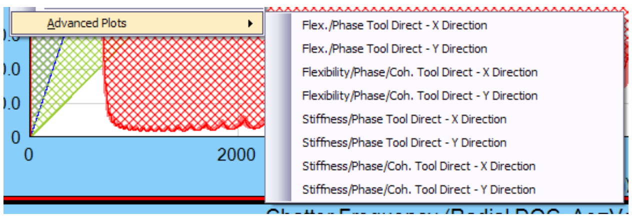


Figure 52: Advanced Plots

### *The Compare Menu*

This menu allows the user a way to compare data stored in separate TXF files.

File List: The user should use the browse button on the right side of the screen and chose the files that he/she wants to compare. Be sure to activate the File Number clicking the check box at the left.

To display all the files entered in the File compare menu the user must go under the drop down menu at the top left of the screen and choose which type of plot to display, as shown in Figure 53 at the right.

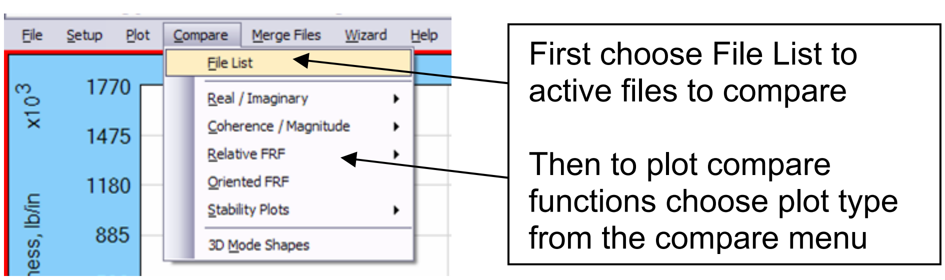


Figure 53: Compare Menu and File List Menu Box

## Mode Shapes

To plot the mode shape the user must first do a modal fit the data, see F8: Modal. There are essentially two types of mode shapes that TXF will plot, 2D shaft mode and a 2 ½ D or plate mode.

To plot a 2D shaft mode shape in the X direction the TXF file must have active X direction measurements recorded. Similarly, to plot a 2D shaft mode shape in the Y direction the TXF file must have active Y direction measurements recorded.

The example shown in Figure 55 shows a 2D shaft mode where a set of measurements was made along a tool at distances 3", 9", 12", and 15" from the tool tip. The master file should be the direct measurement at the tool tip. The impact was made in the X direction. As seen Figure 56 in there are two dominant frequencies and therefore two mode shapes generated and displayed in Figure 55.

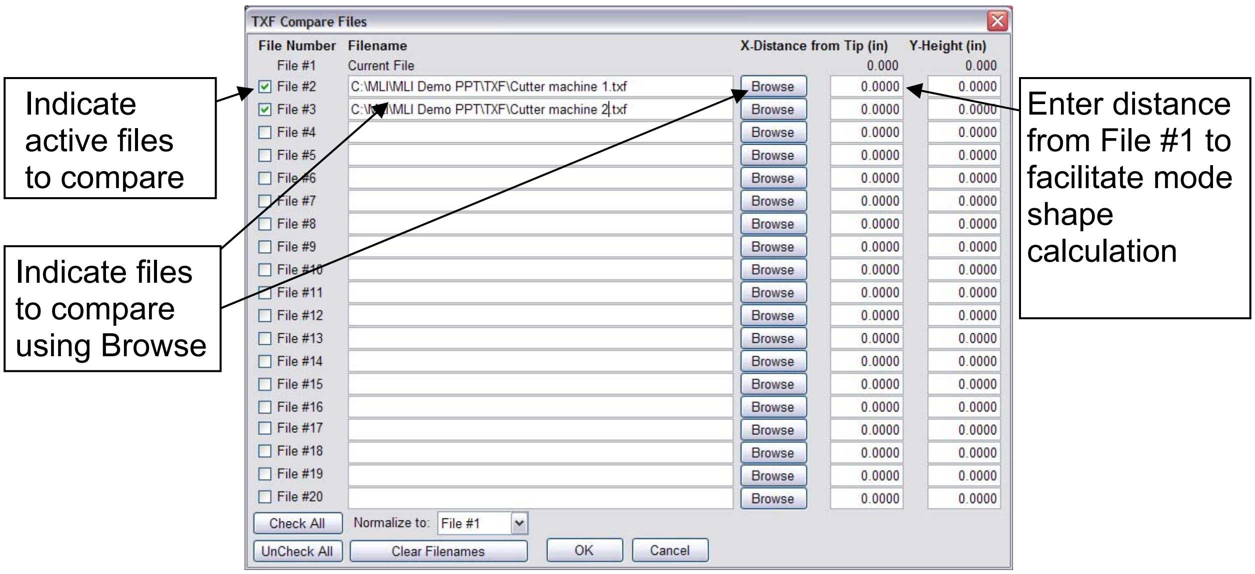


Figure 54: Compare Menu and File List Menu Box

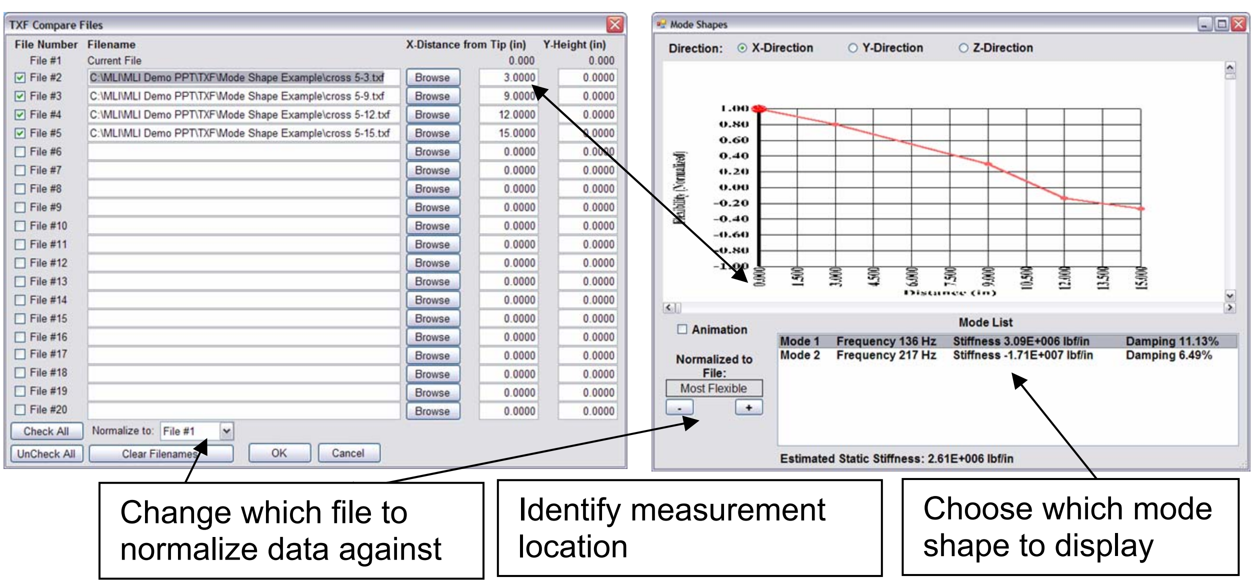


Figure 55: 3D Mode Shapes

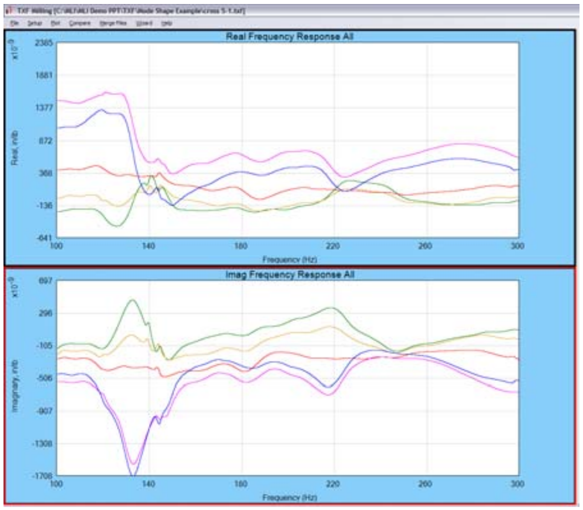

Figure 56: Compare – Real/Imaginary – All, showing 5 measurements for Mode shape generation

To generate a 2D shaft mode type mode shape

- Open each individual measurement file and created a modal fit, F8: Modal.
- Use The Compare Menu and identify the appropriate files as well as identify the measurement location for each file.
- Choose Compare – Real/Imaginary – All to view all the measurement files in one plot, as show in Figure 56.
- Choose Compare – 3D mode shapes to see the mode shapes as show in Figure 55.

***Merge Files***

This menu allows a user to combine files from two different files into one file. For example, if on a given machine the tool tip direct FRF in the X and Y direction was recorded and saved as tool direct.txf. Then a workpiece Direct measurement was saved in file 2, workpiece direct.txf. These file can be combined into one TXF file as shown in Figure 57.

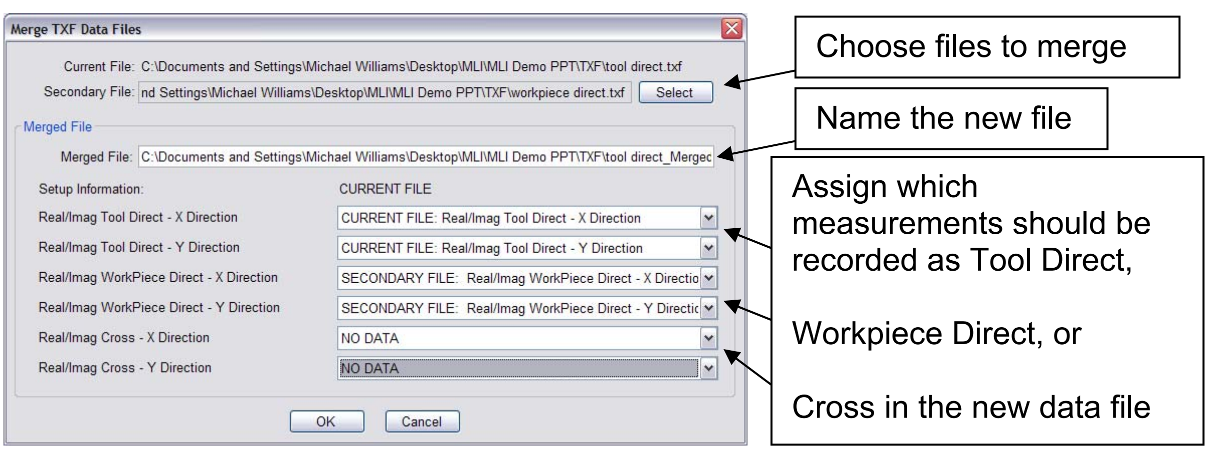

Figure 57: Merge TXF Data Files

### *Wizard*

This menu shows the user step by step instructions on how to setup the hardware and software setting and then to make FRF measurements.

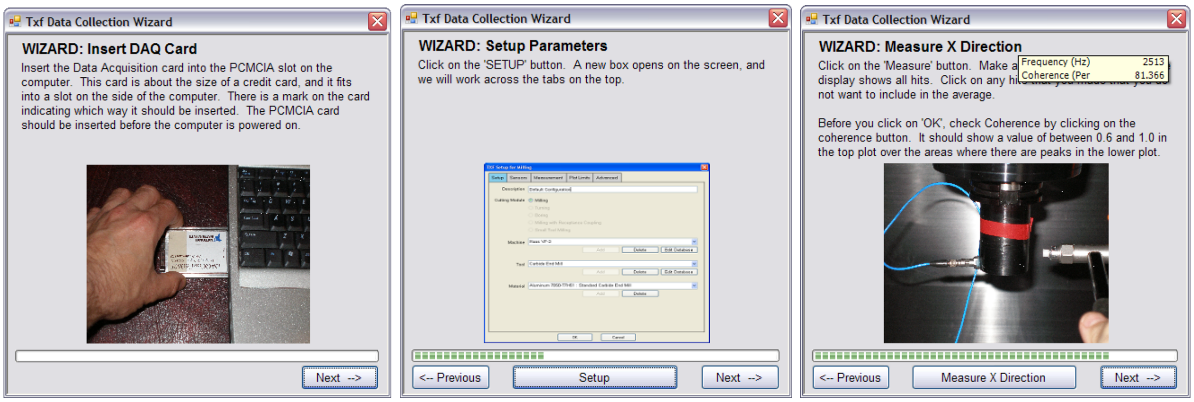

Figure 58: Wizard Snapshots

### *Help Menu*

Manual: opens up TXF user manual as a pdf file.

MLI Website: automatically connects the user to the MLI website if computer is connected to Internet.

About: provides the TXF release that is currently installed, the copyright information, and information about the individuals that were involved in coding the relevant release.

## *2.0 Best Practice Rules*

This section will review some of the best practices to help the user correclty choose a hammer and acclerometer pair for a given measurement and to review techniques for making a good impact on a given structure or tool.

Most hammer and accelerometers of the ICP type, contained in MetalMAX, have a maximum “linear” range of 5 volts. Although they can be utilized and produce output higher than 5 volts the best results are achieved when signals do not significantly exceed 5 volts (a warning is given in the software when this occurs).

Selection of the hammer and accelerometer pair is fundamentally an intuitive decision with some trial and evaluation. Some basic rules in making the initial selection are as follows:

### 2.1 Selection of the appropriate hammer

A hammer will have multiple tips each having a different stiffness for altering the force level and the impact duration, as shown in Figure 59. The choice of hammer and tip is critical to correctly excite the desired structure.

The hammer tip hardness controls the frequency response and has little effect on force levels. Harder tips provide higher frequency response.

Added mass or weight/extender will increase force but not dramatically alter frequency response.

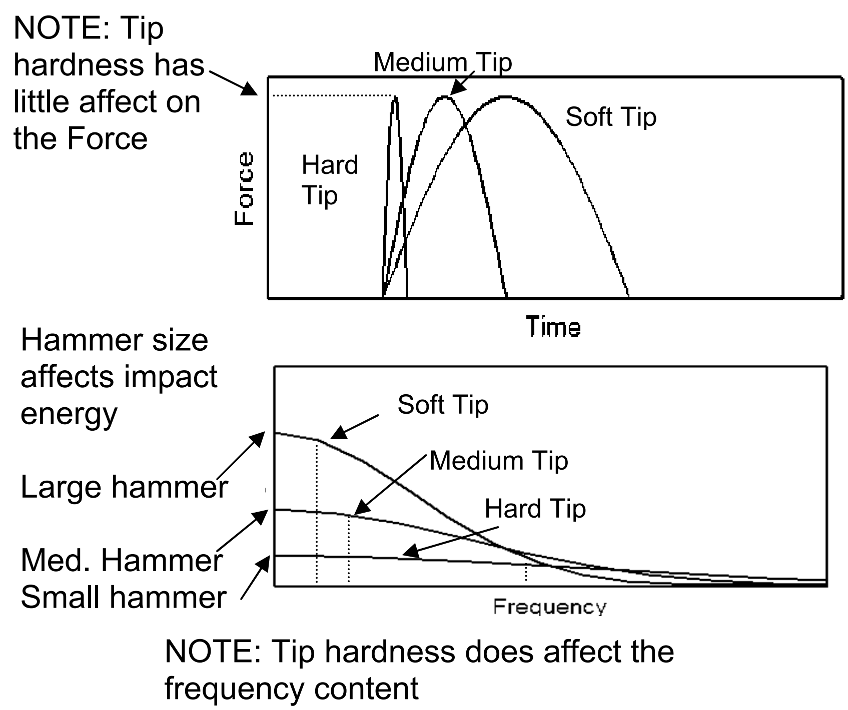


Figure 59: (top) Impact duration for soft, medium, and hard tip (bottom) Magnitude of impact energy versus frequency content of impact for different hammer mass and tip stiffness

A structure with a larger mass will require a larger impact force and therefore generally require added mass or a larger hammer size.

The magnitude of the impact, bottom plot Y axis, is determined by the mass of the hammer, while the frequency content of the impact is controlled by the stiffness of the tip, (X axis on the bottom plot of Figure 59).

## 2.2 Selection of the appropriate accelerometer

It is imperative to choose an accelerometer with suitable sensitivity for the desired frequency range of interest. First, it is desirable to have an accelerometer with as high a sensitivity as possible. However, the higher the sensitivity the higher the mass of the accelerometer. A high mass means a lower maximum working range because of the low natural frequency of the transducer. Additionally, it is feasible that the mass of the accelerometer can change the dynamics of the structure being measured. Second, mounting and orientation are critical. These considerations must be addressed when choosing which accelerometer is best for a given measurement.

The accelerometer mass and sensitivity are the main factors for accelerometer selection.

The accelerometer mass should not exceed 15% (ideally 10%) of the "modal/reflected" mass of the measurement location.

The accelerometer and hammer voltage levels are observed during the "Autorange" process. A minimum signal strength of 10 millivolts is acceptable for most measurements. When making a measurement if the accelerometer signal strength is not at least 10 mV then an accelerometer with a different sensitivity should be used or the hammer mass and strike velocity should be altered accordingly.

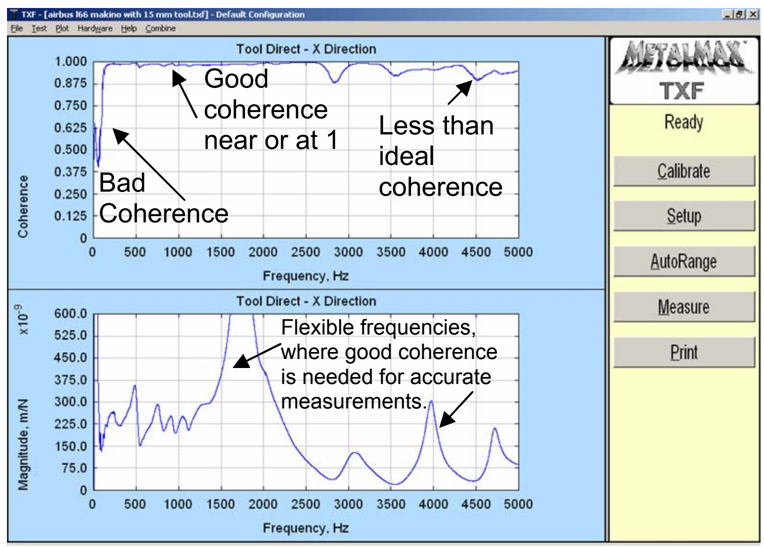


Figure 60: Coherence Magnitude Graph

Quantitative evaluation of the FRF measurement is ultimately made using the "Coherence" plot in TXF. Values of at least 0.80 (80%) at the location of the flexible frequencies (modes) produce the best results, see Figure 60.

## 2.3 Targeting

Basic rules for targeting the hammer on the tool or work piece (or any structure).

Parallel alignment of the hammer tip with the measuement axis of the accelerometer at impact is most important. To achieve this it may be necessary to hit the structure off axis from the accelerometer. This is of course needed when the accelerometer is mounted on the hammer impact side of the structure, as shown in Figure 61.

The machine should be place in an approximate cutting position, e.g. do not measure the home position of the machine (unless for maintenance monitoring purposes to achieve a consistent measurement location).

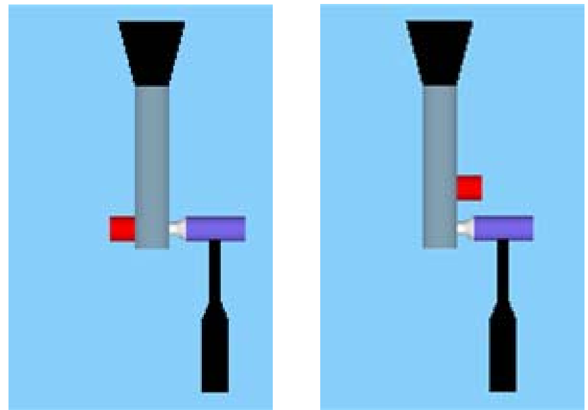

Figure 61: (left) Desired impact configuration, ensure hammer is aligned parallel to the accelerometer measurement axis (right) Impact off axis with the accelerometer to maintain axes alignment

Avoid attaching the accel. or attaching the hammer to secondary structures, e.g. rings, seals, inserts, etc. It will insure that measurement does not contain extraneous vibration characteristics of the secondary structure or produce arbitrary loading conditions.

With any adhesive ensure that the minimum amount of adhesive (wax, loctite, etc.) is used between the accelerometer face or mount and the structure.

Do not attempt to “hammer” the structure. Allow the hammer’s own weight to create the impact force. Additionally allow the hammer to freely “bounce” off the structure. Grip the hammer only tightly enough to guide it to its target.

Table 1: Nominal Sensitivity (Calibration) Factors

| Hammer/Accelerometer Serial No. | Sensitivity (Calibration) |
|---|---|
| SM Hammer 086D80 | 25 mv/lb |
| MD Hammer 086C04 | 5 mv/lb |
| LG Hammer 086C05 | 1 mv/lb |
| SM Accel 352C23 | 5 mv/g |
| MD Accel 352A21 | 10 mv/g |
| LG Accel 352C68 | 100 mv/g |
| Spin Accel 353B14 | 5 mv/g |
| XLG Accel 393A03 | 1000 mv/g |

Note: Added mass/weight/extender will affect the sensitivity; refer to calibration sheets for the specifics.

## *3.0 Sensor Calibration Check Procedure*

This section describes how to use the 1 kg mass (included in the kit) to check the calibration of the sensors. This procedure will identify if a pair of sensors (the hammer and accelerometer pair) used in this measurement procedure below is still within the initial calibration values provided in the calibration sheet. If one of the sensors is out of calibration, the procedure will need to be repeated changing the combination of sensors such that the user can trouble shoot which sensor is out of calibration.

To implement the calibration procedure we will use Newton's second law of motion - the acceleration of a body is parallel and directly proportional to the net force and inversely proportional to the mass (Equation 1), and setup and experimental procedure to test this law.

$$F = ma \qquad \text{Eq (1)}$$

Where F = Force (hammer),
a = acceleration (accelerometer)
m = mass (calibration mass 1 kg plus mass of accelerometer)

$$m = m_c + m_a \qquad \text{Eq (2)}$$

$m_c$ = calibration mass = 1 kg
$m_a$ = mass of the accelerometer

### 3.1 Setup Procedure

The experimental setup needs to allow the application of a force to a mass and then measure the acceleration of that mass. One of the most important parts of the setup is to suspend the mass such that it is free to swing in a pendulum fashion, see Figure 62.

Step 1: Suspend the mass from a string as shown in Figure 62. The longer the length of the string the better.

Step 2: Attach the accelerometer to the mass

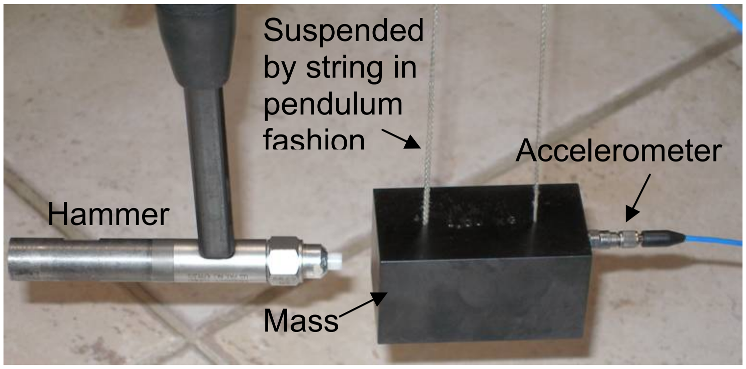

Figure 62: Sensor calibrations setup

Step 3: Start TXF and press F12 or select from the pull down menu “Preferences”. The screen shown in Figure 63 will appear. Please insure that “Metric” units are selected.

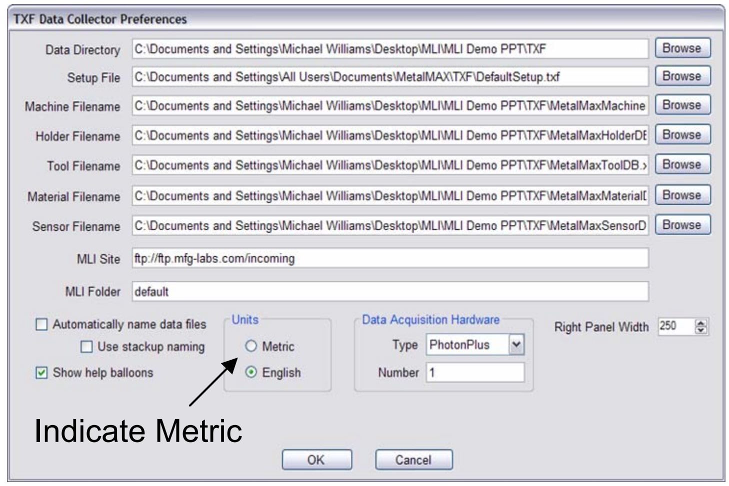


Figure 63: Preferences Menu

Step 4: Next use the “Settings” button on the right hand pane and click on the Measurement Tab or from the pull down menu select Settings: Measurement. Make only the X-direction active.

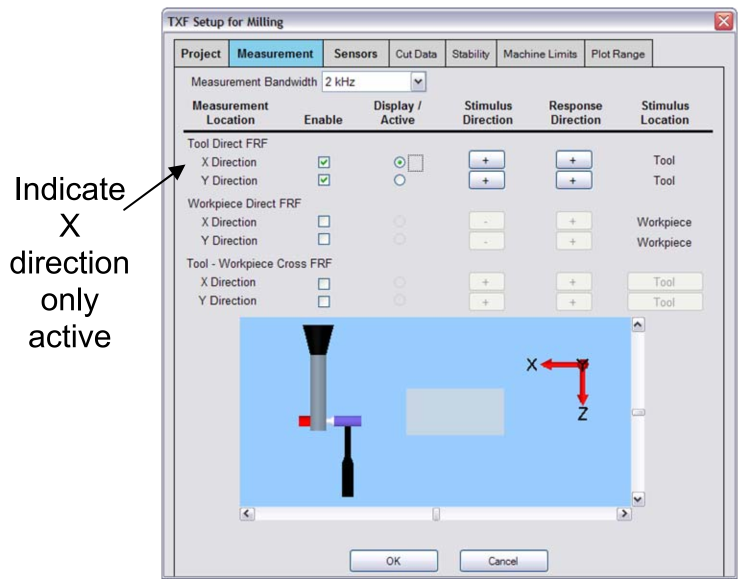


Figure 64: Settings: Measurement

Step 5: Next click on the Sensors Tab or select from the Setup pull down menu, “Sensors”. Select the sensors you wish to calibrate (hammer and accelerometer).

NOTE: Select “None” for Integration on the accelerometer.

Uncheck or deselect “Trap Overloads” and “Trap Double Hits” for both the hammer and accelerometer.

Step 6: Return to the main screen to take a sample.

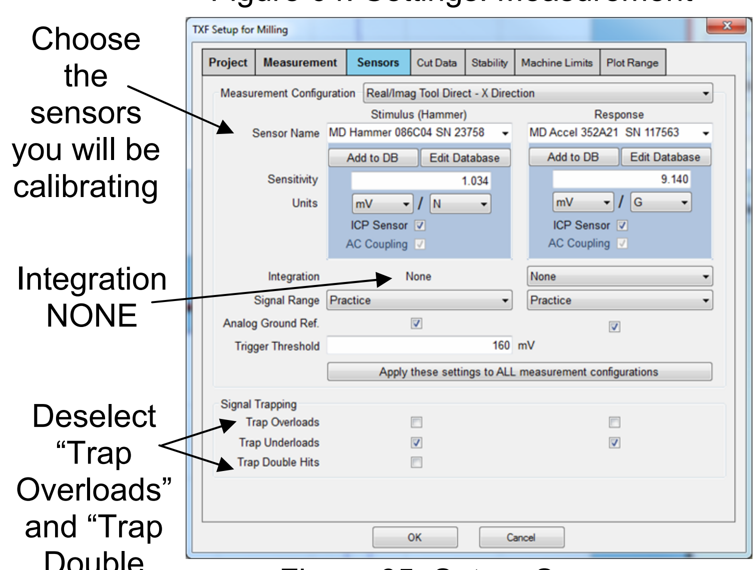


Figure 65: Setup: Sensors

Step 7: Go through the “Practice procedure” by striking the mass as parallel and square as possible. Steady the mass after each hit. Do this until the levels are acceptable.

NOTE: that levels that exceed 5 V will likely contain some non-linearity. Try to keep the hammer and accelerometer configuration as such that the practice levels do not exceed 5-6 V.

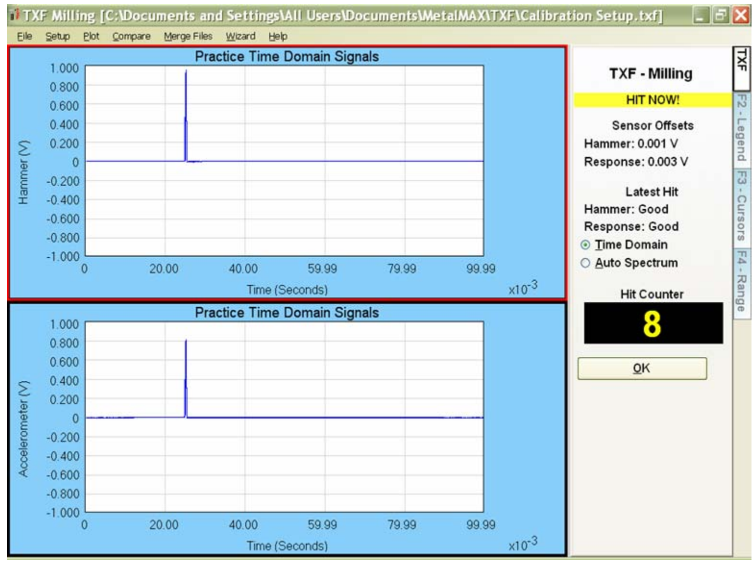


Figure 66: TXF Practice Screen

Step 8: Go to Measure and make 5-10 measurements for averaging. Be careful to capture any bounce or double hits.

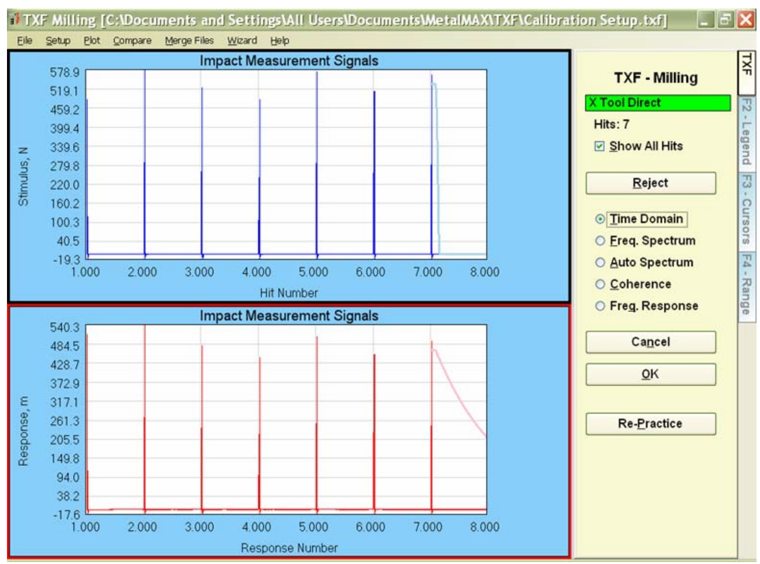


Figure 67: TXF Measure

Step 9: After completing a measurement click on OK and then right click on the graph and select “Coherence/Magnitude” “X-direction”.

You may wish to adjust the display range using the “Range” (F4) tab.

You should see a plot like above. The plot is of $\frac{a}{F}$ (acclerance)

NOTE: neglect or overlook the units

Solving from Equation 1 for $\frac{a}{F}$ gives Equation 2

$$\frac{a}{F} = \frac{1}{m} \qquad \text{Eq (3)}$$

If both of the sensors are calibrated correctly, the average value shown on the Magnitude graph (i.e. the lower graph in Figure 68) should be the inverse of the mass, $\frac{1}{m}$, in kilograms including the added mass of the accelerometer, within ±7%.

For example, the large accelerometer (352C68) has a mass of 2 grams. So m=1kg + 0.002 kg. Therefore, the value of the plot should be $\frac{1}{1+0.002} = \frac{1}{1.002} = 0.998$. Taking into account the ±7% the range of acceptable values is 0.9281 to 1.0677.

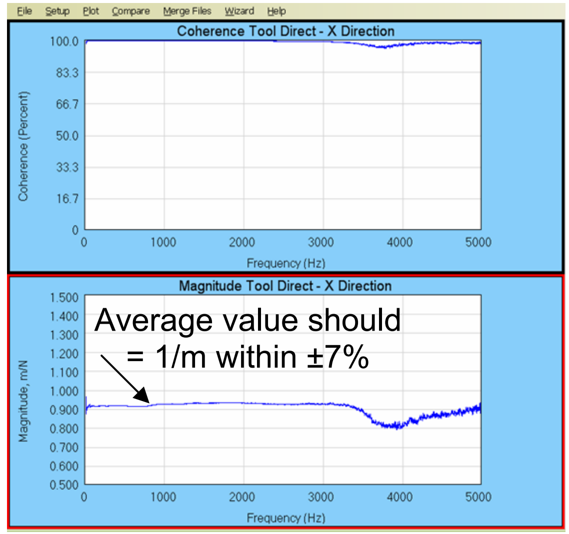


Figure 68: TXF Coherence and Magnitude Graph

If one of the sensors is not well calibrated then the value in the graph will fall outside this region. In this case an adjustment can be made to either or both of the calibration/sensitivity factors to compensate.

CAREFUL: the adjustment to these calibration factors will only be valid when making measurements using the same combination of sensors.

If the user desires to determine which sensor is the one that is out of calibration, this procedure should be repeated with other sensors including using two hammers or two accelerometers, until the problem sensor is located. At this time an adjustment can be made to this calibration factor for the sensor that is out of calibration. Alternatively the use can send the sensor back to PCB for recalibration.

## *4.0 Troubleshooting Guide*

THE FOLLOWING ARE TYPES OF PROBLEMS YOU MAY ENCOUNTER AND POSSIBLE SOLUTIONS. THE SOLUTIONS ARE LISTED IN ORDER OF LIKELY SUCCESS BUT NOT ALL NEED TO BE PERFORMED AS LISTED.

***Problem (1): Practice does not respond to hammer hits.***

- Check connections.
- Check that power is connected to the SIM2 module.
- Check that all connections are made to the sensor.
- Check that the data cable is firmly inserted into the SIM2 module.
- Make sure the DAQ CARD (PCMCIA Card) is fully inserted to the computer.
- Reboot the computer.
- Switch sensors and repeat Calibrate.

***Problem (2): Practice triggers automatically and reports "Practice Complete"***

- This is definitely a loose connection or bad cable problem.
- Check all connections especially the hammer.
- Reset Practice and see if touching or moving the hammer cable causes the Practice to complete.
- Replace hammer cable.

***Problem (3): Practice refuses to complete, signals look like they are excessive.***

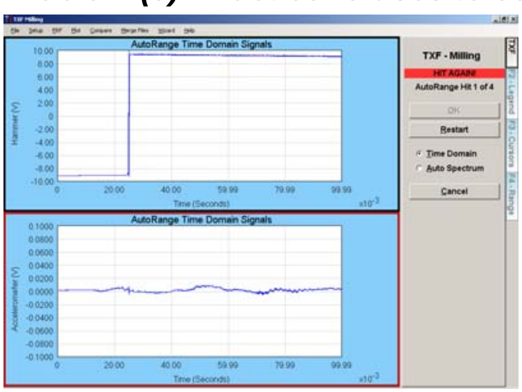


Figure 69: Troubleshooting Error (3) Practice refuses to complete

This is a cable connection problem. Check all connections, see Problem (2)

***Problem (4): Practice produces a "warning" or an "error".***

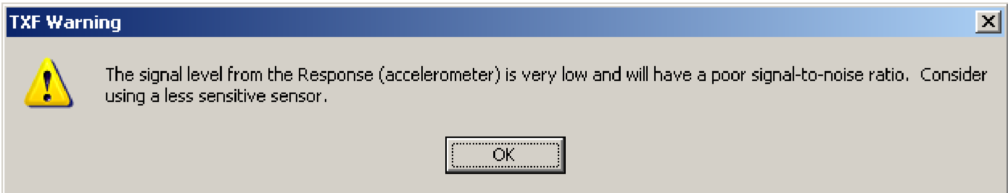


Figure 70: Troubleshooting Error: Low signal levels.

A low signal on one of the channels is resulting in an inability to get a good reading. Use a bigger hammer or a more sensitive accelerometer.

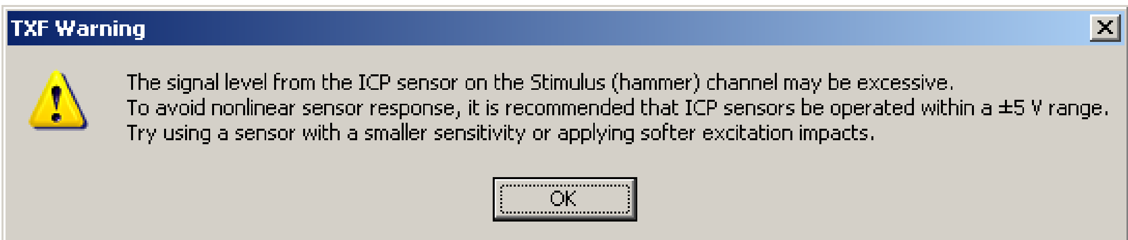


Figure 71: Troubleshooting Error: Signal levels may be excessive

This is a "warning". It indicates that you have some overloads on either the hammer or accelerometer. Click on OK and decide if you want to accept the Practice or restart. The results will be usable if well be low +/- 10V and you can accept the Practice and go to Measure, it is just not optimal. If the readings go full scale, check other problem like Problem (2).

***Problem (5): Measure shows Repeated red arrows point up or down.***

An arrow that points up ↑ indicates the channel is being overloaded and the signal is too HIGH, one pointed down ↓ indicates the channel is under-loaded and the signal is to LOW. The Upper display is for the hammer and lower display is for the accelerometer.

- Check connections.
- Use a smaller lighter hammer or tap the tool lighter for upward pointed arrow or use less sensitive accelerometer.
- Use a heavier hammer or tap harder for an arrow pointed down or use a more sensitive accelerometer.
- If you get arrows pointed in both directions then Re-Practice using the re-practice button.

***Problem (6): Can't get Measure to accept any hits (getting red arrows).***

- Check connections.
- Use the Re-Practice Button and Practice again. Then it will come back to Measure automatically and try making measurements again.

- If you are consistently getting double hits, try tapping harder both in Measure and Practice.
- If unable to get it to stop, go back to Setup Menu and the Sensors Tab and uncheck all the trap boxes at the bottom of the window.
- Use different sensors.

***Problem (7): Practice worked but Measure does not respond.***

- Check Connections.
- Try tapping harder.
- Cancel Measure and go to Setup Menu and Sensors Tab and reduce "trigger threshold" to 80.
- Use different sensors, bigger or heavier hammer or more sensitive accelerometer.

***Problem (8): Getting allot of noise on the measurement.***

- Check Connections.
- Run from battery power.
- Cancel Measure and go to Setup Menu and Sensors Tab and raise "trigger threshold" to 400.
- Hit the tool harder or use a larger accelerometer.

***Problem (9): Persistent double hits (indicated by double arrows up or down).***

- Check Connections.
- Tap harder.
- Re-practice.
- Cancel Measure and go to Setup Menu and Sensors Tab and uncheck "Double Hits" at bottom of the window.

## 5.0 *Procedure for Obtaining Material/Tooling Parameters*

The following test procedure is useful for determining the proper material (cutting tool) parameters to be input into the MetalMax™ "material" database. These values include:

- Cutting Stiffness (Ks), Metric units $N/mm^2$ and English Units psi
- Process damping wavelength (λ)

In the procedural description we will refer to the general stability graph in Figure 72.

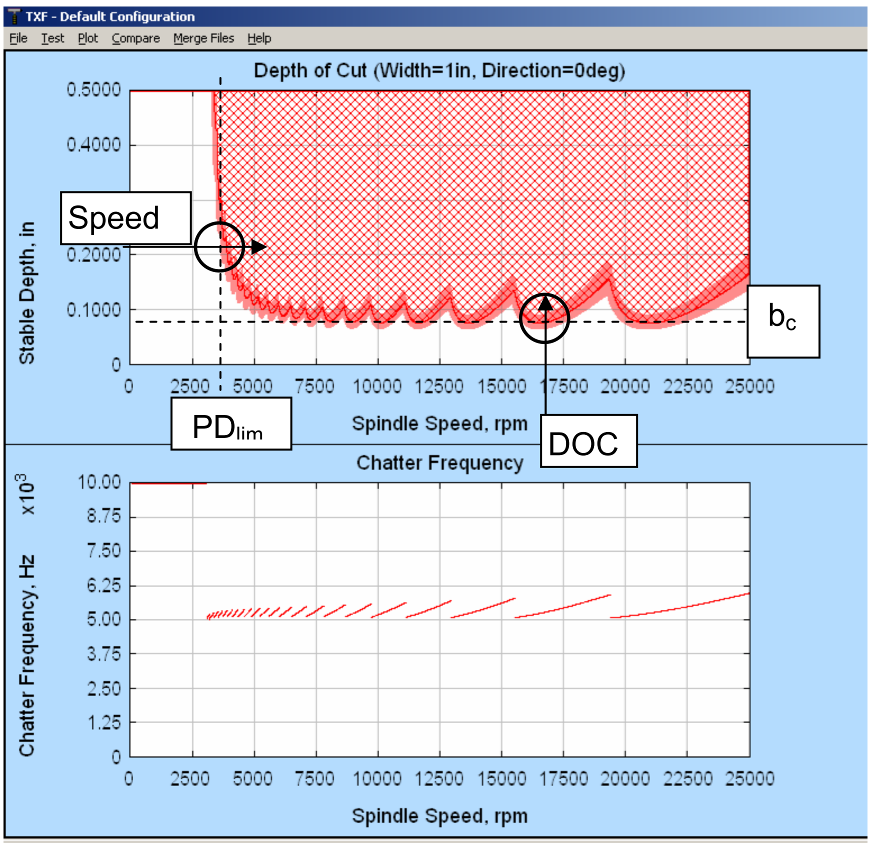


Figure 72: Stability Lobe Diagram

### *Obtain the FRF*

Measure the cutting tool as generally prescribed.

### *Calculate the Stability Lobe Diagram*

The computation should be for a slot-type cut and use a material definition that is closest to the one being cut (e.g. Aluminum 7075-T6 for an unknown grade and heat treat aluminum).

### *Cutting Tests and Initial Cutting Parameter Start Points*

Two cutting tests will be performed:

1. At a pre-selected spindle speed, the first set of tests will increment depth of cut from a low depth of cut to higher until chatter is detected.
2. At a pre-selected depth of cut, the second set of tests will increment spindle speed using a constant depth cut starting at some low spindle speed and increasing speed until chatter is detected.

Depth-of-cut test:

- At some high speed select a "worst" case spindle speed (~16250 rpm in Figure 72). This spindle speed corresponds to the bottom of a lobe, (i.e. a depth of cut that produces a critical limit value ($b_{cr}$) from the stability chart).
- Start at a depth of cut that is ⅓ to ½ the $b_{cr}$ and program successively deeper cuts in an increment equal to 10% of $b_{cr.}$
- Using the Harmonizer detect at what depth of cut chatter starts. When chatter occurs use the prior non-chatter cut as the test value ($b_{cr\text{-}test}$).

So for the example in Figure 72 you would start at a depth of cut of 0.04" or 0.06" and then increment in steps of 0.01".

Spindle speed test:

- Evaluate at what spindle speed the depth of cut asymptotically rises to a maximum, labeled $PD_{lim}$ (on the left side of the graph in Figure 72). Use ¼ to ½ of this speed as the starting speed. For DOC use 2 times the limit value that was found in the DOC tests.
- Increase spindle speed in 10% increments of PDlim until chatter occurs. When chatter occurs record prior stable speed test as the test limit speed ($PD_{lim\text{-}test}$).

So for the example in Figure 72, $PD_{lim}$ is at 3750 rpm so you would start at 1875 rpm. The depth of cut would be between 0.16" and 0.2". You would increment your spindle speed by 10 rpm for each cut, yielding 3750, 3790, 3830, 3870, etc until you get chatter.

In both cases utilize the Harmonizer to get a clear detection of chatter conditions.

***Adjust the Database***

Cutting Stiffness Value ($K_s$)

- Create and new material definition.
- Calculate the ratio between the predicted limit depth of cut $b_{cr}$ and the test limit depth of cut $b_{cr\text{-}test}$.
- Using the original Ks to calculate the new cutting stiffness ($K_{s\text{-}new}$).

$$K_{s-new} = K_s \frac{b_{cr}}{b_{cr-test}}$$

Process Damping Wave Length (λ)

- Calculate the ratio between the predicted limit speed, $PD_{lim}$ and the test limit speed $PD_{lim}$, test
- Using the original wave length, λ, use the ratio to calculate the new wavelength $\lambda_{new}$.

$$\lambda_{new} = \lambda \frac{PD_{\lim - test}}{PD_{\lim}}$$

***Special Notes***

Generally, Cutting force coefficients and Process Damping coefficients are determined experimentally. For a given work piece in a particular set up, it is possible to make a precise measurement, but there is substantial variability. In this sense, these coefficients are like other material properties such as Young's modulus or fatigue life. The usual procedure is to tabulate a typical value. If you need a more precise number, you have to measure your work piece in your set up.

However, you do not need a more precise number if you are not an academic. If you are a practitioner, you want to stay away from the edges of stability, because at the edges you are sensitive to all of the variables, many of which are not in your robust control. Hence, the warning track in TXF. Very precise evaluation of the cutting force coefficients for a particular specimen in a particular set up gives a false impression of precise control.

While it is possible to carry out finite element simulations of cutting with the proper constitutive material model to determine cutting coefficients, a more common technique is to use the tool and work piece in question and measure the force during cutting. This information can then be used to determine the corresponding cutting force coefficients. See Section 4.7 in the book Machining Dynamics by Schmitz and Smith. However, approximate values are often sufficient to get you "in the ballpark" for process predictions. These are included in MetalMax.