



ME'scopeVES Application Note #18

Simulated Multiple Shaker Burst Random Modal Test

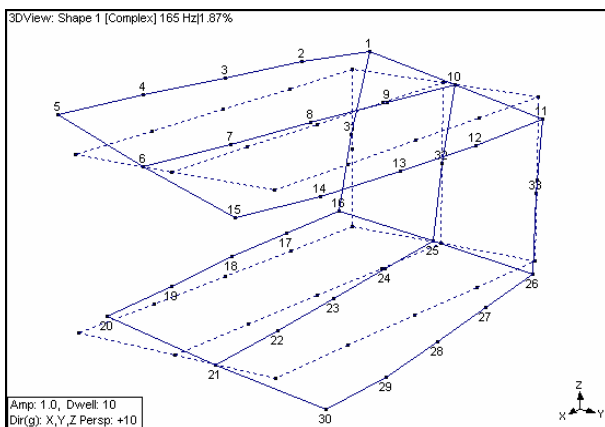
INTRODUCTION

In this Application Note you will use the MIMO (Multiple Input Multiple Output) calculation and data acquisition features of **ME'scopeVES** to simulate a modal test using two shakers driven with burst random signals. The dynamics of the structure under test will be modeled using a modal model with mode shapes that have 99 DOFs. Therefore, this exercise will simulate a test using **2 uncorrelated signal sources** and **101 data acquisition channels**.

The following steps will be carried out in this exercise:

1. Synthesize two burst random force signals using the **File | New Data Block** command.
2. Using the **Transform | MIMO | Responses** command to calculate the time domain forced response of the Jim Beam structure using its modal model and the two burst random signals.
3. Use the **Acquisition** window to **acquire** the time domain force and response signals from a Data Block file, and calculate multiple reference FRFs, Multiple Coherences, and Partial Coherences.
4. Curve fit the multiple reference FRFs and compare MAC values between the resulting mode shapes and the modes of the original modal model.

MODAL MODEL



A mode of the Jim Beam Structure.

To obtain the modal model for the Jim Beam structure:

- Execute **Help | Demo | Mode Shapes** in the **ME'scopeVES** window.

This will open a Project file with the structure file, **Jim-Beam.STR**, animating a mode shape from the Shape Table file, **JimBeam.SHP**, as shown in the figure.

Notice that the Shape Table has 10 modes in it, ranging in frequency from 165 Hz to 1550 Hz. Each mode shape has 99 DOFs that define the resonant deformation of the structure in 3 directions at 33 Points. This constitutes the modal model that will be used to define the dynamics of the structure over the frequency range from 0 Hz to 2000 Hz, and between any two DOFs of the structure where mode shape components are defined.

This modal model is a *truncated* dynamic model since it only includes the first 10 (lowest frequency) modes of the structure. The real Jim Beam structure (made out of three aluminum plates bolted together), has many more modes above 2k Hz. Nevertheless, we assume that these first 10 modes can be used to represent the majority of the overall dynamics of the structure from 0 to 2k Hz.

FORCED RESPONSE

To calculate the forced response of the structure, two time domain burst random force signals will be synthesized using the **File | New | Data Block** command. The forces will be applied to Points **5 & 15** (the corners of the top plate) in the Z direction.

Then, using the **Transform | MIMO | Responses** command in the force Data Block window, the modal model will be used to synthesis FRFs between the two shaker excitation DOFs and 99 response DOFs of the structure. These FRFs will then be multiplied by the Fourier spectra of the two force signals to obtain Fourier spectra of the 99 response DOFs. Finally, the response spectra will be Inverse Fourier transformed to yield time domain forced responses of the structure.

NOTE: To carry out the commands in this Application Note, your system must include Visual Modal Pro or VES 450, and (at least) one VES 700 series option.

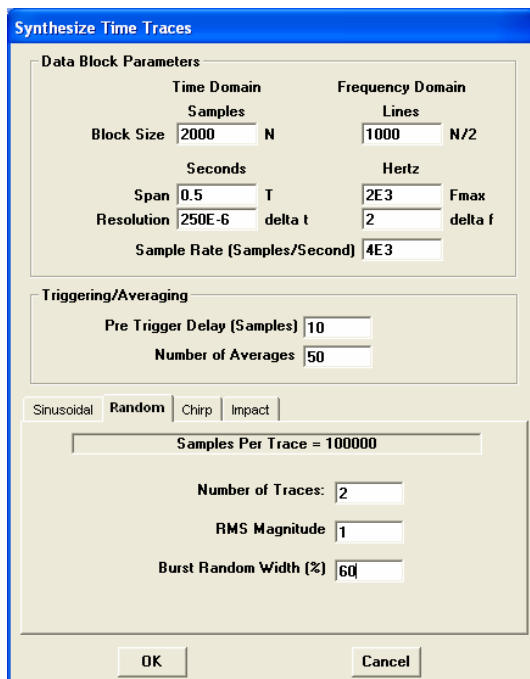
Synthesizing Burst Random Signals

Burst random excitation signals are ideal for modal testing because both the force and response signals are completely contained within the sampling window time period, **T**. Hence the FRFs calculated from these signals are leakage free, and don't require any special time domain windowing (such as a Hanning window). Furthermore, burst random excitation can be combined with spectrum averaging to reduce the effects of non-linearities in the FRFs, thus making them more suitable for curve fitting using a linear FRF model.

A burst random is the same as a pure random signal, but it is *shut off* prior to the end of the sampling window time, **T**. This is done to allow the damped response of the structure to decay to *near zero* before the end of the sampling window. Therefore, both the excitation and response signals will be completely contained within the sampling window time period, **T**.

To synthesize the two burst random force signals:

- Execute **Animate | Draw** in the Structure window to terminate animation.
- Execute **File | New | Data Block** in the ME'scopeVES window. The **Synthesis Time Traces** dialog box will open.



- Enter the following parameters into the **Synthesis Time Traces** dialog box:

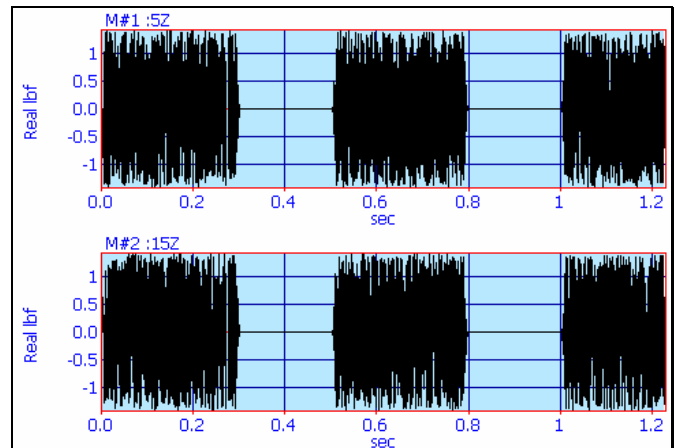
Block Size: 2000 samples
Fmax: 2000 Hz
Pre Trigger Delay (Samples): 10
Number of Averages: 50

- On the **Random** tab:
Number of Traces: 2
RMS Magnitude: 1
Burst Random Width (%): 60
- Press the **OK** button to synthesize the Traces.

A new Data Block window will open with the two burst random signals in it.

- Use the **Display | Zoom** command in the Data Block window to display the Traces more clearly.

Since 50 averages were specified, each Trace contains 50 burst random signals arranged one after another. Each burst random signal is defined over a sampling window period of **T = 0.5** seconds, followed by the next (*different*) random burst. Each signal is **2000** samples long, so with **50** bursts there are **100,000** samples per Trace. (You can check this in the **File | Properties** box.)



Data Block Window Showing 2 Burst Random Traces.

Each different random burst will excite a non-linear structure differently, so averaging 50 response spectra together will remove the non-linearities, leaving only the linear response.

The burst random width of **60%** means that the signal is shut off at 60% of **T**, or **0.3** seconds. The burst random width should be chosen to ensure that the structural response has decayed to *near zero* by **T = 0.5** seconds. We

will see later that this burst random width is short enough to ensure that the response of the Jim Beam structure has decayed sufficiently.

Rule of thumb: Structural response decay is *near zero* when its amplitude is 1% or less of the peak amplitude of response.

Next, the DOFs and units of the force signals need to be edited.

- Click on the **DOF** spreadsheet cell for the first Trace (**M#1**) and enter **:5Z** as its DOF. Do the same for the second Trace (**M#2**), but enter **:15Z** for its DOF.

Notice that the colon (:) is placed in the front of the DOF to designate it as a *reference* input.

- Double click on the **Units** column heading. In the dialog box, choose **lb_f** from the drop down list, and click on **OK** and **Yes** to change the units from acceleration to force units.

With these changes, each signal will apply a 1 lb_f RMS force to the structure at its DOF; one at 5Z and the other at 15Z. We are now ready to calculate the forced response of the structure.

Re-scaling the Mode Shapes

To simulate a real modal test where accelerometers are used to measure responses, we will re-scale the mode shapes so that the modal model can be used to synthesize MIMO FRFs with units of (acceleration/force).

We will do this in three steps. First, we will convert the previously measured (single reference) *residue* mode shapes to *unit modal mass* (UMM) mode shapes. This removes all dependence upon the *reference* DOF used in the original analysis. Second, we will convert the UMM mode shapes back to residue mode shapes, specifying the *two* desired *reference* DOFs for the MIMO test. Third, we will convert the *displacement* residues to *acceleration* residues.

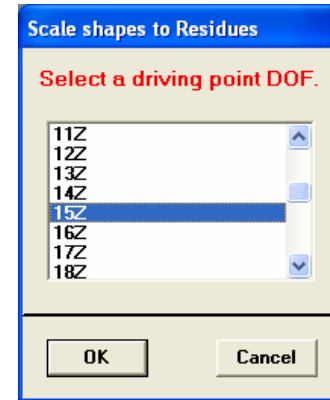
To re-scale the original residue mode shapes to UMM:

- Execute **Tools | Scaling | Unit Modal Mass** in the **JimBeam.SHP** window.

UMM mode shapes can be used to create Residues between any pair of DOFs in the mode shapes. In this case, we will create Residues between all mode shape DOFs and the excitation DOFs (**5Z** and **15Z**). These Residues (called **Residue mode shapes**) will then be used as the modal model for calculating structural responses to the burst random forces.

To create the new Residue mode shapes:

- Execute **Tools | Scaling | Residues** in the **Jim-Beam.SHP** window. The following dialog box will open.



- Hold down the Ctrl key on the keyboard, and select **5Z** and **15Z** from the list in the dialog box. Then click on **OK** to create the Residue mode shapes.

The units of the Residues are *displacement/force-sec*. To convert the residues to *acceleration/force-sec* units:

- Execute **Tools | Differentiate twice** in the **Jim-Beam.SHP** window.

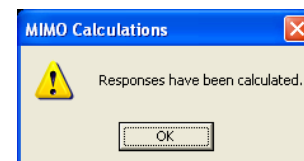
Now, the modal model is ready to calculate forced responses.

Calculating the Forced Response

To calculate the forced response using the MIMO FRFs and the burst random time domain signals:

- Execute **Transform | MIMO | Responses** in the Data Block window. The MIMO Analysis window will open.
- Verify that the Data Block with burst random forces in it is listed under **Forces**, and **JimBeam.SHP** file is listed under **FRFs**, and click on the **Calculate** button.

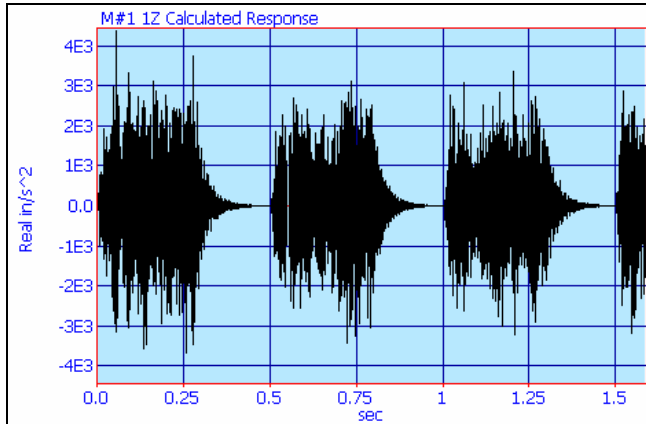
When the calculation is finished, the following message box will open.



- Click on **OK**, The Data Block Selection box will open. Click on the **New File** button, and on **OK**.

A new Data Block window will open displaying 99 forced response Traces.

- Use the **Display | Zoom** command in the Data Block window to display the Traces more clearly.



Forced Responses due to the 2 Burst Random Forces.

It is now clear that shutting off the burst random signals at 60% of each sampling window length (0.3 seconds) was sufficient to allow the structural response to decay to near zero before the end of each sampling time ($T = 0.5$ seconds).

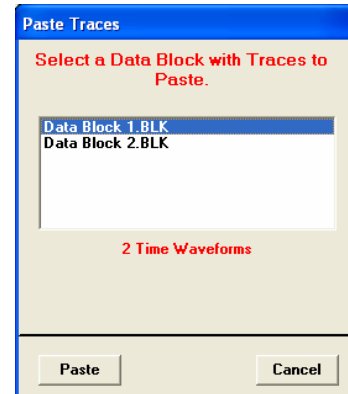
Now that the forced response due to two shakers driven by burst random signals has been calculated for 50 averages, all of this time domain data will be put into a Data Block and saved to disk. The Acquisition window will then be opened, and the data will be acquired from the Data Block to simulate data acquisition from actual front-end hardware.

To save the force signals together with the response signals:

- Execute **Edit | Paste Traces** in the Data Block with 99 response Traces in it.
- Select the Data Block (with 2 *Time Waveforms* in it), and click on the **Paste** button.

To save the Data Block with forces and responses in it,

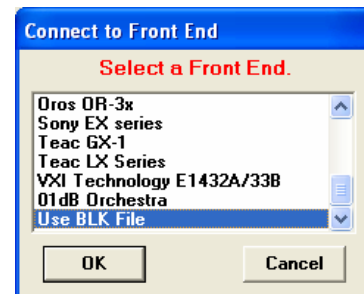
- Execute **File | Save As** in the Data Block with 101 *Traces* in it. The Windows file dialog box will open.
- Enter a name **Burst Random Test** as the file name, and save it to disk.



SIMULATED DATA ACQUISITION

We will now simulate data acquisition from a multi-channel acquisition front-end by acquiring 101 channels of time domain data from the **Burst Random Test.BLK** file on disk. To acquire the data:

- Execute **File | New | Acquisition** in the **ME'scopeVES** window. A new (empty) Acquisition window will open.
- Execute **Connect To | Front End** in the **Acquisition** window. A dialog box will open listing all of the (option VES 700) **Front Ends** installed in your system. Select **Use BLK File** from this list, and click on **OK**.



Next the **Windows file open** dialog box will open.

- Navigate to the **Burst Random Test.BLK** file that you just saved to disk, and open it.

After the **Acquisition** window has been connected to the **Use BLK File** Front End, the **Channels spreadsheet** will list the properties of the **101** channels time domain **Traces** in the file. Notice that the first 99 channels are response channels and the last two are the force channels. A few parameters have to be set up on the **Acquisition** tabs prior to acquiring the data.

- On the **Measurement** tab, click on the **Frequency** radio button, and *check* the **FRF** and **Coherence** boxes.

- In the **Averaging** section, enter:
Number of Averages: 50
- On the **Sampling** tab, enter:
Number of Samples: 2000

Compare the time and frequency sampling parameters on this tab with those from the **Synthesize Time Traces** dialog that was used to synthesize the force **Traces** earlier. Both the time and frequency domain parameters should be the same as those used to synthesize the original burst random force data.

- On the **Trigger** tab, accept the default **Free Run** status.

In this simulation, the timing of the **Burst Random** pulses properly paces the acquisition. There is no need to trigger on an input signal. Each excitation burst and the resulting responses will be properly captured because the excitation and capture windows have identical length, **T**.

The **Acquisition** window is now ready to acquire data from the BLK file, and calculate multiple reference (2 in this case) **FRFs** and **Coherences** using **50** averages.

Notice in the **Window** column of the **Channels spreadsheet** that all channels are using a **Rectangular** window. This is the default time domain window. It is also called a Uniform or Boxcar window, or None.

NOTE: A **Rectangular** window does not alter the time domain data before it is Fourier transformed.

To acquire the multi-channel data:

- Execute **Acquire | Start** in the **Acquisition** window, or press the **F5** key on the keyboard.

As the data is acquired, the number of averages is displayed on the Toolbar.

The acquired time domain **Traces** are displayed in the upper graphics area, while the calculated **FRFs** and **Coherences** are displayed in the lower area. When 50 averages of data have been acquired, the display on the Toolbar will read **“Front End Ready”**.

Notice that a total of **495** **Traces** of **FRF** and **Coherence** data have been calculated. To sort the **Traces** by **DOF**:

- Click on the lower **Traces** graphical area to make them *active*.
- Execute **Edit | Sort Traces**. A dialog box will open with **Roving DOF** displayed in the drop down list.
- *Check* the **Select All** box, select the **Ascending** radio button and press the **Sort** button, then press the **Close** button.

To display all of the measurements associated with each response **DOF** of the structure:

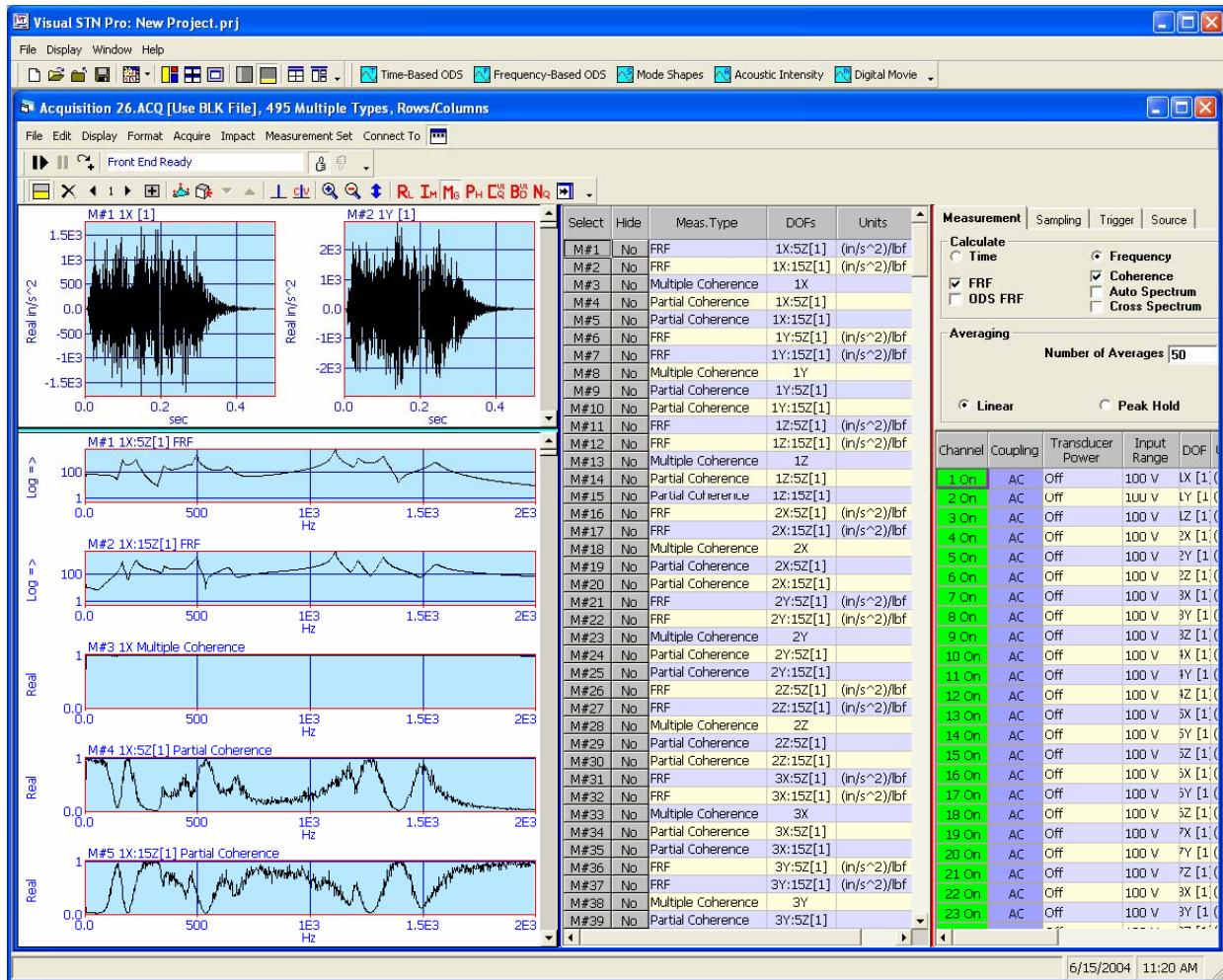
- Execute **Format | Rows/Columns**, and select **(5,1)** from the drop down list.

Starting with the (vertical) **Trace** scroll bar at the top, the following 5 **Traces** will be displayed for each **Roving DOF**:

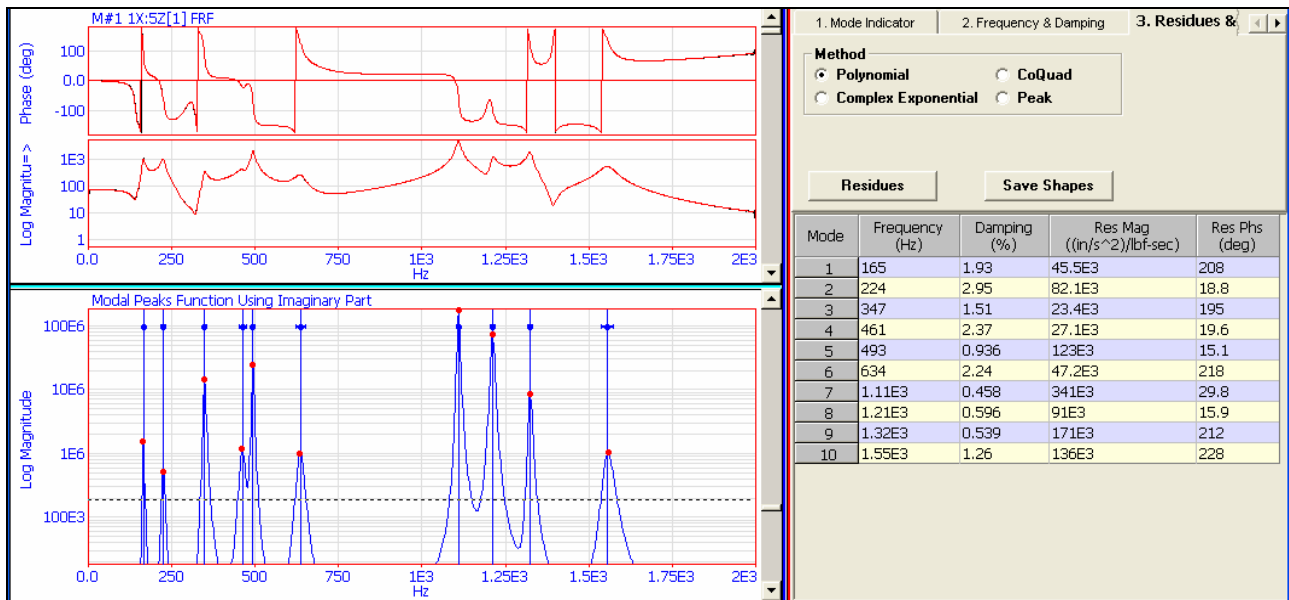
- 2 **FRFs** between the **Roving DOF** and each **Reference (force) DOF**.
- 1 **Multiple Coherence** function.
- 2 **Partial Coherence** functions between the **Roving DOF** and each **Reference (force) DOF**.

Multiple Coherence measures how much of the measured response is linearly related to (correlated with or caused by) the two measured forces. A value of “1”, which is expected in this case, indicates that each response is completely correlated with the forces.

Each **Partial Coherences** measures how much of a measured response is due to *each* of the measured forces. Notice that the sum of the two **Partial Coherences** is always *close to* “1”. Also notice that if the **FRF** from one reference has a zero (very low value), and the **FRF** from the other reference does not, then the **Partial Coherence** of the **FRF** with low value will also be low while the **Partial Coherence** of the other is high. This is indicating that force is more easily applied to a structure at **DOFs** and frequencies where it has a larger response (it is more compliant) than at **DOFs** and frequencies where it is very stiff.



Acquisition Window Showing FRFs, Multiple Coherence, and Partial Coherences for One Response DOF.



A Typical FRF Curve Fit.

CURVE FITTING THE FRFS

Next, we will save the measurements from the Acquisition window into a Data Block and curve fit them to recover the modal parameters of the Jim Beam structure.

- Execute: **Acquire | Save**, or press the **F9** key on the key board. A dialog box will open.
- Click on the **New File** button, and click on **OK** to save the measurements in the new Data Block file.
- Close the **Acquisition** window, and don't save it.

To curve fit the FRFs,

- Execute **Modes | Modal Parameters**. The curve fitting panel will be displayed on the right side of the window.
- Execute **Curve Fit | Quick Fit**.

When curve fitting of the FRFs is completed, modal parameters for 10 modes will be displayed in the spreadsheet on the right, and a **red** fit function will be overlaid on each FRF.

- Scroll through the **Traces** in the upper graphical area to review the **FRFs** and *fit functions*, as shown below.

To save the modal parameters into a new Shape Table file:

- Click on the **Save Shapes** button on the curve fitting panel. The **multiple reference shapes** dialog box will open. Click on **OK**. The **Shape File** selection box will open.
- Click on the **New File** button, enter **Curve Fit Modes** into the dialog, and click on **OK** to save the shapes in a new Shape Table file.

COMPARING MODE SHAPES

To compare mode shapes in animation, make sure that **Curve Fit Modes.SHP** is displayed in the **Animation Source** box on the **Structure** window Toolbar and,

- Execute **Draw | Animate** to initiate animation.

Mode shapes from **Curve Fit Modes.SHP** are displayed by selecting them in its window, while shapes from **Jim-Beam.SHP** are displayed by selecting them in its window.

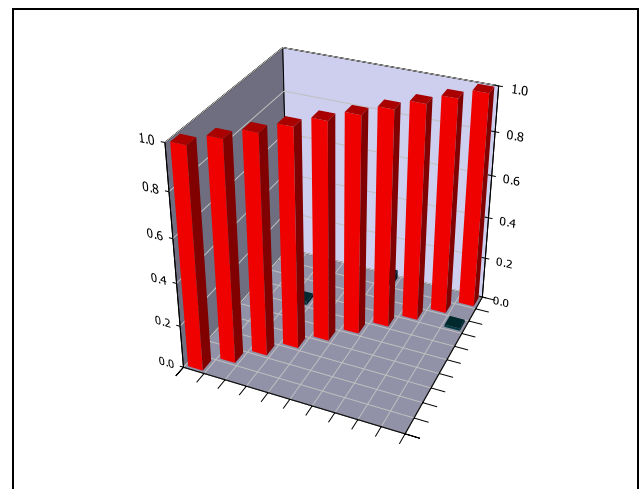
MAC Comparison

Finally, the mode shape values, themselves, can be compared by calculating **Cross MAC**'s between pairs of modes from the two Shape Table files. To display the **Cross MAC** values between the two Shape Tables:

- Execute **Display | Cross MAC** in the **JimBeam.SHP** window. The **Shape Table file selection box** will open. Select **Curve Fit Modes.SHP** from the list, and click on **OK**.

Notice that the diagonal values in the **MAC** spreadsheet are all **1**, indicating that each mode shape in **Curve Fit Modes.SHP** file is *identical* to the same frequency shape in **JimBeam.SHP**.

- Click on the **Plot** button in the **MAC** window to display the MAC values in a 3D bar chart, as shown below.



Cross MAC Values between Original and Curve Fit Modes.

CONCLUSIONS

A two-shaker 101-channel modal test was simulated by acquiring time domain force and response signals from a Data Block file using the Acquisition window in ME'scopeVES. The forced responses were calculated using 2 synthesized, uncorrelated burst random excitation signals, a modal model of the Jim Beam structure, and the **Transform | MIMO | Responses** command.

After the simulated force and response signals were "*acquired*" from a Data Block, multiple reference FRFs, Multiple and Partial Coherences were calculated using 50 averages.

The multiple reference FRFs acquired by the Acquisition window were then curve fit, and the resulting mode shapes compared with the original modes used by the MIMO model to calculate the forced responses. The mode shapes resulting from curve fitting the FRFs were *nearly identical* to the modes shapes used to calculate the forced responses. These results verify that a multiple shaker modal test using burst random excitation signals yields *leakage free* FRFs that preserve the linear dynamic properties (i.e, the modal properties) of a structure.

The Multiple Coherences calculated from the burst random data were all at or near a value of "1", indicating that the measured responses were linearly related to the measured forces at all frequencies. In this case, there were no other unmeasured forces or extraneous noise contributing to the measured responses.

The Partial Coherences summed to values at or near "1" for all frequencies, again indicating that the all of the measured forces were linearly related to the measured responses. The Partial Coherences further showed the percentage of each force that causes each response as a function of frequency.