Vibrant Technology, Inc.

ME'scopeVES Application Note #11

Using a Tuned Absorber to Suppress Vibration

INTRODUCTION

In this note, the use of the Tuned Absorber command in the *Visual* SDM option in ME'scopeVES will be illustrated.

Tuned Absorbers are used in many industrial applications to suppress the vibration level of troublesome resonances, or modes of vibration. A Tuned Absorber is modeled as a mass attached to the problem structure with a spring and damper, as shown in Figure 1.

Constructing a physical Tuned Absorber that behaves as a mass-spring-damper system is a separate challenge. Nevertheless, ME'scopeVES is useful for examining the effects of different absorber parameters and locations.

The key idea behind the use of the Tuned Absorber is that the mass and spring stiffness are chosen so that the ***Tuned Absorber vibrates at the same frequency as the troublesome mode***. Also, the Tuned Absorber is attached to the structure at an anti-node (high amplitude point) of the troublesome resonance, so the absorber will absorb energy instead of the resonance.

The best way to examine the effect of a Tuned Absorber is to compare FRFs at an active point on the structure, ***before and after the absorber has been attached to it***.

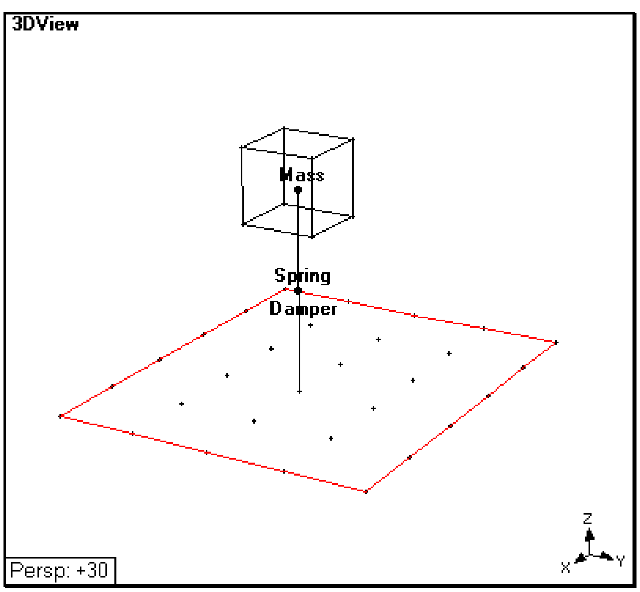


Figure 1. Tuned Absorber on a Plate.

Figure 6 shows the typical effect of a Tuned Absorber on an FRF. After the absorber is applied, a single high amplitude resonance is replaced by two resonances on either side of it. More importantly, the vibration level at the troublesome resonant frequency is greatly reduced because of the removal of the resonance at that frequency.

How It Works

Adding a Tuned Absorber to a structure involves solving a substructuring problem. To solve this substructuring problem, three parts are needed;

1. The mode shapes of the unmodified structure.
2. The ***rigid body mode shape*** of the Tuned Absorber mass.
3. The Tuned Absorber spring and damper to connect the two SubStructures together.

Part 1, the mode shapes of the unmodified structure, must be obtained by modal testing or finite element analysis. The **Modify | Add Tuned Absorber** command provides parts 2 & 3; the rigid body mode of absorber and the spring and damper to connect it to the structure.

Once these three parts are in place, the **Modify | Calculate New Modes** command can be used to calculate the new modes of the combined substructures; the Tuned Absorber and the unmodified structure.

Once the Tuned Absorber has been defined, the **Modify | Calculate New Modes** command provides two ways to calculate the new modes; either by pressing the Store Parameters button and the Calculate New Modes button.

Store Parameters Button

The **Store Parameters** button merely adds the rigid body mode of the Tuned Absorber to the mode shapes of the unmodified structure, and also adds the Tuned Absorber mass, spring, and damper elements to the structure model. Then, the **Modify | Calculate New Modes** command must be executed separately (using only the Tuned Absorber spring and damper elements) to obtain the new modes of the structure with the Tuned Absorber attached.

Calculate New Modes

The **Calculate New Modes** button carries out the steps of the **Store Parameters** button, but it also internally executes the **Modify | Calculate New Modes** command. In addition, it hides all finite elements except the Tuned Absorber spring and damper before calculating the new modes, and un-hides the other elements when it is done.

Use of the Tuned Absorber will be illustrated with two examples. In the first example, an absorber is applied to an SDOF system, and the answer is validated by comparing it with a 2-DOF eigen solution, and an analytical solution. In the second example, an absorber is applied to a plate structure, and its effect on the modes of the plate is examined.

EXAMPLE #1: ADDING AN ABSORBER TO AN SDOF.

For this example, we will create an SDOF (mass-spring-damper) system and solve for its mode of vibration using the **Modify | Calculate Element Modes** command in ME'scopeVES. Then, we will add a Tuned Absorber to the SDOF.

First, we will use the **Modify | Add Tuned Absorber** command itself to add an SDOF system to a drawing. (We could also add the mass, spring, and damper elements one by one to two Points, but using the Add Tuned Absorber command is more convenient.)

- Start a new Project by executing the **File | Project | New** command in the ME'scopeVES window.

Building the SDOF

- Create a new structure file by executing the **File | New | Structure** command.
- To set up the structure units, execute the **File | Options** command in the Structure window, and click on the **Units** tab. Select **Kilograms**, **Newton Force**, and **Meters** as units, and click on **OK**.
- Select **Points** from the Object list on the Toolbar in the Structure window.
- Press the **Add** button , and click in a View to add **a single Point** to the drawing.

This will be the ground (fixed) Point to which the mass-spring-damper will be attached.

- Execute the **Edit | Animation Equations** command to display the Animation Equations for the Point, click on the **Vector** tab, select **Fixed** for all three directions, and click on **Save** to fix the ground Point.

Adding a New Shape Table

Since the Tuned Absorber command normally requires the modes of the unmodified structure in a Shape Table, we have to create a new Shape Table with nothing in it in order to use this command.

- Execute the **File | New | Shape Table** command in the ME'scopeVES window. Click on **OK** to create the new table.
- When the Shape Table opens, double click on the **Meas. Type** column heading. A dialog box will open. Select **Unit Modal Mass mode shapes** from the list, and click on **OK**.

Now, a valid Shape Table is available so that the **Tuned Absorber** command can be used.

- Make sure the ground Point is ***selected***.

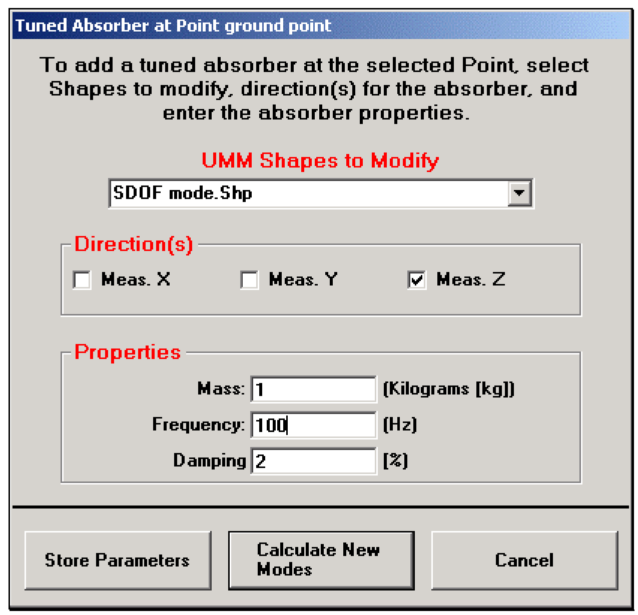


Figure 2. Tuned Absorber Dialog Box.

- Execute the **Modify | Add Tuned Absorber** command. The Tuned Absorber dialog box will open.
- Select the **Meas. Z** direction.
- Enter the parameters for a **1 Kilogram mass** at **100 Hz** with **2% damping** as shown in Figure 2.
- Press the **Store Parameters** button to add the mass-spring-damper to the ground Point.

Now, the Structure window should contain the mass-spring-damper added to the ground Point.

- Change the SubStructure label **Tuned Absorber 1** to **SDOF Model**.

- Change the labels of the mass, spring, and damper elements from **TAM1**, **TAS1**, and **TAD1** to **Mass**, **Spring**, and **Damper** in their respective spreadsheets.
- To separate the elements for better clarity, change the ground Point coordinates to (**0,0,0**) and the mass Point coordinates to (**0,0,1**) in the Points spreadsheet.
- To make the SDOF look more realistic, add a **Cube** SubStructure to the mass Point, and a **Square** SubStructure to the ground Point, as shown in Figure 3.
- Put the **Lock/Unlock** button in the **Lock** position .
- Execute the **File | Save As** command, and save the **SDOF model** to disk.

Now the model is ready to solve for its single mode of vibration.

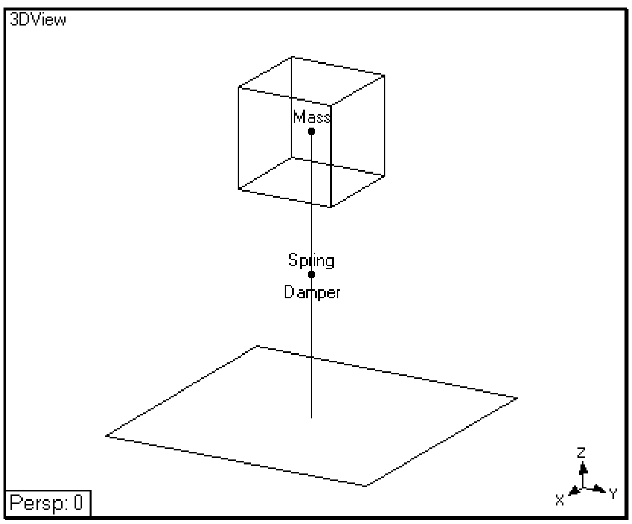


Figure 3. SDOF Model.

Solving For The SDOF Mode

- Make sure that the mass Point is labeled as Point **#1**, and that no other Points except the ground Point are labeled.
- Make sure that the mass, spring, and damper are not hidden by checking their **Hide** property in their respective spreadsheets.
- Close the two Shape Tables without saving them.
- Execute the **Modify | Calculate Element Modes** command. Click on **OK** ***twice*** to create a new Shape Table with the SDOF mode in it.

Since we designed the Tuned Absorber to vibrate at 100 Hz with 2% damping, the mode of the SDOF should have the expected parameters in it.

- Execute the **Display | Shapes** command to display the mode shape in the Shape Table.

Notice that this is a Unit Modal Mass scaled mode shape with a value of (**1.00**). (It also has a small amount of phase due to the damper.) All mode shapes are ***unique in shape***, but ***arbitrary in magnitude***. Unit Modal Mass scaling means that when a mode shape is pre- and post-multiplied by the mass of the structure, the answer will be (**1.00**). In this is case, Unit Modal mass scaling is easy to verify.

Synthesizing the Driving Point FRF

To synthesize the driving Point FRF at the mass Point,

- Execute the **Tools | Synthesize FRFs** command in the Shape Table window of the SDOF mode shape. The FRF Synthesis dialog box will open.
- Enter **200 Hz** for the **Ending Frequency**, select **1Z** for **both DOFs**, and click on **OK**. A Data Block window will open showing the driving Point FRF with a 100 Hz peak.

This is the expected (displacement/force) driving point FRF for an SDOF.

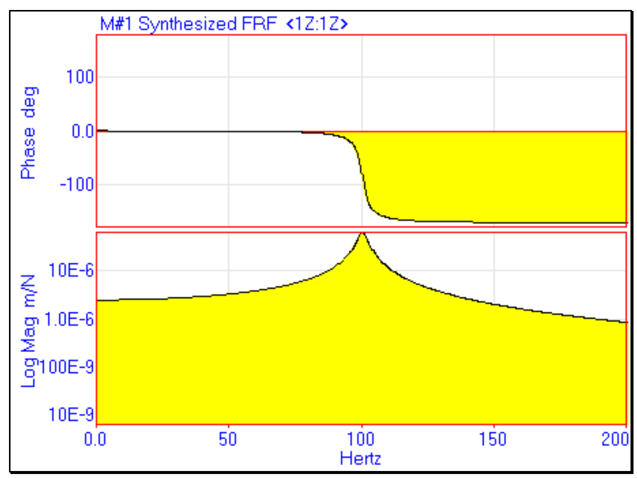


Figure 4. Driving Point FRF at the Mass.

Adding the Tuned Absorber

Now, we will add a Tuned Absorber to the SDOF structure and look at its effects on the FRF at DOF **1Z**.

- Select **Points** from the Objects list on the Toolbar in the Structure window.
- ***Select*** the **mass Point** on the structure.
- Execute the **Modify | Add Tuned Absorber** command. The Tuned Absorber dialog box will open.

- Select the Shape Table with the **100 Hz mode** (of the unmodified structure) in it.
- Make sure that the parameters are the same as those in Figure 2. (**1 Kilogram mass** at **100 Hz** with **2% damping).**

As explained earlier, there are two ways to add a Tuned Absorber with the **Modify | Add Tuned Absorber** command; use either the **Store Parameters** or the **Calculate New Modes** button. We will examine the use of both buttons.

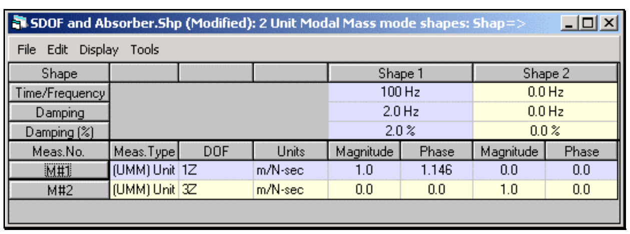
Store Parameters Button

- Press the **Store Parameters** button. Click on **OK** to accept the new Shape Table name. A Shape Table window will open with two modes in it.

The two modes are the mode of the (unmodified) SDOF and the rigid body mode of the Tuned Absorber Mass.

- Execute **Display | Shapes** in the Shape Table.

Notice that the rigid body mode of the Tuned Absorber (**Shape 2**) is also a Unit Modal Mass mode shape, and that its frequency is (**0.0**) Hz. Its damping is also (**0.0**).


SDOF and Absorber.Shp (Modified): 2 Unit Modal Mass mode shapes: Shap=>

File Edit Display Tools

Shape				Shape 1		Shape 2	
Time/Frequency				100 Hz		0.0 Hz	
Damping				2.0 Hz		0.0 Hz	
Damping (%)				2.0 %		0.0 %	
Meas.No.	Meas.Type	DOF	Units	Magnitude	Phase	Magnitude	Phase
M#1	(UMM) Unit	1Z	m/N-sec	1.0	1.146	0.0	0.0
M#2	(UMM) Unit	3Z	m/N-sec	0.0	0.0	1.0	0.0

Figure 5. SDOF and Absorber Modes.

Notice also that the Tuned Absorber mass, spring, and damper have been added on top of the SDOF in the Structure window, and their properties have been added to the appropriate spreadsheets.

- To separate the Tuned Absorber mass from the SDOF mass, edit the Tuned Absorber mass Point coordinates to **(0,0,2**) in the Points spreadsheet.

The structure model and Shape Table are now setup to calculate the new modes of the combined substructures. However, before using the **Modify | Calculate New Modes** command, only the ***Tuned Absorber spring and damper*** should be visible because the other elements were used to define the unmodified structure.

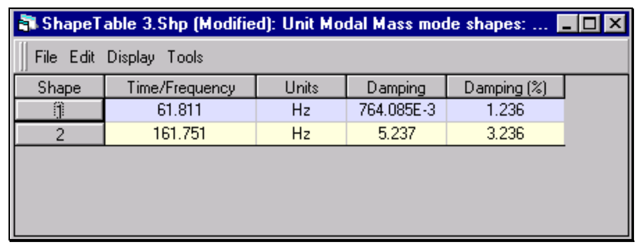
- Hide the SDOF mass, spring, and damper elements in their respective spreadsheets. (Notice that the Tuned Absorber mass is already hidden. This was done by the Tuned Absorber command.)

NOTE: The **Modify | Calculate New Modes** command uses the Animation Equations from the structure model to retrieve mode shape data from the Shape Table with the unmodified structure modes in it.

Therefore, the **M#'s** of this Shape Table must be assigned to the structure beforehand.

- Execute the **Tools | Assign M#'s** command in the Shape Table with the two mode shapes in it. (Both Shape DOFs should be assigned to the two mass Points on the structure.)
- Execute the **Modify | Calculate New Modes** command. Select the Shape Table with the 2 modes in it, and click on **OK *twice***.

A new Shape Table will open with the two new modes in it, as shown in Figure 6. These are the new modes of the SDOF with the Tuned Absorber attached to it.


ShapeTable 3.Shp (Modified): Unit Modal Mass mode shapes: ...

File Edit Display Tools

Shape	Time/Frequency	Units	Damping	Damping (%)
1	61.811	Hz	764.085E-3	1.236
2	161.751	Hz	5.237	3.236

Figure 6. Modes of the SDOF With Tuned Absorber.

Calculate New Modes Button

Now, lets use the **Calculate New Modes** button in the Tuned Absorber dialog box to obtain the same answer as that in Figure 6.

- Select **SubStructures** from the Object list on the Toolbar in the Structure window.
- Select the **Tuned Absorber 1** SubStructure, and execute **Edit | Delete** to delete it from the model.
- Select the **mass Point** on the SDOF structure.
- Execute the **Modify | Add Tuned Absorber** command. The Tuned Absorber dialog box will open.
- Make sure the Tuned Absorber parameters are the same as before.
- Press the **Calculate New Modes** button, and click on **OK.**

A new Shape Table will open with two modes in it, the same ones as those shown in Figure 6.

Synthesizing the Driving Point FRF at 1Z Again

Now, let's synthesize the driving Point FRF at DOF **1Z** using the new modes to observe the effect of the Tuned Absorber.

- Execute the **Tools | Synthesize FRFs** command in the Shape Table window with the two new mode shapes in it. The FRF Synthesis dialog box will open.
- Enter **200 Hz** for the **Ending Frequency**, select **1Z** for both **DOFs**, and click on **OK**. A Data Block window will open showing the driving Point FRF.
- Execute the **Edit | Paste Data Block** command in the new Data Block window. Select the other Data Block with the SDOF Driving point FRF in it.
- Execute the **Format | Overlay Traces** command. The two FRFs should be displayed at shown in Figure 7.

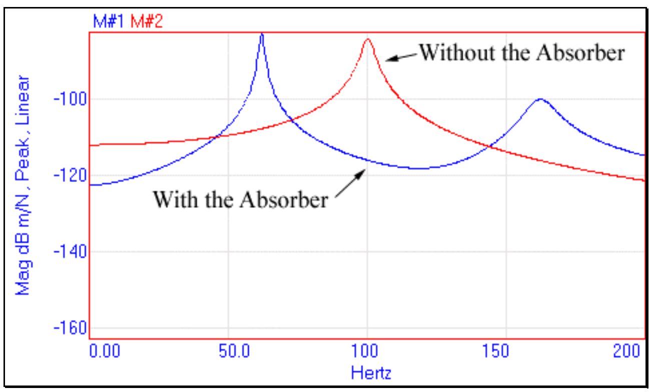


Figure 7. Driving Point FRFs Overlaid.

Now it is clear that the Tuned Absorber split the SDOF 100 Hz mode into two modes on either side of it (at 61.8 and 161.75 Hz.). At 100 Hz, the response of the structure at DOF **1Z** has been reduced by about **32 dB**. (You can verify this by displaying the Line cursor values of the two Traces at 100 Hz when they are not overlaid.)

If 100 Hz were the only frequency at which there was a vibration problem, then the Tuned Absorber did its job. However, a higher amplitude resonance at 62 Hz has also been created, which could cause an even greater problem than the one we solved at 100 .

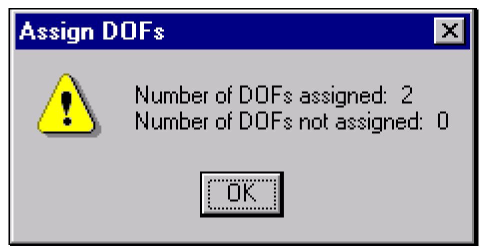
Animating the Mode Shapes

To display the mode shapes in animation, we will first make the model a little easier to understand.

- Select the Cube SubStructure on the SDOF, and execute the **Edit | Copy to Paste** command to copy it to the paste buffer.
- Execute the **Edit | Add Marker** command, hold down the **right mouse button**, and position the **Add Marker** over the Tuned Absorber mass.
- Execute the **Edit | Paste to Drawing** command to add another Cube at the Tuned Absorber mass.
- Execute **Edit | Add Marker** again to turn OFF the Add Marker.

Before animation can occur, the Shape Table measurements (**M#'s**) must be assigned to DOFs of the structure model. To assign the shapes to the structure model,

- Select the 2 mode Shape Table (the last one created) from the **Animation Source** list on the Toolbar in the Structure window.
- Execute **Draw | Assign M#'s**. After clicking on **OK** and **Yes**, the dialog box should indicate that both DOFs (**M#'s**) in the Shape Table have been assigned to the structure.



- Execute the **Draw | Animate** command.

Fixing Interpolation

Notice that the interpolated motion of the "**unmeasured**" Points on the model is incorrect. To fix this problem,

- Execute the **Animate | Draw** command.
- Select **Points** from the Objects list on the Toolbar.
- Hold down the **Alt** key, and enclose the ground Point and Square SubStructure with the Selection Box.
- Execute the **Draw | Interpolate Selected Points** command. A dialog box will open. Click on **OK.**
- Repeat the above two steps for the SDOF mass Point and its Cube SubStructure, and again for the Tuned Absorber mass Point and its Cube Substructure.
- Execute the **Draw | Animate** command again.

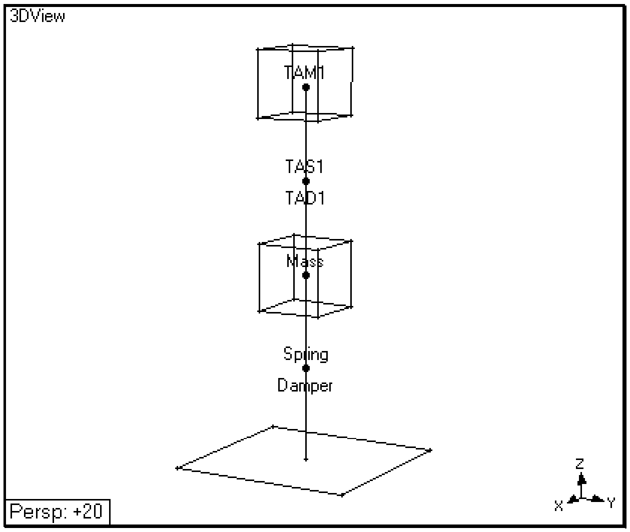


Figure 8. SDOF with Tuned Absorber.

Checking the Results

Since this is a very simple example, we can check the accuracy of the results in two different ways, 1. Use the **Modify | Calculate Element Modes** command on the 2-DOF model (SDOF with the Tuned Absorber attached), and 2. Compare the frequencies with those from an analytical formula.

To calculate the modes of the 2-DOF model,

- Make sure that both masses, springs, and dampers are **not hidden** by checking their **Hide** property in their respective spreadsheets.
- Execute the **Modify | Calculate Element Modes** commands. Click on **OK** ***twice***.

A new Shape Table will open, containing the same two modes as obtained from the Add Tuned Absorber command (Figure 6.). You can animate these mode shapes and compare them with the Tuned Absorber modes.

An Explanation

You might ask, "What's the difference?" The **Modify | Calculate Element Modes** command calculated the modes (eigenvalues and eigenvectors) of 2-DOF model directly by solving an eigensolution problem.

The **Calculate New Modes** button in the Add Tuned Absorber box solved a substructuring problem. It used the mode of the unmodified SDOF system plus the **rigid body mode** of the Tuned Absorber, and then connecting the two SubStructures together using the Absorber spring and damper. Both methods yielded the same result.

To compare the Tuned Absorber frequencies with analytically derived results, the reference book "**Formulas for Natural Frequency and Mode Shape**" by Robert D. Blevins, was used. It contains the following formulas **(in Table 6.2, page 48)** for a two mass, two spring system,

$$\omega_1 = \frac{\left(3 - 5^{1/2}\right)^{1/2}}{\pi 2^{3/2}} \left(\frac{k}{m}\right)^{1/2}$$

$$\omega_2 = \frac{\left(3 + 5^{1/2}\right)^{1/2}}{\pi 2^{3/2}} \left(\frac{k}{m}\right)^{1/2}$$

The springs spreadsheet reveals that the springs both have a stiffness of **394,942 N/m**. Using this and a mass of **1 Kg** in the above formulas gives,

$$\omega_1 = 61.82 \text{ Hz}, \quad \omega_2 = 163.84 \text{ Hz}$$

This is good agreement even though these formulas are for ***undamped*** natural frequencies, whereas ME'scopeVES calculated the ***damped*** natural frequencies.

EXAMPLE #2: ADDING A TUNED ABSORBER TO A PLATE STRUCTURE

In this example, we will look at the effects of adding a Tuned Absorber to the center of the plate structure shown in Figure 1. The experimental mode shapes of the plate were obtained by impact testing the plate, and then curve fitting a set of FRF measurements. The FRF measurements, mode shapes, and structure model are all contained in the **PLTMODES** Project in the **Examples** subdirectory on disk. To open the PLTMODES project,

- Select the **ME'scopeVES\Examples** subdirectory in the ***lower pane*** of the **Project Panel** in the ME'scopeVES window.
- Double click on **PLTMODES.PRJ** in the middle pane of the Project Panel.

The Structure, Data Block, and Shape Table windows for this Project will open in the Work Area.

- Execute the **Windows | Arrange Windows** command in the ME'scopeVES window to display them in tiled format.
- Execute the **Draw | Animate** command to display the mode shapes in animation.
- Execute **Display | Point Labels** to display the Point numbers.

Notice that **Point #13** is a nodal point (little or no motion) for all of the shapes ***except Shapes 2 & 3***. Suppose that these are the modes of a platform and that a sensitive instrument is to be mounted at **Point #13**. Therefore, we would like to investigate the effects of placing a Tuned Absorber at or near **Point #13** (or any other anti-nodal Point) to suppress the structural response.

Suppose we designed the Tuned Absorber to suppress the **423 Hz** mode. The only other parameter that needs to be specified is the weight (mass) of the Tuned Absorber. Let's choose a ***1-pound mass***.

- Execute **File | Options** in the Structure window, and select units of **Pounds force**, **Pounds mass**, and **inches**.
- Select **Point #13** on the Plate model.
- Execute the **Modify | Add Tuned Absorber** command. The Tuned Absorber dialog box will open.
- Enter the parameters shown in Figure 8.
- Press the **Calculate New Modes** button, and click on **OK**. A Shape Table window will open with the new modes in it.

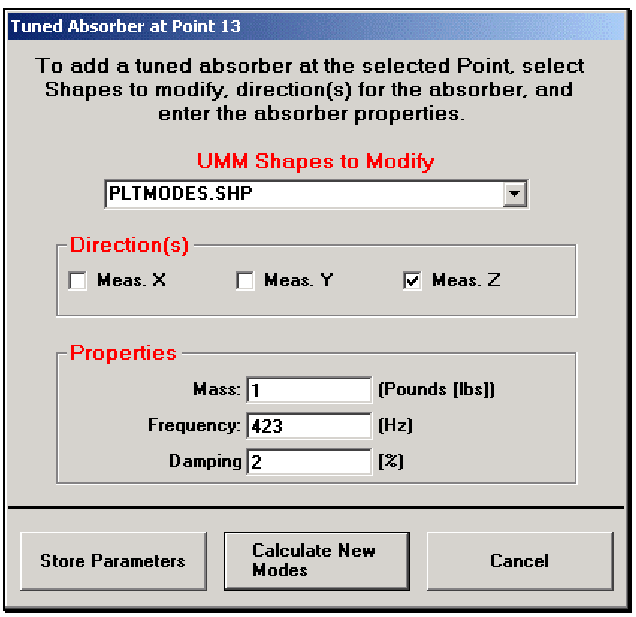
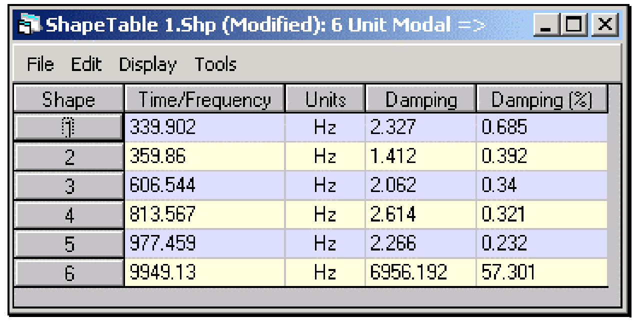


Figure 8. Adding Tuned Absorber to Plate Structure.

- Execute the **Draw | Animate** command in the Structure window, and select the new Shape Table from the Animation Source list on the Toolbar.

Notice that the **339**, **813**, and **978** Hz modes were not affected by the Tuned Absorber. On the other hand, both the **423** and **752** Hz modes have been replaced by a **359** Hz and a **606** Hz mode. There is also a 6th mode at **9849** Hz, which is ***unrealistic***. This mode is the result of using a truncated modal model with the SDM algorithm.



Shape	Time/Frequency	Units	Damping	Damping (%)
1	339.902	Hz	2.327	0.685
2	359.86	Hz	1.412	0.392
3	606.544	Hz	2.062	0.34
4	813.567	Hz	2.614	0.321
5	977.459	Hz	2.266	0.232
6	9949.13	Hz	6956.192	57.301

Figure 9. New Modes of the Plate with Absorber.

Comparing FRFs

Finally, to compare driving Point FRFs at DOF **13Z** before and after the Tuned Absorber is added,

- Execute the **Tools | Synthesize FRFs** command in the PLTMODES.SHP window. Enter an Ending Frequency of 1500 Hz, select 13Z for both DOFs, and click on **OK**.
- Repeat the above step for the Shape Table with the new modes.
- Paste one Data Block into the other, and overlay the two Traces.

Figure 10 shows the two Traces overlaid. Clearly, the vibration response at 423 Hz has been substantially reduced by the tuned absorber.

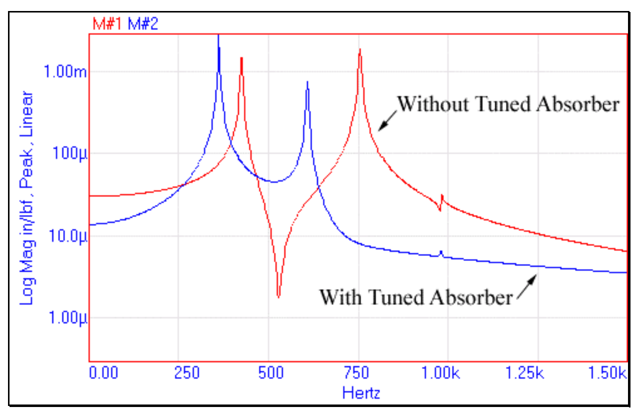


Figure 10. Driving Point FRFs Overlaid.