MEscope Application Note 11

Using a Tuned Absorber to Suppress Vibration

The steps in this Application Note can be carried out using any MEscope package that includes the **VES-3600 Advanced Signal Processing, VES-4000 Modal Analysis, VES 5000 SDM & VES-8000 FEA** options. Without those options, the steps can also be carried out using the **AppNote11** project, but the results cannot be saved. These steps might also require MEscope software with ***a more recent release date***.

APP NOTE 11 PROJECT FILE

- To retrieve the Project for this App Note, **click here** to download **AppNote11.zip**

This Project file contains **numbered Hotkeys & Scripts** for carrying out the steps of this App Note.

- ***Hold down*** **the Ctrl key** and ***click*** **on a Hotkey** to display its Script window

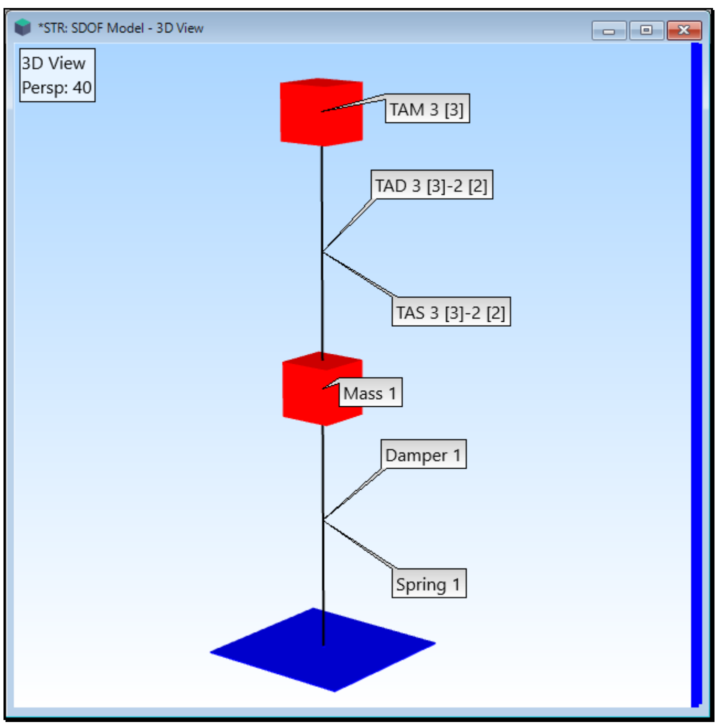
INTRODUCTION

Tuned Absorbers are used in many applications to suppress the level of troublesome resonant vibration. A Tuned Absorber is modeled as a mass attached to the problem structure with a spring & damper, as shown below.

Constructing a physical Tuned Absorber that behaves as a mass-spring-damper system is a separate challenge. Nevertheless, MEscope is useful for examining the effects of different absorber parameters and locations before fabricating an actual absorber.

The key idea behind the use of the Tuned Absorber is that the mass value and spring stiffness are chosen so that the Tuned Absorber vibrates at the **same frequency as the troublesome resonance** and therefore absorbs the energy that is exciting the resonance. To have a maximum effect, the Tuned Absorber should be attached to the structure at an **anti-node** (high amplitude point) of the mode shape of the troublesome resonance to absorb the energy from that resonance.

The best way to examine the effect of a Tuned Absorber is to compare FRFs between a pair of DOFs on the structure **before & after** the absorber has been attached to it.

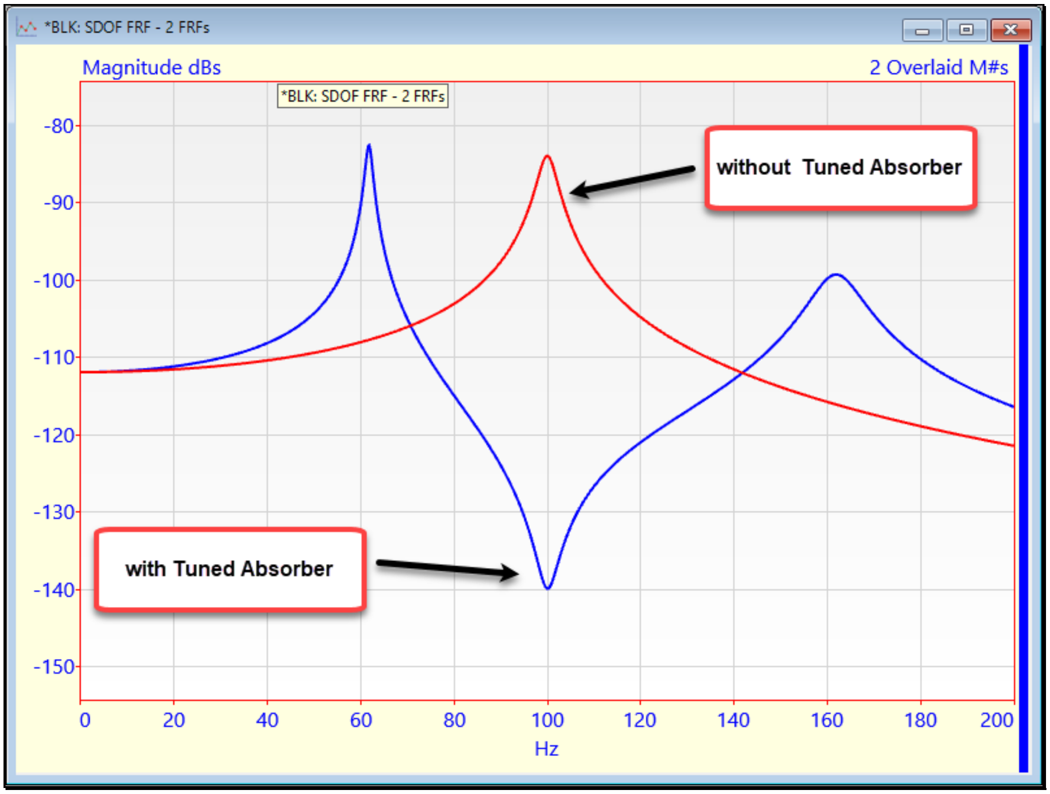


***SDOF Model** With a Tuned Absorber Attached.*

The figure below shows the typical effect of a Tuned Absorber on the Driving Point **FRF** at its attachment Point to a structure.

After the absorber is attached, **a single high amplitude resonance peak** in the **FRF** is replaced by **two lower amplitude resonance peaks** on either side of it.

More importantly, the troublesome vibration level at the original resonant frequency (at **100 Hz** below) is **greatly reduced** because of the suppression of the resonance at that frequency



Driving Point FRFs Without & With a Tuned Absorber Attached.

HOW A TUNED ABSORBER IS MODELED WITH SDM

Adding a Tuned Absorber to a structure involves solving a sub-structuring problem. To solve this problem, three parts are required

1. Mode shapes of the ***unmodified* structure**
2. The **rigid body mode shape** of the Tuned Absorber mass in space
3. An **FEA spring & FEA damper** attached between the Tuned Absorber and the structure

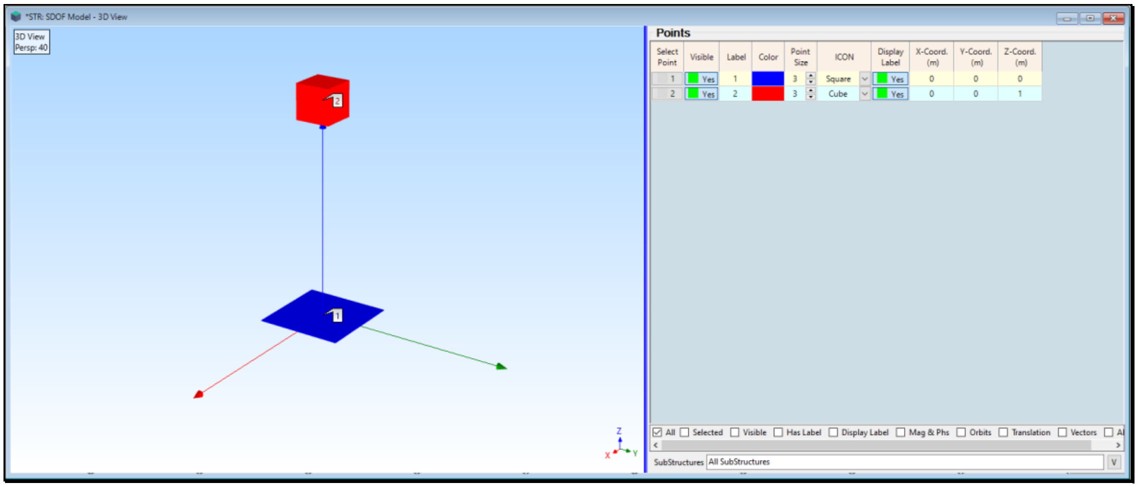
In this App Note, a Tuned Absorber will be attached to the **SDOF** mass-spring-damper shown above. The accuracy of the results will be checked in two ways,

1. Comparing the mode shapes of the **SDOF Model** with the Tuned Absorber attached to it, with the FEA mode shapes of a 2-DOF model (two masses connected together with two springs and two dampers)
2. Comparing modal frequencies with those calculated from an analytical formula

STEP 1 - CREATING AN SDOF MODEL

- ***Press* Hotkey 1 Create the SDOF Model**

A Structure window will open showing the mass-spring-damper structure.



***SDOF Model**.*

- To re-draw the mass & base plate, ***click* on Yes** in the dialog box that opens

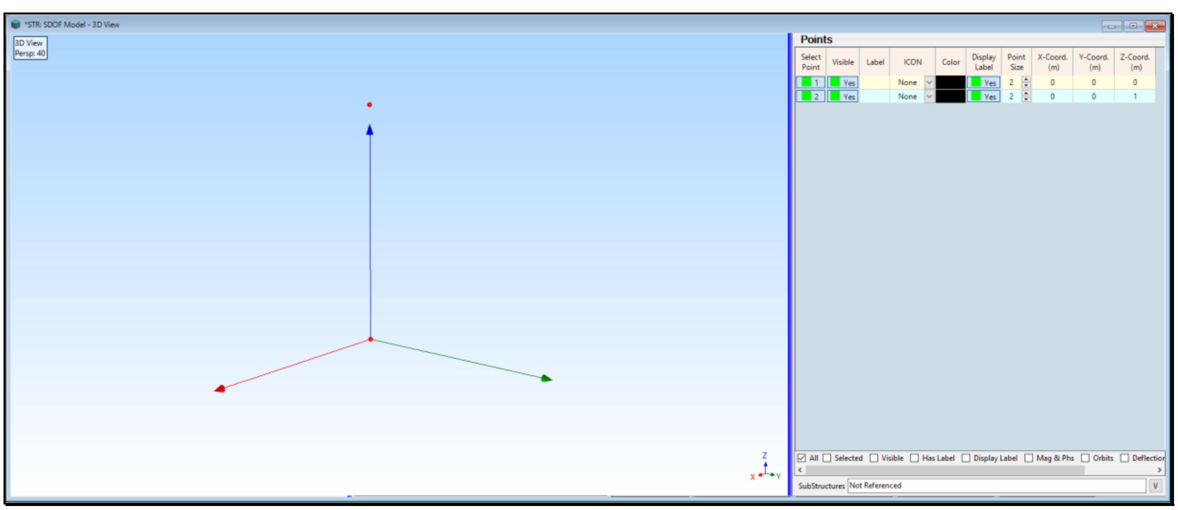
RE-DRAWING THE MASS CUBE & BASE PLATE

In this step, an **SDOF Model** is created using the drawing tools in a Structure (**STR**) window.

- If you ***clicked* on Yes**, an empty Structure window **STR: SDOF Model** will open

The **SDOF Model** is drawn with two Points, one meter apart.

- ***Right click* in the graphics area** and execute **Edit | Points**
- ***Right click* in the graphics area** and execute **Edit | Add Objects**
- ***Click near the origin*** to add a Point
- ***Click on the Z-Axis*** line to add a second Point as shown below
- Change the coordinates of **Point 1** to X-Coord ➔ 0, Y-Coord ➔ 0, Z-Coord ➔ 0
- Change the coordinates of **Point 2** to X-Coord ➔ 0, Y-Coord ➔ 0, Z-Coord ➔ 1

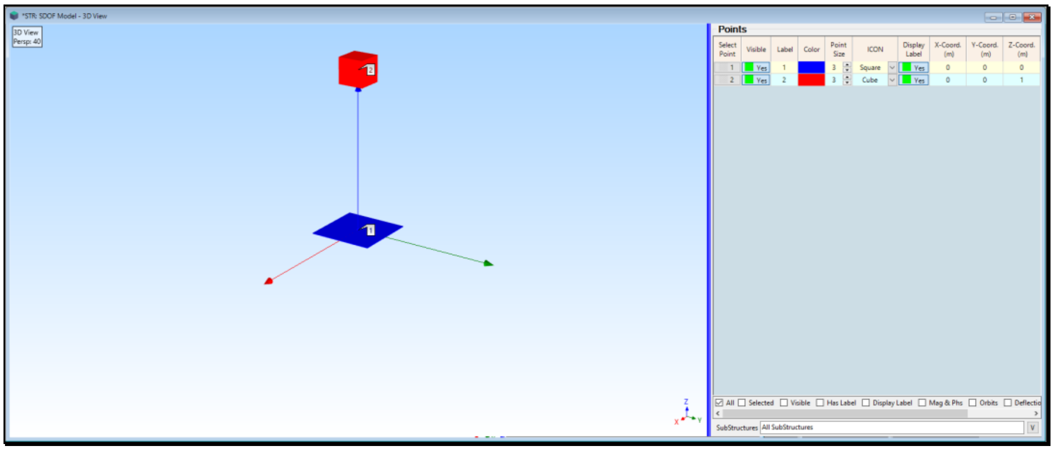


Structure Window Showing Two Points.

- ***Double click*** on the **Label** column and ***Press*** **OK** in the dialog box that opens
- ***Double click*** on the **Point Size** column and ***enter*** **3** in the dialog box that opens
- Select **Point 1**, Color it **Blue**, and select the **Square** ICON for it as shown below
- Select **Point 2**, Color it **Red**, and select the **Cube** ICON for it as shown below
- Execute **Draw | Resize Objects** and use the controls in the dialog box to increase the size of the Cube & Square, as shown below

The **SDOF Model** is now complete. As a final step, the Points will be added to a Substructure so they are easily identified as part of the overall model.

- ***Select*** (or ***un-select***) both Points
- Execute **Draw | Substructures | Add Objects**
- ***Click*** **on New Substructure** and enter **"SDOF Model"** in the dialog box that opens

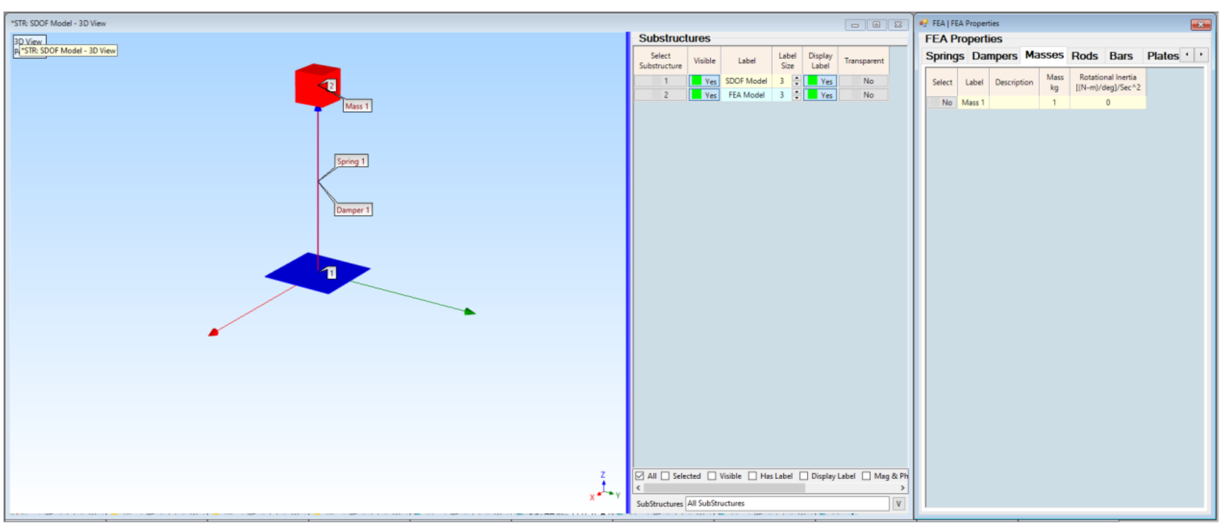


SDOF Model *Showing Mass Point Cube & Ground Point Square Icons.*

STEP 2 - ADDING AN FEA MASS, SPRING, & DAMPER

- ***Press*** **Hotkey 2 Add the Mass-Spring-Damper**

The **STR: SDOF Model** window is displayed ***on the left*** and the **FEA | FEA Properties** window ***on the right*** as shown below.



SDOF Model *Showing mass, Spring & Damper Attached.*

- To add the FEA mass, spring & damper again, ***click* on Yes** in the dialog box that opens

ADDING THE FEA MASS, SPRING, & DAMPER PROPERTIES

- If you ***clicked* on Yes**, an empty Structure window **STR: SDOF Model** will open ***on the left***
- ***Click*** on the **Masses** tab in the **FEA | FEA Properties** window
- Enter (or verify) **1 kg** into the spreadsheet, as shown below
- ***Click*** on the **Springs** tab in the **FEA | FEA Properties** window
- Enter (or verify) **394,942 N/m Translational Stiffness** into the spreadsheet
- ***Click*** on the **Dampers** tab in the **FEA | FEA Properties** window
- Enter (or verify) **25.12 N/(m/sec) Translational Damping** into the spreadsheet

ADDING THE MASS

- Execute **FEA | Masses** in the **STR: SDOF Model** window
- Execute **Edit |Add Objects**
- ***Click near Point 2*** to add the Mass
- Execute **Edit |Add Objects *again*** to terminate Add Objects

An **FEA Mass** has been added as a ***row*** in the **Masses** spreadsheet in the **STR: SDOF** window.

- Select **Mass 1** in the **FEA Property** cell in the **Masses** spreadsheet
- Execute **Draw | Substructures | Add Objects**
- ***Click* on New Substructure** and enter **"FEA Model"** in the dialog box that opens

ADDING THE SPRING

- Execute **FEA | Springs** in the **STR: SDOF Model** window
- Execute **Edit |Add Objects**
- ***Click near Point 2*** and then ***near* Point 1** to add the Spring
- Execute **Edit |Add Objects *again*** to terminate Add Objects

An **FEA Spring** has been added as a ***row*** in the **Springs** spreadsheet in the **STR: SDOF** window.

- Select **Spring 1** in the **FEA Property** cell in the **Springs** spreadsheet
- Execute **Draw | Substructures | Add Objects**
- Select **"FEA Model"** and ***click* on Add To** in the dialog box that opens

ADDING THE DAMPER

- Execute **FEA | Dampers** in the **STR: SDOF Model** window
- Execute **Edit |Add Objects**
- ***Click near Point 2*** and then ***near* Point 1** to add the Damper
- Execute **Edit |Add Objects *again*** to terminate Add Objects

An **FEA Damper** has been added as a ***row*** in the **Dampers** spreadsheet in the **STR: SDOF** window.

- Select **Damper 1** in the **FEA Property** cell in the **Dampers** spreadsheet
- Execute **Draw | Substructures | Add Objects**
- Select **"FEA Model"** and ***click* on Add To** in the dialog box that opens

STEP 3 - CALCULATING THE MODE SHAPES OF THE SDOF

With the FEA Mass, FEA Spring, & FEA Damper attached to the **SDOF Model** the ground point of the model **must be fixed** before the FEA mode shapes can be calculated. This is done by the **Script for Hotkey 3** before the mode shapes are calculated.

- ***Press*** **Hotkey 3 Calculate SDOF Mode Shapes**

The **STR: SDOF Model** window is displayed ***on the left*** and the **SHP: SDOF Mode Shapes** window is displayed ***on the right*** as shown below. Sweep animation will begin through the mode shapes in **SHP: SDOF Mode Shapes**.

- ***Click*** on a **Select Shape** button in **SHP: SDOF Mode Shapes** to display its mode shape

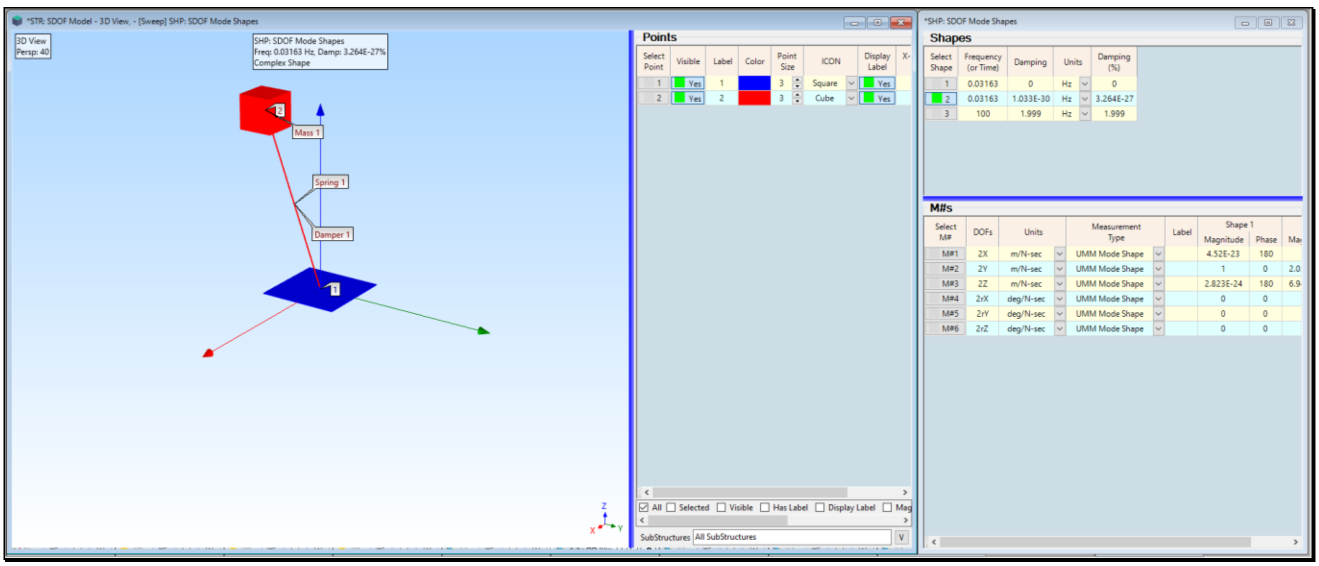
The **SDOF Model** has three mode shapes.

- The **first two mode shapes** have **essentially zero frequency & zero damping**

That is because the FEA Spring & FEA Damper have no effects in the directions of these **two rigid-body mode shapes**.

- The **third mode shape** has a **100 Hz frequency & 2% damping**

The FEA Mass, FEA Spring, and FEA Damper values were chosen so that the third mode shape would have **100 Hz frequency & 2% damping**.



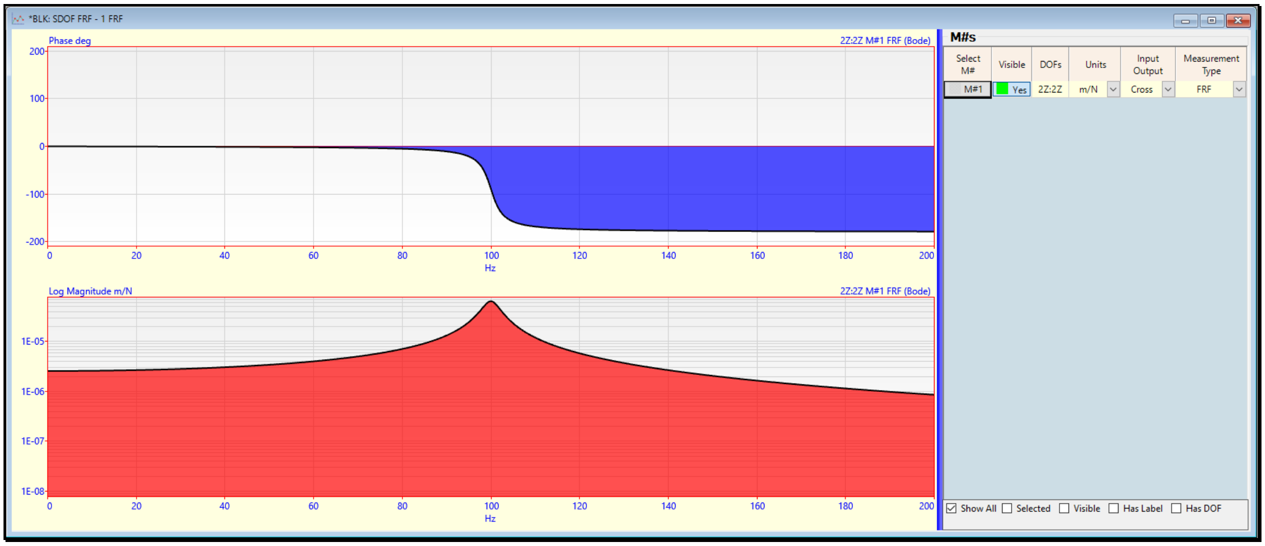
*Rigid-Body Mode Shape of the **SDOF Model**.*

STEP 4 - DRIVING POINT FRF

- ***Press*** **Hotkey 4 Driving Point FRF**

A **Driving Point FRF** is any **FRF** where the **Roving DOF is the same as the Reference DOF**.

A Data Block window will open showing the driving Point **FRF** with the **100 Hz peak of the third mode shape**. This is the expected (**displacement/force**) driving point **FRF** for an **SDOF**.



*Driving Point **FRF** at the Mass Point.*

STEP 5 - ADDING A TUNED ABSORBER TO THE MASS

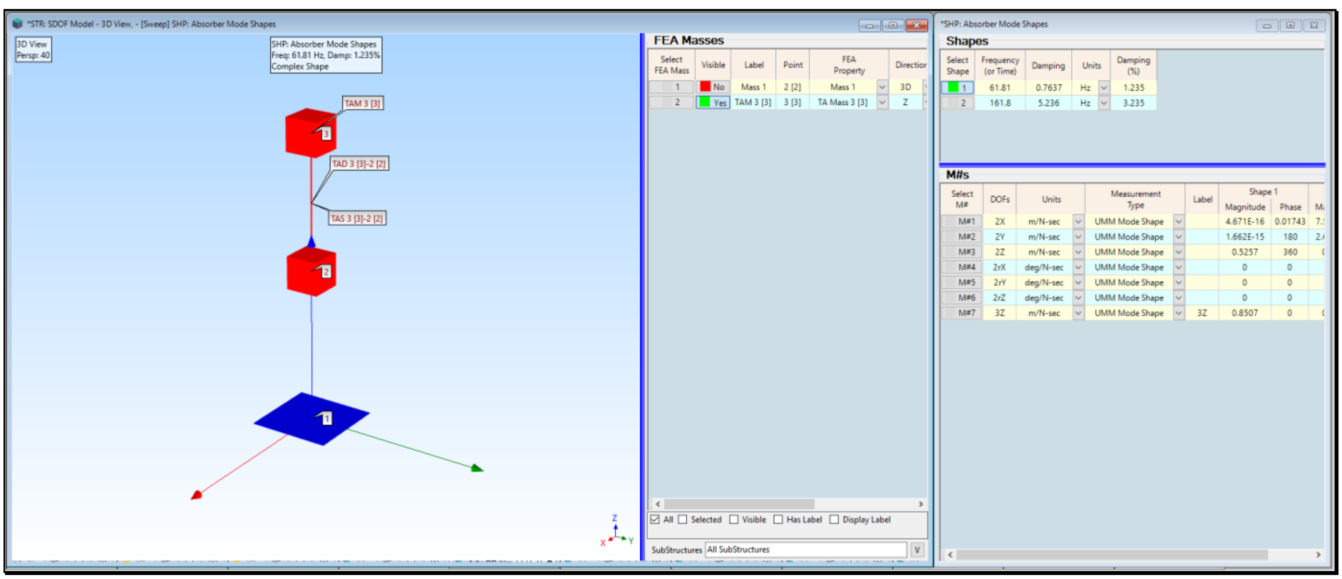
- ***Press* Hotkey 5 Add a Tuned Absorber**

When **Hotkey 5 is *pressed***, a Tuned Absorber is attached to the Mass Point of the **SDOF Model**. The following steps are carried out in the Script for this Hotkey.

1. The **FEA Mass, FEA Spring, & FEA Damper *are hidden*** to prevent them from being used again by **SDM** during the Tuned Absorber calculation
2. The **third mode** of the **SDOF Model *is selected*** to represent the **dynamics of the unmodified structure**
3. The Tuned Absorber is attached to the **Mass Point in the Z-direction**

The **STR: SDOF Model** window is displayed ***on the left*** and the **SHP: Absorber Mode Shapes** window is displayed ***on the right*** as shown below. Sweep animation is begun through the mode shapes in **SHP: Absorber Mode Shapes**.

- ***Click*** on a **Select Shape** button in **SHP: Absorber Mode Shapes** to display its mode shape



***SDOF Model** Showing Tuned Absorber Mode Shapes.*

When the **SDM | Tuned Absorber** command is executed in the script, the FEA mass, FEA Spring & FEA Damper of the tuned absorber are added to the **SDOF Model**

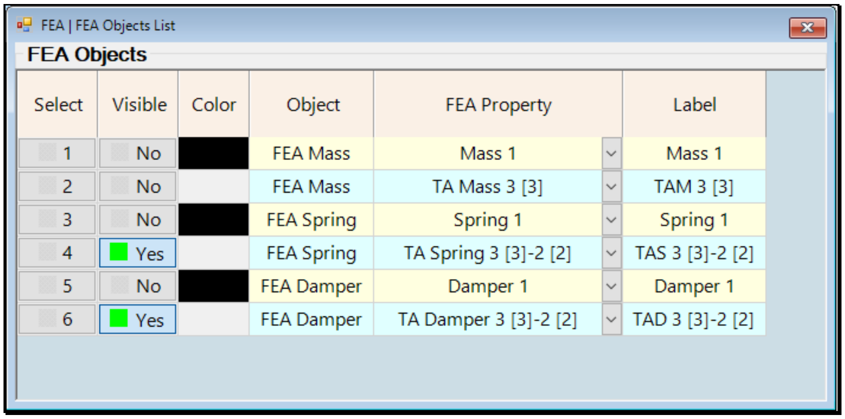
The new mode shapes are **two flexible-body mode shapes**.

At **61.8 Hz**, the Tuned Absorber Mass ***moves in-phase*** with the SDOF Mass.

At **161.8 Hz**, the Tuned Absorber Mass ***moves out-of-phase*** with the SDOF Mass.

The Tuned Absorber Mass, Spring, & Damper properties were added to their respective Object spreadsheets To list all the FEA Objects attached to the **SDOF Model**,

- Execute **Animate | Pause Continue**
- Execute **FEA | FEA Objects List** to open the **FEA Objects** window



FEA | FEA Objects List

FEA Objects

Select	Visible	Color	Object	FEA Property	Label
1	No		FEA Mass	Mass 1	Mass 1
2	No		FEA Mass	TA Mass 3 [3]	TAM 3 [3]
3	No		FEA Spring	Spring 1	Spring 1
4	Yes		FEA Spring	TA Spring 3 [3]-2 [2]	TAS 3 [3]-2 [2]
5	No		FEA Damper	Damper 1	Damper 1
6	Yes		FEA Damper	TA Damper 3 [3]-2 [2]	TAD 3 [3]-2 [2]

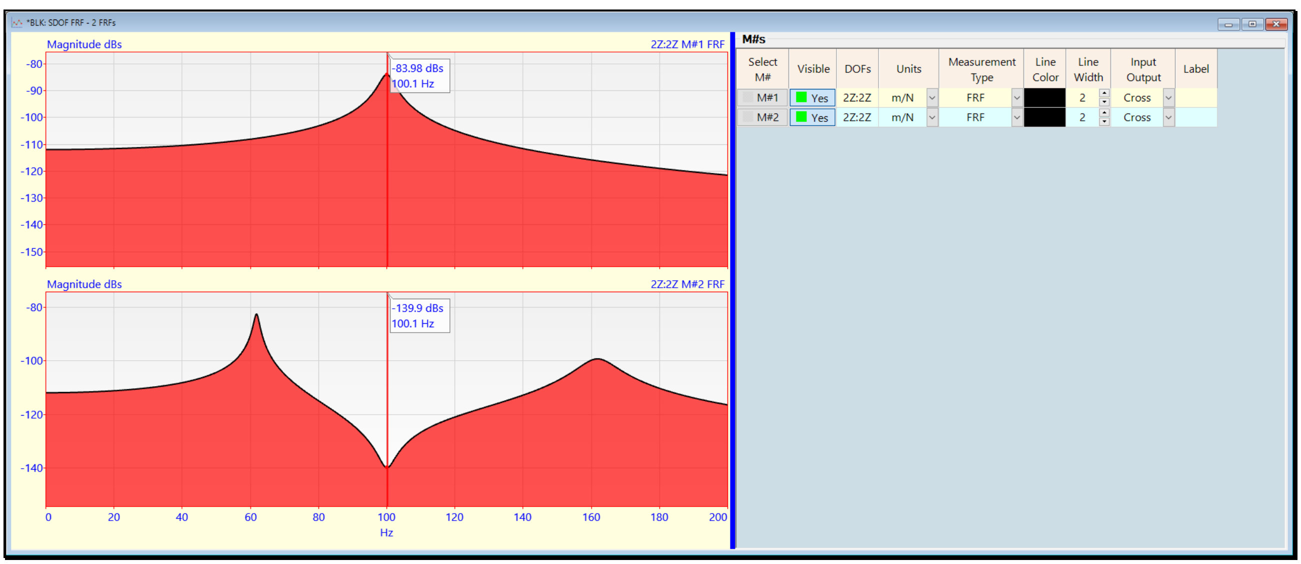
FEA | FEA Objects List.

STEP 6 - DRIVING POINT FRF WITH THE ABSORBER ATTACHED

- ***Press* Hotkey 6 Driving Point FRF with Absorber**

A Data Block window will open showing the two driving Point FRFs.

- **M#1** is the **FRF *before*** the Tuned Absorber was attached
- **M#2** is the **FRF *after*** the tuned absorber is attached to the Mass at Point 2



*Driving Point FRFs Before & After the Tuned Absorber is Attached to the **SDOF Model**.*

The Tuned Absorber replaced the original 100 Hz mode shape with two modes on either side of it **at 61.8 Hz & 161.8 Hz**.

The cursor values at 100 Hz show that the Tuned Absorber reduced the magnitude of **response DOF 2Z by about 56 dB**.

If 100 Hz was the only frequency at which there was a vibration problem, the Tuned Absorber did its job by **reducing the response by 56 dB**.

However, a **new relatively high amplitude resonance at 61.8 Hz** was created by the Tuned Absorber. If excited, this resonance could cause a new vibration problem.

SDM MODE SHAPES VERSUS FEA MODE SHAPES

When **Hotkey 5 was *pressed***, **SDM** solved a sub-structuring problem to calculate new mode shapes when the tuned absorber was attached to the Mass of the **SDOF Model**.

- **SDM** used the **100 Hz mode shape** of the ***unmodified* SDOF Model** substructure together with the **rigid body mode shape** of the Tuned Absorber Mass substructure, and calculated new mode shapes with the FEA Mass connected to the **SDOF Model** using the FEA Spring & FEA Damper of the tuned absorber

CHECKING THE RESULTS

The accuracy of the **SDM** results can be checked in two ways,

1. ***Un-hide* all the FEA Objects** on the model (**2 Masses, 2 Springs, & 2 Dampers**) and calculate the FEA mode shapes
2. Compare the modal frequencies with those calculated using an analytical formula

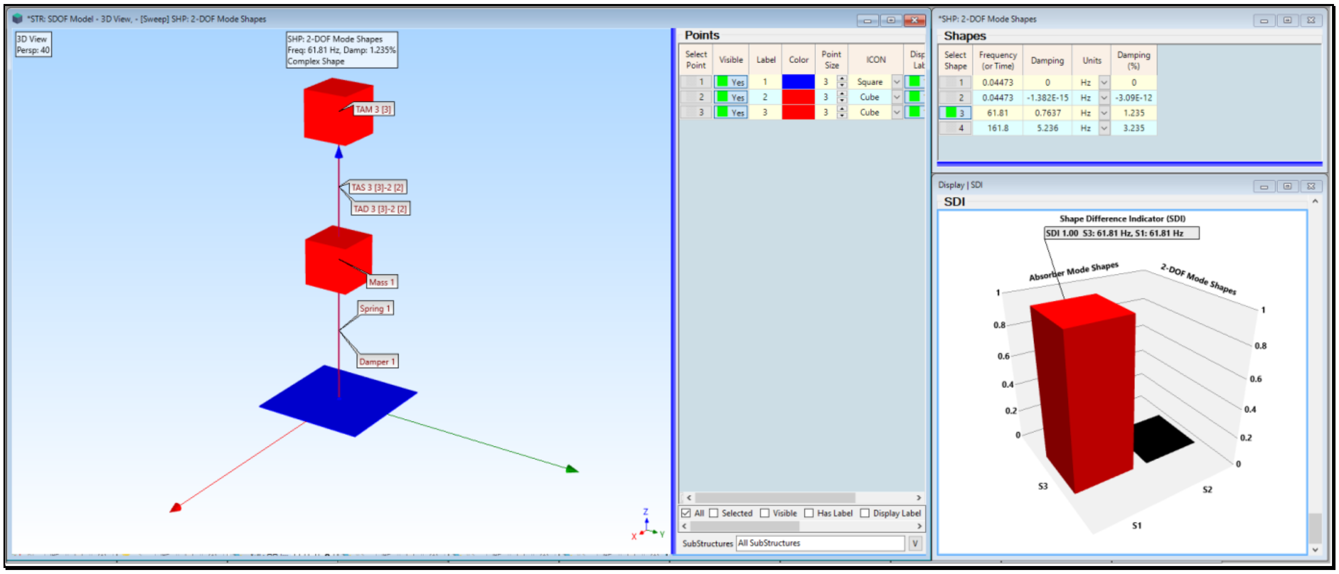
STEP 7 - CALCULATING THE MODE SHAPES OF THE 2-DOF MODEL

- ***Press* Hotkey 7 Calculate 2-DOF Mode Shapes**

When **Hotkey 7 is *pressed***, ***all the* FEA Objects** on the new model (**2 Masses, 2 Springs, & 2 Dampers**) are used by the **FEA | Calculate FEA Modes** to calculate the mode shapes of the 2-DOF model. The results are shown below.

The first two FEA mode shapes are **rigid-body mode shapes**.

The **flexible-body mode shapes** match the Tuned Absorber mode shapes exactly.



FEA Mode Shapes of the 2-DOF Model.

USING SDI TO COMPARE MODE SHAPES

The Shape Difference Indicator (**SDI**) metric is used to compare the FEA mode shapes with the Tuned Absorber mode shapes. **SDI** values between pairs of mode shapes are shown in the bar chart in the ***lower-right corner*** above.

- **SDI** has values **between 0 & 1**
- **SDI = 1.0 ➔** two shapes have equal components for their matching DOFs
- **SDI >= 0.9 ➔** two shapes have components with similar values
- **SDI < 0.9 ➔** two shapes have components with different values

TUNED ABSORBER VERSES ANALYTICAL FREQUENCIES

To compare the Tuned Absorber frequencies with analytically derived frequencies, 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 **FEA | FEA Properties** window shows that the FEA springs used to calculate the mode shapes of the ***unmodified*** **SDOF Model** and the mode shapes of the Tuned Absorber both have a stiffness of **394,942 N/m**. Using that stiffness and a mass of **1 Kg** in the formulas above gives,

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

These analytical frequencies are in ***close agreement*** with the Tuned Absorber frequencies even though the analytical formulas are for **undamped natural frequencies**.

STEP 8 - REVIEW STEPS

To review the steps of this App Note,

- ***Press*** **Hotkey 8 Review Steps**