MEscope Application Note 31

Attaching a Tuned Vibration Absorber to a Plate

The steps in this Application Note can be carried out using any MEscope package that includes the **VES-5000 SDM** and **VES-4000 Modal Analysis** options. Without these options, you can still carry out the steps in this App Note using the **AppNote31** project file. These steps might also require a ***more recent release date*** of MEscope.

APP NOTE 31 PROJECT FILE

- To retrieve the Project for this App Note, **click here** to download **AppNote31.zip**

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

STRUCTURAL DYNAMICS MODIFICATION (SDM)

SDM has become a practical tool for improving the engineering designs of mechanical systems. It provides a very quick and inexpensive approach for investigating the effects of design modifications to a structure, thus eliminating the need for costly prototype fabrication and testing.

TUNED ABSORBER

A tuned absorber is used to ***reduce the amplitude of vibration*** in a structure.

A tuned absorber is designed to ***absorb energy from the structure***, thereby reducing the vibration amplitude of the structure at the tuned frequency.

A tuned absorber ***replaces a single resonance with two resonances***, each with a lower amplitude.

The components of a tuned absorber are a ***mass, spring & damper***. Its mass is connected by the spring & damper to the structure

The **SDM | Add Tuned Absorbers** command is used to attach one or more tuned vibration absorbers to a structure model.

MODAL MODEL

SDM is unique in that it works directly with a **modal model** of the structure, either an **Experimental Modal Analysis (EMA) modal model**, a **Finite Element Analysis (FEA) modal model**, or a **Hybrid modal model** consisting of both **EMA** and **FEA** modal parameters. **EMA** mode shapes are extracted from experimental data and are referred to as **EMA** mode shapes. **FEA** mode shapes are extracted from an analytical finite element model and are referred to as **FEA** mode shapes.

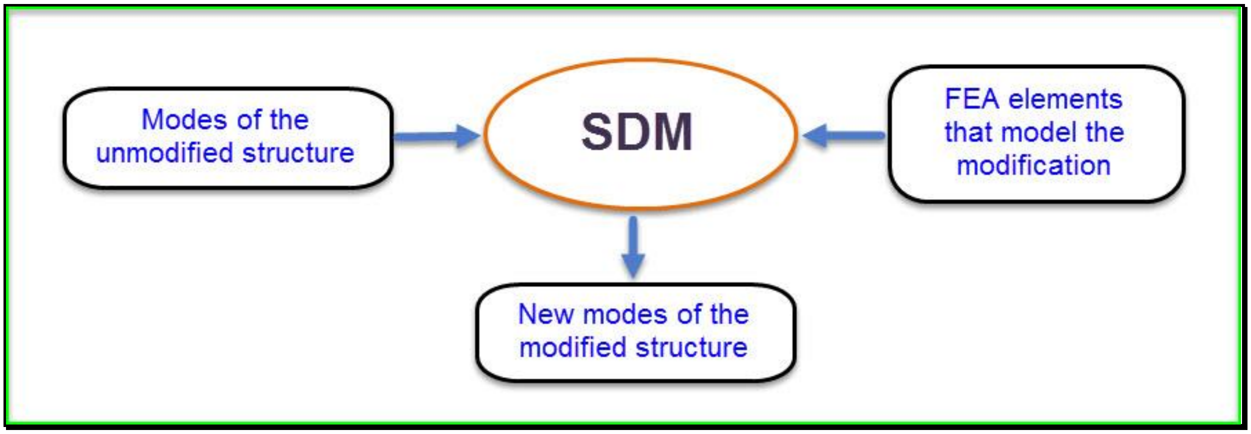
A **modal model** is a set of ***scaled mode shapes***.

A **modal model** preserves the dynamic properties of a structure (its mass, stiffness & damping properties), and therefore can be used to ***fully represent the dynamics*** of a structure.

SDM requires the mode shapes to be scaled to **Unit Modal Masses,** called **UMM** mode shapes

DESIGN MODIFICATIONS

Once the dynamic properties of an ***unmodified structure*** are defined in the form of its **modal model**, **SDM** can be used to predict the dynamic effects of mechanical design modifications to the structure. These modifications can be as simple as ***additions*** or ***removals of*** point masses, linear springs, or linear dampers. Or more complex modifications can be modeled using **FEA** elements such rods & bars, plates (membranes) and solid elements.



***SDM** Input-Output Diagram*

SDM is computationally ***very efficient*** because it solves an eigenvalue problem in ***modal space***.

FEA mode shapes are obtained by solving an eigenvalue problem in ***physical space***.

Another advantage of **SDM** is that the **modal model** of the ***unmodified structure*** must only contain mode shape data for the **DOFs (points & directions)** ***where the modification elements are attached*** to the structure. **SDM** then provides a new **modal model** of the modified structure, as depicted above.

MODELING A TUNED ABSORBER

SDM is used to model the attachment of ***tuned mass-spring-damper vibration absorbers*** to a structure. A tuned vibration absorber is designed to absorb ***some of the vibration energy so that one of the modes*** of the structure absorbs less energy and hence the structure vibrates with less amplitude.

The mass & stiffness of a tuned absorber is chosen so that its natural frequency is ***close to a resonant frequency*** of a structural resonance to be suppressed.

Ideally, the absorber should be attached to the structure at a point and in a direction where the magnitude of the resonance is large, near an ***anti-node of its mode shape***.

The absorber will ***have no effect if attached at a node*** of the mode shape, where its magnitude is zero.

> **SDM** models the attachment of a tuned absorber to a structure by solving a sub-structuring problem.
>
> A tuned absorber is modeled by attaching an **FEA** mass to the structure using an **FEA** spring & **FEA** damper.
>
> **SDM** solves for the new modes of the structure with the tuned vibration absorber attached.

TUNED ABSORBER AS A SUBSTRUCTURE

A tuned absorber is modeled as a ***free-body mass in space*** attached to the structure with a spring. A damper can also be added between the mass and the structure.

The free-body dynamics of the absorber mass are defined with a ***single rigid-body mode*** of the mass in space. The mode shape of the unattached absorber is the ***rigid-body*** **UMM mode shape** of the absorber mass.

The tuned absorber is then modeled by attaching the absorber mass to a structure using an **FEA** spring element.

Given an amount of absorber mass, the stiffness of the attachment **FEA** spring is calculated to make the absorber ***vibrate at or near the frequency*** of the mode to be suppressed.

SDM uses the absorber spring together with the **UMM rigid-body mode shape** of the absorber mass and the **UMM** mode shapes of the ***unmodified structure*** as inputs. **SDM** then solves for the new modes of the structure with the absorber mass attached to it with the absorber spring.

ABSORBER MASS

To begin a tuned absorber design, the absorber mass must be chosen. If a real-world tuned absorber is going to be fabricated and attached to a real-world structure, a realistic absorber mass must be chosen that is consistent with the size & weight of the structure.

Choosing a mass that is either ***too light or too heavy*** compared with the weight of the structure will minimize the effect of the absorber.

The following rule should be used in choosing an absorber mass.

Rule of Thumb: The mass of a tuned absorber ***should not exceed 10%*** of the mass of the structure

ABSORBER STIFFNESS

After the mass has been chosen, the frequency of the structural mode to be suppressed together with the mass of the absorber will determine the stiffness of the spring required to attach the absorber to the structure. These three values are related to one another by the formula,

$$\mathbf{k = m\ \omega^2}$$

$\mathbf{m}$ ➔ tuned absorber mass

$\boldsymbol{\omega}$ ➔ frequency of the structural mode to be suppressed

$\mathbf{k}$ ➔ tuned absorber stiffness

ABSORBER DAMPER

Adding a damper between the absorber mass and the structure is optional. If a damper is added, its damping value must also be chosen.

A realistic damping value of a ***few percent of critical damping*** is calculated using the following formulas.

$$\mathbf{k = m\ (\omega^2 + \sigma^2)}$$

$\boldsymbol{\sigma} = \frac{\boldsymbol{\omega}}{\sqrt{\mathbf{1 - \%^2}}}$ ➔ damping decay constant

% ➔ percent of critical damping

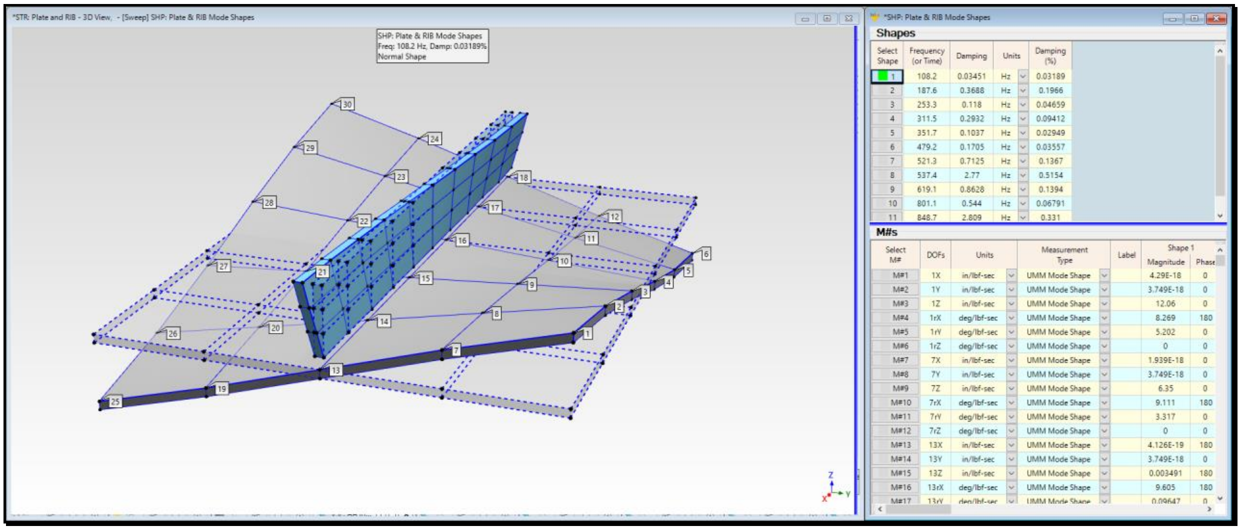
After one or more tuned absorbers have been defined using the **SDM | Add Tuned Absorbers** command in MEscope, new mode shapes are calculated when the **Calculate New Modes button is *pressed***. The following steps are necessary before using the **SDM | Add Tuned Absorbers** command,

1. The absorber mass Point must be ***numbered with a different Point number*** than the Points on the ***unmodified* structure**
2. The ***attachment* DOF** (point & direction) of the tuned absorber to the ***unmodified* structure** must be defined

MODE SHAPES OF THE UNMODIFIED PLATE & RIB

SDM will be used to model the attachment of a tuned vibration absorber to one corner of the flat aluminum **Plate & RIB** shown below. The dimensions of the aluminum plate are 20 inches (508 mm) by 25 inches (635 mm) by 3/8 inches (9.525 mm) thick. The dimensions of the RIB are 3 inches (76.2 mm) by 25 inches (635 mm) by 3/8 inches (9.525 mm) thick.

Plate & RIB *Stiffener*



Mode Shape of the 108 Hz Resonance.

STEP 1 - MODE SHAPES OF THE UNMODIFIED PLATE & RIB

- ***Press* Hotkey 1 Plate & RIB Modes**

When **Hotkey 1 is *pressed***, the mode shapes on the unmodified **Plate & RIB** are displayed in sweep animation, as shown above.

ABSORBER MASS AS A SUBSTRUCTURE

The absorber will be designed to suppress the amplitude of the **high-Q resonance at 108 Hz**, shown above.

The weight of the absorber can be arbitrarily chosen, but its weight should be compatible with the weight of the unmodified structure.

Rule of Thumb: The mass of a tuned absorber ***should not exceed 10%*** of the mass of the structure.

In this case, the absorber weight will be chosen as **0.5 lbm (0.23 kg)**.

When the **SDM | Add Tuned Absorbers** command is executed, the stiffness of the absorber is calculated so that the ***absorber will vibrate at 108 Hz***, thus absorbing the energy that ***would normally excite the 108 Hz mode*** of the **Plate & RIB**.

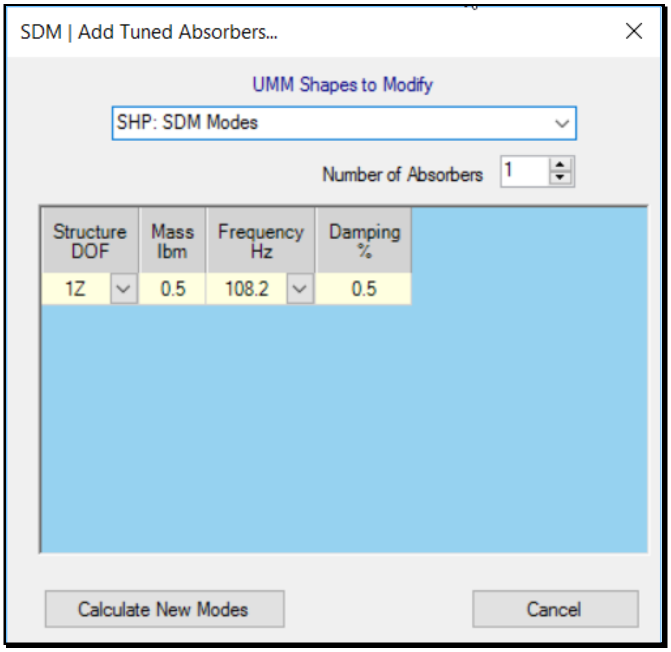
The absorber parameters are,

Mass: 0.5 lbm (0.23 kg)

Frequency: 108.2 Hz → Stiffness: 586.6 lbf/in (104.8 N/mm)

Damping: 0.5%

The absorber will be attached to **Point 1** of the plate in the vertical direction, or **DOF 1Z**. These parameters can be entered into the dialog box below, or they will be entered as parameters in a Script command that executes **SDM | Add Tuned Absorbers**.



Definition of the Tuned Absorber

STEP 2 - ADDING A TUNED ABSORBER TO THE PLATE & RIB

- ***Press*** **Hotkey 2 Add Tuned Absorber**

When **Hotkey 2 is *pressed***, the **SDM | Add Tuned Absorbers** command is executed using the above parameters. The **UMM** mode shape of the free-body mass is added in ***block-diagonal format*** to the **UMM** mode shapes of the ***unmodified*** **Plate & RIB**.

The **FEA** spring & **FEA** damper are attached between the absorber mass and the corner of the plate at **DOF 1Z**. This ***substructure*** **modal model** in ***block-diagonal*** format is used by **SDM** to solve for the new modes of the **Plate & RIB** with the absorber attached to it.

When **Hotkey 2 is *pressed***, the driving point **FRF 1Z:1Z** is synthesized using the tuned absorber mode shapes and it is ***overlaid*** on the **FRF 1Z:1Z** synthesized using the mode shapes of the ***unmodified*** **Plate & RIB**.

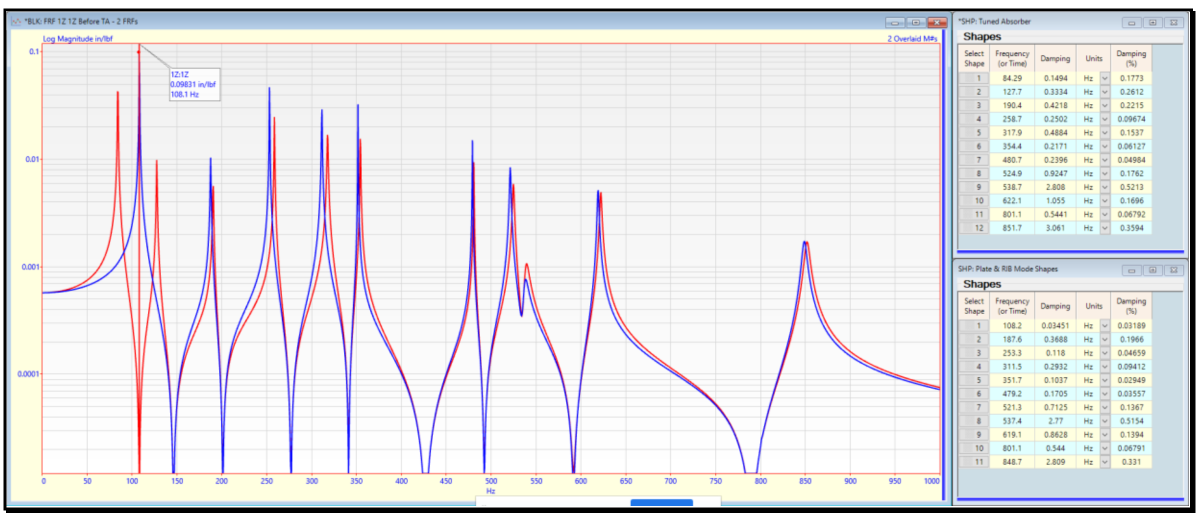
In the figure below, the driving point **FRF 1Z:1Z** (in **red**) ***from after*** the absorber is is overlaid on the **FRF 1Z:1Z** (in **blue**) ***from before*** the tuned absorber was attached.

The original **108 Hz** resonance has been ***split into two new resonances***, ***one at* 84.3 Hz** and the ***other at* 127.7 Hz**.

The two new resonances have ***less magnitude peaks*** than the original resonance peak at 108 Hz.

As a result of adding the tuned absorber, all but one of the resonance peaks have less magnitude.

The overall vibration level of the **Plate & RIB**, which is ***a summation of contributions from all the resonances***, has been reduced.



*FRFs (1Z:1Z) Before (**Blue**) and After (**Red**) Tuned Absorber*

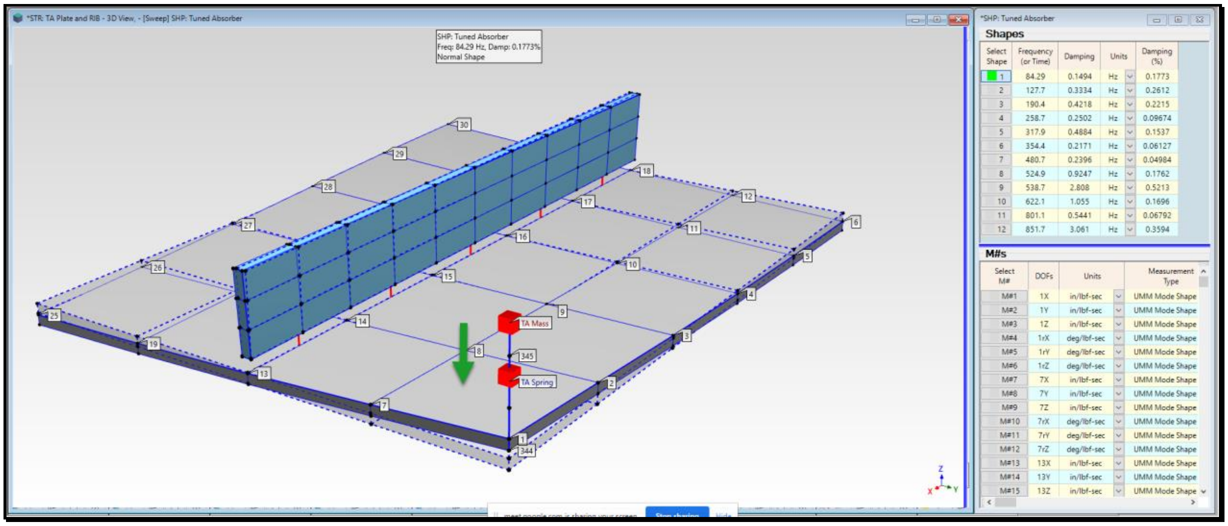
STEP 3 - TUNED ABSORBER MODE SHAPES

To display the new mode shapes calculated by **SDM** with the tuned absorber attached,

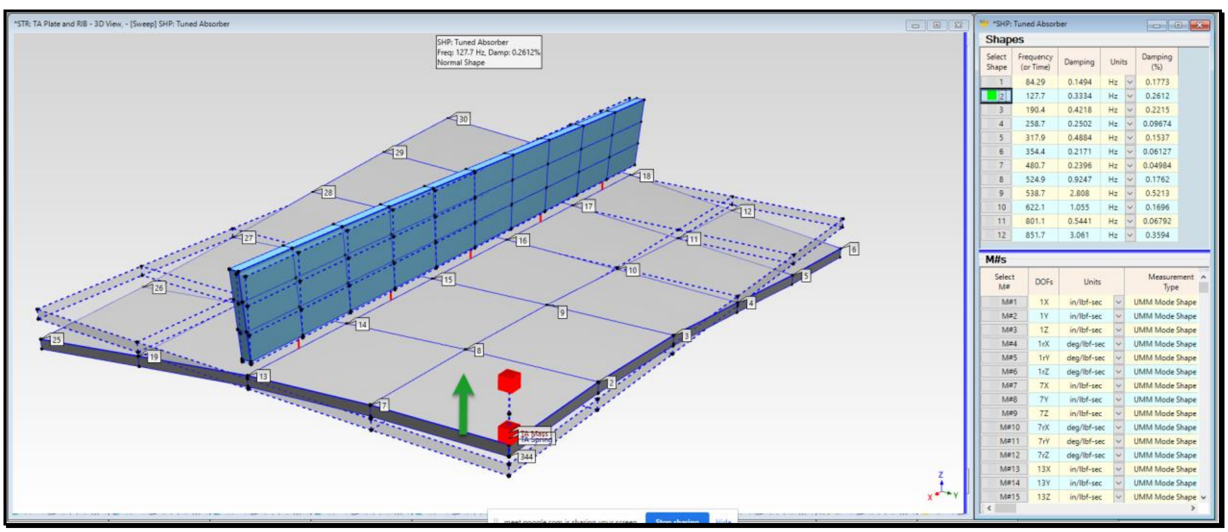
- ***Press* Hotkey 3 Tuned Absorber Mode Shapes**

Sweep animation will begin through the tuned absorber mode shapes in **SHP: Tuned Absorber**. The two figures below show how the tuned absorber mass moves with respect to the deflection of the **Plate & RIB**.

- At **84 Hz** the tuned absorber mass ***moves in-phase*** with the plate
- At **128 Hz** the tuned absorber mass ***moves out-of-phase*** with the plate



*Absorber Mass **In-Phase** with plate at 84 Hz*



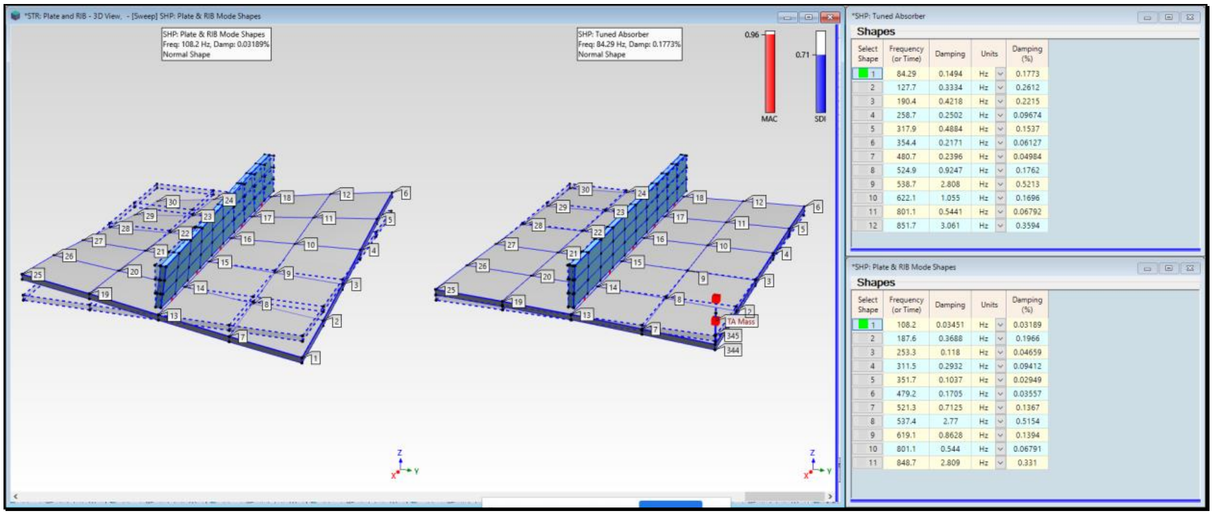
*Absorber Mass **Out-Of-Phase** with Plate at 128 Hz*

STEP 4 - MODE SHAPES BEFORE & AFTER THE TUNED ABSORBER

- ***Press* Hotkey 4 Compare Mode Shapes**

Sweep animation will begin through the tuned absorber mode shapes, each mode shape displayed side-by-side with the ***closest-matching*** mode shape from the ***unmodified* structure**.

The ***large in-phase* motion** of the absorber mass at **84 Hz** and its ***large out-of-phase* motion** at **128 Hz** have replaced the **108 Hz** mode shape of the ***unmodified* structure** and ***absorbed the energy at* 108 Hz**.



Mode Shapes Before & After the Tuned Absorber

The MAC & SDI values of ***each matching pair*** of mode shapes is also displayed.

The **Modal Assurance Criterion (MAC)** measures the ***co-linearity*** of two shapes

MAC >= 0.9 ➔ two shapes are ***similar***

The **Shape Difference Indicator (SDI)** measures whether ***two shapes have equal components***

SDI >= 0.9 ➔ two shapes have components with ***similar values***

The tuned absorber ***only affected the* 108 Hz mode shape** of the **Plate & RIB**.

All the other mode shapes have **MAC & SDI *at or close to* 1.00**.

The **MAC** values between the new **84 Hz & 128 Hz** mode shapes and the **108 Hz** mode shape indicate that the mode shapes ***are similar in shape***

The **SDI** values between the new **84 Hz & 128 Hz** mode shapes and the **108 Hz** mode shape indicate that both new mode shapes have ***reduced amplitudes*** compared with the **108 Hz** mode shape.

The tuned absorber damper ***increased the modal damping of all* mode shapes** compared with the modal damping of the modes of the ***unmodified* structure**.

The table below summarizes the effect of the tuned absorber on all the mode shapes of the **Plate & RIB**.

Shape Pair	Before TA Frequency (Hz)	Before TA Damping (Hz)	After TA Frequency (Hz)	After TA Damping (Hz)	MAC	SDI
1	108.2	0.0345	84.3	0.285	0.96	0.71
2	108.2	0.0345	127.6	0.635	0.93	0.91
3	187.6	0.368	190.4	0.482	0.99	0.99
4	253.3	0.118	258.7	0.381	0.98	0.98
5	311.5	0.293	317.9	0.689	0.98	0.98
6	351.7	0.104	354.4	0.328	0.99	0.99
7	479.2	0.170	480.7	0.306	1.00	1.00
8	521.3	0.713	524.9	1.097	0.97	0.97
9	537.4	2.769	538.7	2.892	0.98	0.98
10	619.1	0.863	622.1	1.247	1.00	1.00
11	801.1	0.544	801.1	0.544	1.00	1.00
12	848.7	2.809	851.7	3.315	1.00	1.00

Modes Before and After the Tuned Absorber is Attached at DOF 1Z

STEP 5 - MAC & SDI BAR CHARTS

- ***Press*** **Hotkey 5 MAC & SDI Bar Charts**

The MAC & SDI values ***clearly reveal*** what the tuned absorber did to the 108 Hz mode shape of the **Plate & RIB**.

For the 84 Hz mode shape,

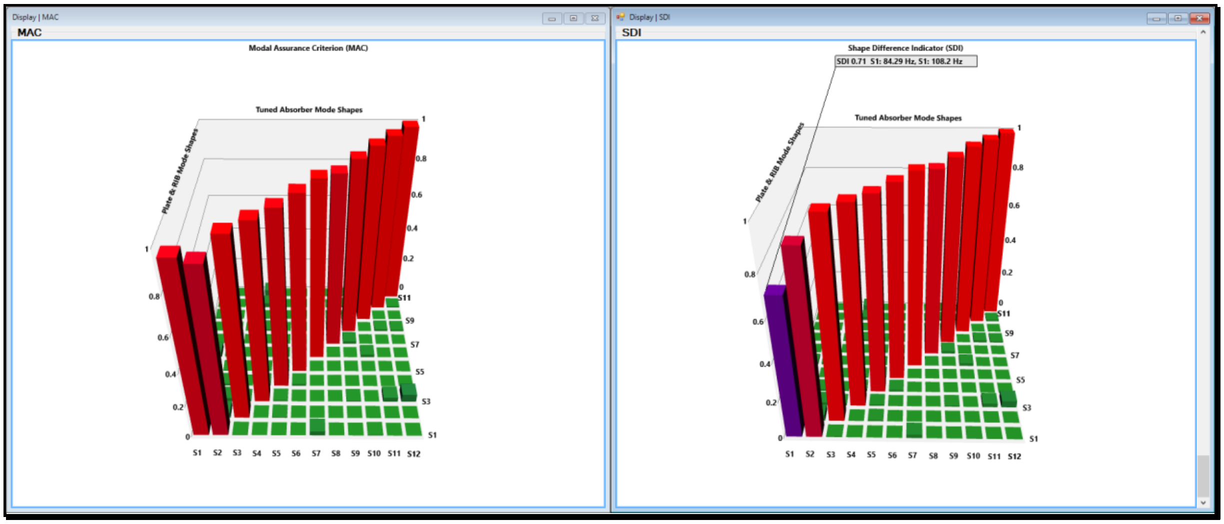
MAC = 0.96 ➔ the **84 Hz & 108 Hz** mode shapes have ***similar shapes***

SDI = 0.71➔ the **84 Hz** mode shape has ***reduced amplitude***

For the 128 Hz mode shape,

MAC = 0.93 ➔ the **128 Hz & 108 Hz** mode shapes have ***similar shapes***

SDI = 0.91➔ the **128 Hz** mode shape has ***reduced amplitude***



SDI Shows Large Reduction in Amplitude of First Two Mode Shapes

STEP 6 - REVIEW STEPS

To review the previous steps of this App Note,

- ***Press* Hotkey 6 Review Steps**