# MEscope Application Note 44

# Structural Dynamics Modification (SDM)

The steps in this Application Note can be carried out using any MEscope package that includes the **VES-5000 SDM option**. Without this option, you can still carry out the steps in this App Note using the **AppNote44** project file. These steps might also require MEscope software with a ***more recent release date***.

## APP NOTE 44 PROJECT FILE

- To retrieve the Project for this App Note, **click here** to download **AppNote44.zip**

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

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

## IN THIS APP NOTE

This App Note contains two examples that illustrate uses of **SDM**,

- Adding an **axial stiffener** between the top & bottom plates of the Jim Beam structure
- Adding a **3-DOF stiffener** between the top & bottom plates of the Jim Beam

## MODELING STRUCTURAL DYNAMIC MODIFICATIONS

There are only two ways to ***reduce vibration levels*** in a machine or structure,

1. ***Isolate*** the structure from its excitation forces
2. ***Physically modify*** the structure or ***change its boundary conditions***

The vibration of a machine or structure will change if,

1. A ***physical property*** (mass, stiffness, or damping) is changed
2. A ***boundary condition*** is changed
3. Two or more structural components ***are coupled together***

## SDM AND THE LAW OF MODAL ANALYSIS

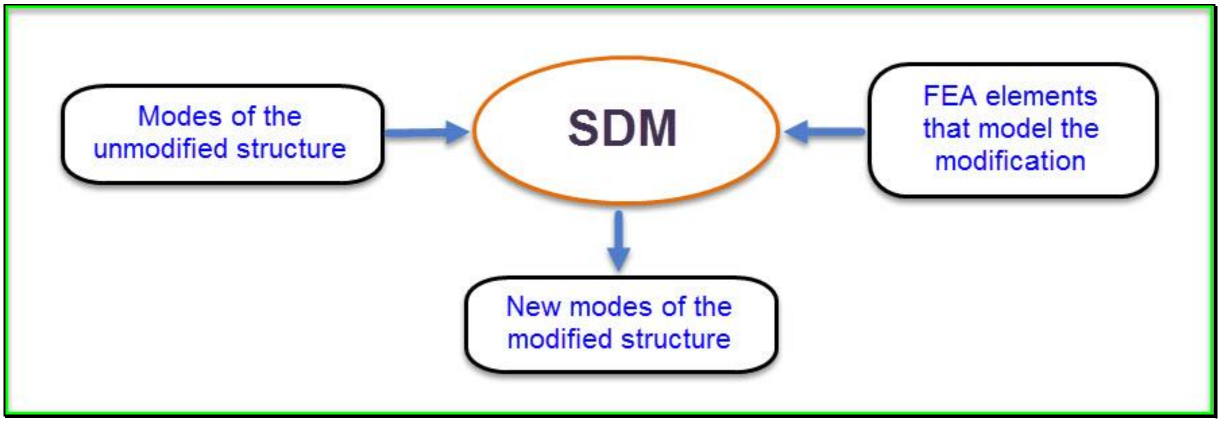
SDM relies on a **Law of Modal Analysis** to perform its calculations. If uses a **Modal Model** of the ***unmodified*** **structure** together with FEA Objects that define the structural modifications to calculate the mode shapes of the ***modified*** **structure**.

**Law of Modal Analysis**: ***All vibration is a summation of mode shapes***.

The **Structural Dynamics Modification (SDM)** method allows you to model one of the three types of modifications**, physical change, boundary condition change**, or **component coupling (sub-structuring)**. **SDM** calculates the new modal parameters (**frequency, damping, & mode shape**) that result from making those structural modifications.

**SDM** converts all structural modifications into **changes in the mass, stiffness & damping properties** of the structure. Those mass, stiffness, & damping changes are used together with the **mode shapes of the *unmodified* structure** to calculate the **new modes of the *modified* structure**.

**SDM** calculates the mode shapes of the ***modified*** **structure** as **weighted summation of the mode shapes** of the ***unmodified*** **structure**, therefore utilizing of the **Law of Modal Analysis**.




## MODAL MODEL

**SDM** is unique in that it works directly with a **Modal Model** of the ***unmodified*** **structure**. The **Modal Model** can contain mode shapes from an **Experimental Modal Analysis** called **EMA mode shapes**, mode shapes from a **Finite Element Analysis** called **FEA mode shapes**, or both **EMA & FEA modal parameters merged together** in a **Hybrid Modal Model**.

A **Modal Model** is a set of **scaled mode shapes**.

**SDM** requires the mode shapes to be scaled to Unit Modal Masses, called UMM 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 Input Output structural dynamics**.

Once the dynamic properties of an ***unmodified*** **structure** are defined in terms of its **Modal Model**, **SDM** can be used to predict the dynamic effects of 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 structural modifications can be modeled using **FEA** elements such **rods & bars, plates (membranes) and solid elements**.

**SDM** is computationally very efficient because it solves an eigenvalue problem in **modal space**. The eigenvalue problem size is determined by the number of modes in the **Modal Model**.

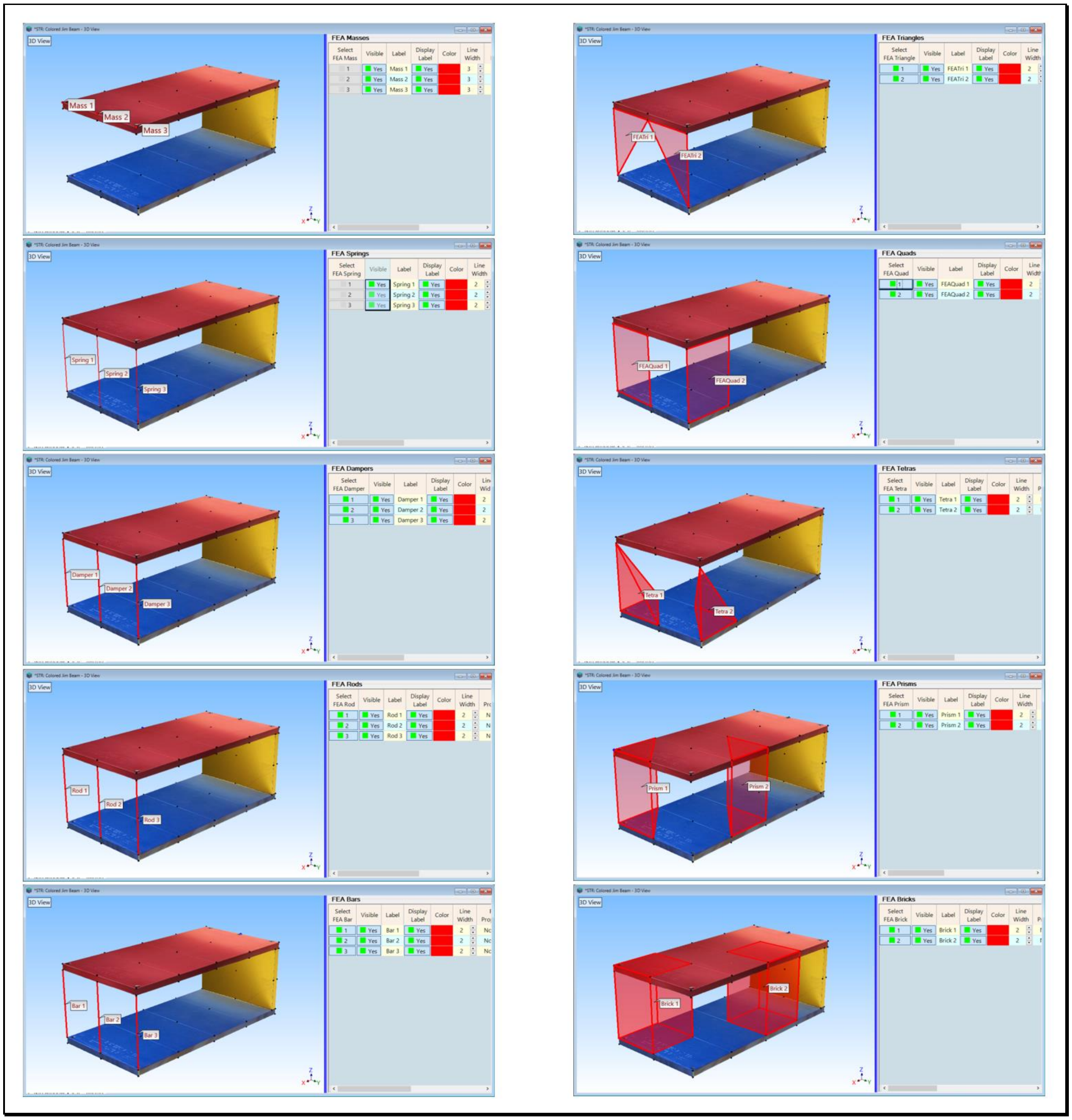
Another advantage of **SDM** is that the **Modal Model** of the ***unmodified*** **structure** must only contain mode shape data for the **DOFs (points & directions) where the modification elements are attached** to the structure.

## FEA OBJECTS FOR MODELING STRUCTURAL MODIFICATIONS

**SDM** uses **industry-standard finite elements** to model structural modifications.

Finite elements are called **FEA Objects** in MEscope.

The following types of **FEA** Objects can be used for modeling structural modifications.

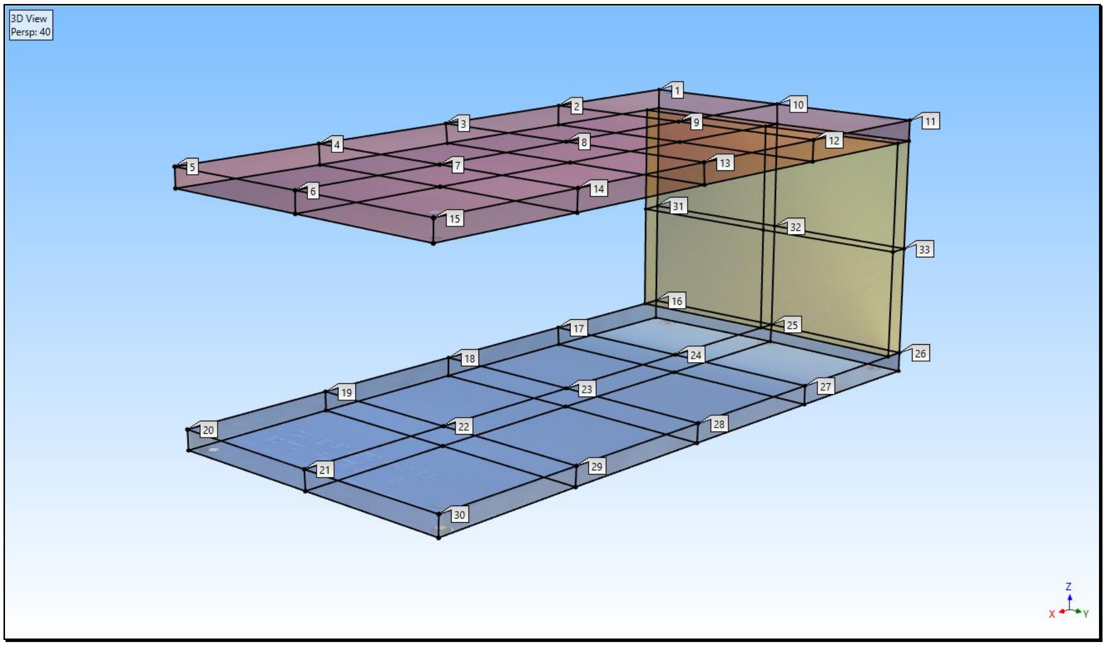


*Types of **FEA** Objects used by **SDM***

## IMPACT TEST OF THE JIM BEAM

To acquire a set of **FRFs**, the Jim Beam was impacted at one corner of the top plate. A tri-axial accelerometer was moved between impacts and attached to each of 33 different points on the top, bottom, & vertical plates of the beam structure, as shown below.

This provided **99 FRFs**, which preserve the dynamics between the **Input** at **DOF 15Z**, and **3D (X, Y, Z) Outputs at 33 Points**. By curve fitting the **FRFs**, **Residue** mode shapes for ten modes with **99 DOFs in each mode shape** are estimated from the **FRFs**. A **Modal Model** is then created by re-scaling the **Residue** mode shapes to **UMM** mode shapes starting with the driving point mode shape component (**15Z:15Z**) of each **Residue** mode shape.




*Jim Beam Model Showing 33 Test Points.*

## STEP 1 - MODE SHAPES OF THE UNMODIFIED JIM BEAM

- ***Press* Hotkey 1 Mode Shapes of the Jim Beam**

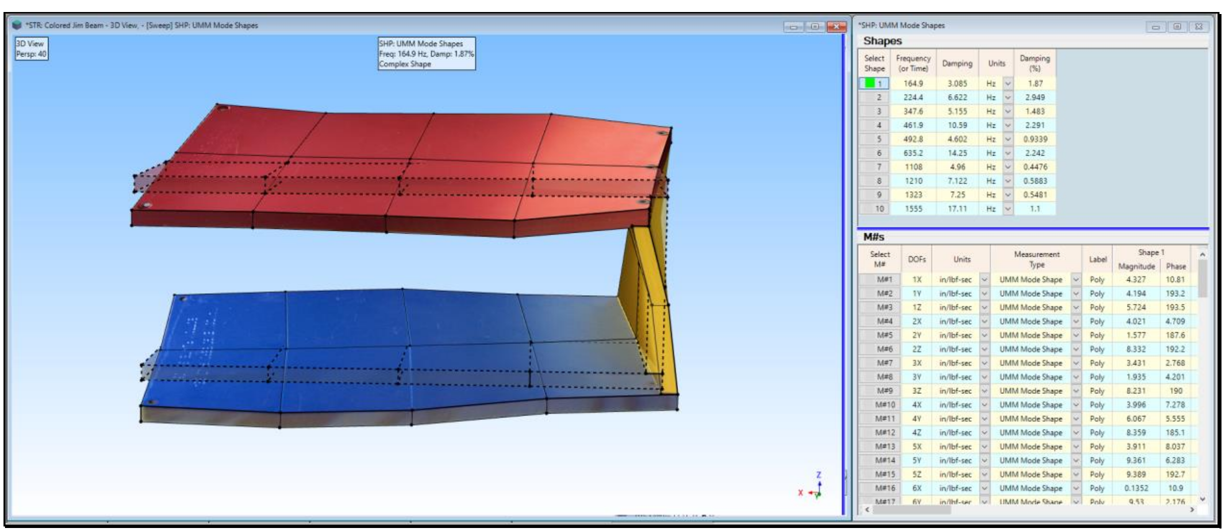
When **Hotkey 1 is *pressed***, a **Modal Model** of the Jim Beam is obtained by curve fitting a set of **FRFs** for the Jim Beam, and re-scaling the **Residue** mode shapes estimated from curve fitting to **UMM** mode shapes.

Sweep animation is then begun through the mode shapes in the Shape Table **SHP: UMM Mode Shapes** displayed ***on the right side***. Each shape is deflected using **several cycles of sine dwell animation**.

- ***Press*** a **Select Shape** button in **SHP: UMM Mode Shapes** to display its mode shape

From the animated display of each mode shape it is evident that the dominant motion of each mode shape is in the **vertical Z-direction**, except for the **165 Hz** mode shape. The **165 Hz** mode shape is a **torsional (twisting)** mode shapes of the back vertical plate.

The **165 Hz** mode shape has **dominant motion of the top & bottom plates in the horizontal plane**.

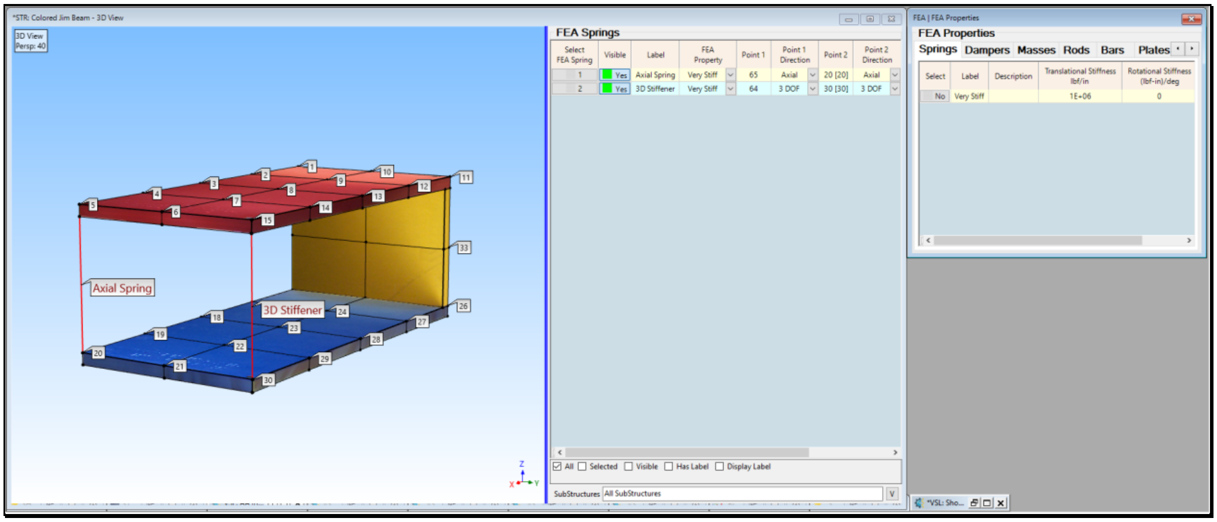



*Deflection of the 165 Hz Jim Beam Mode Shape.*

## STEP 2 - SPRING & STIFFENER BETWEEN THE TOP & BOTTOM PLATES

- ***Press* Hotkey 2 Show the Axial Spring and 3D Stiffener**

Two **FEA Springs** have already been added to the **FEA** Springs spreadsheet on the right of the **vertical blue splitter bar**, as shown below




*Two **FEA** Springs Between the Top & Bottom Plates.*

The **Axial Spring** is connected between **Point 65 & Point 20** on the model

The **Axial Spring** provides stiffness in the **Axial direction** at both points

**Point 20** also has a label [**20**]. Point 65 is the point on the bottom of the top plate. Point 65 has no label but it has an **M# Link** that uses the mode shape data from **Point [5]** above it.

**SDM** will use the mode shape data for **Point [5] and Point [20]** for its calculation.

**3D Stiffener** is connected between **Point 64 & Point 30** on the model

**3D Stiffener** will provide stiffness in **3 DOFs** at both end points

**Point 30** has a label [**30**]. Point 64 is the point on the bottom of the top plate. Point 64 has no label but it has an **M# Link** that uses the mode shape data from **Point [15]** above it.

**SDM** will use the mode shape data for **Point [15] and Point [30]** for its calculation.

When used by **SDM**, each of these FEA Springs will add stiffness between the top & bottom plates. A spring property called **Very Stiff** has already been selected in the **FEA Properties cell** for each **FEA** Spring

A very large **Stiffness** has already been defined in the **FEA | Properties** box. **Very Stiff ➔ 1E+06 lbf/in**

## COMPATIBLE ENGINEERING UNITS

To use **SDM**, the engineering units of the mode shapes in the Shape Table (**SHP: UMM Mode Shapes**) **must be compatible** with the units of the structural modification **FEA Objects** that are attached to the model.

The current engineering units for ***each*** **M#** in **SHP: UMM Mode Shapes** are **(in/lbf-sec)** as shown above. Those are compatible with the **force (lbf) & displacement (in) units** of the **Stiffness** in the **FEA | Properties** box.

## CHANGING UNITS

To change engineering units from **English** to **Metric** units in **SHP: UMM Mode Shapes**,

- ***Double click*** on the **Units** column heading in the **M#s** spreadsheet of **SHP: UMM Mode Shapes**
- Enter "**m/N**" into the dialog box that opens
- ***Click*** **on Yes** in the next dialog box to re-scale the mode shapes to Metric units (**m/N-sec**)

To change engineering units from **English** to **Metric** units in the **FEA | Properties** box,

- Execute **File | MEscope Options** to open the **MEscope Options** box
- On the **Units** tab, select **Mass, Length, & Force** units to match the units in **SHP: UMM Mode Shapes**

If you change engineering units in the **STR** window, properties in the **FEA | Properties** dialog box **will be changed to the new units**.

The model is now ready to perform **SDM** calculations.

## STEP 3 - AXIAL SPRING BETWEEN THE TOP & BOTTOM PLATES

- ***Press*** **Hotkey 3 SDM with the Axial Spring**

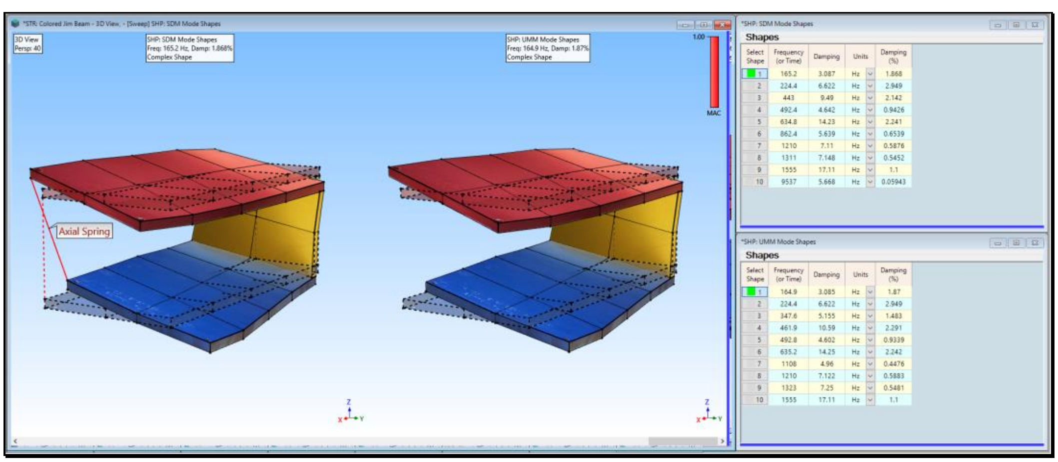
When **Hotkey 3 is *pressed***, **SDM** will calculate the new modes of the Jim Beam with the **stiff Axial Spring** attached between the top & bottom plates, and save the new mode shapes in the Shape Table **SHP: SDM Mode Shapes**.

The **Axial Spring only applies stiffness** to the top & bottom plates **along its own axis**.

This becomes apparent when the new mode shapes are displayed in animation.

Sweep animation will begin through the mode shapes in **SHP: SDM Mode Shapes**, displaying each shape with **several cycles of sine dwell animation**. Each new mode shape is displayed side-by-side with its ***closest-matching*** mode shape from the mode shapes of the ***unmodified*** **structure** in **SHP: UMM Mode Shapes**.

Each ***closest-matching*** mode shape pair has a **Maximum MAC** value from among all the mode shapes in both Shape Tables.



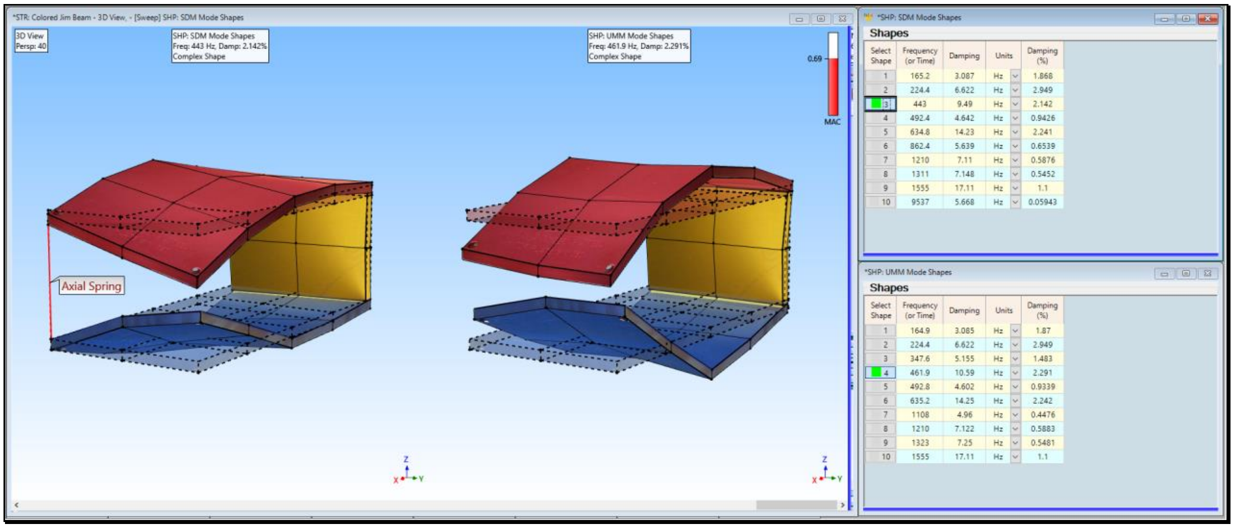

*Closest-Matching Mode Shapes of Modified & Unmodified Jim Beam.*

The mode shapes of **Shape 1 & Shape 2** in both Shape Tables are the same (**MAC ➔ 1.00**) because those two mode shapes have **little or no relative motion along the axis of the FEA spring between the upper & lower plates**. The stiffener did not affect these two modes.

- ***Click*** **on Shape 3 (443 Hz) in SHP: SDM Mode Shapes**

This **new mode shape** clearly shows the effect of the stiffener. The ***unmodified* structure** had modes at **348 & 462 Hz**, both of which no longer exist in the modified structure.

**MAC ➔ 0.69** between this new mode shape and the ***closest-matching*** **462 Hz** mode shape of the ***unmodified* structure** indicating that a new mode shape exists at **443 Hz**.



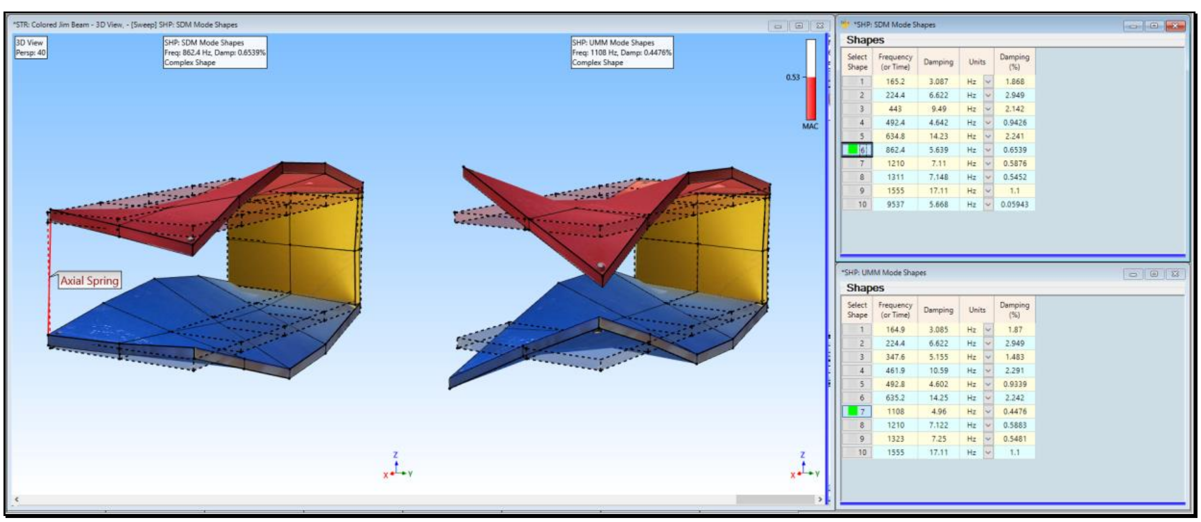

*443 Hz Mode Shape Showing Influence of the Axial Spring.*

- ***Click*** **on Shape 6 (862 Hz) in SHP: SDM Mode Shapes**

This **new mode shape** also clearly shows the effect of the stiffener.

**MAC ➔ 0.53** between this new mode shape and the ***closest matching*** **1108 Hz** mode shape of the ***unmodified* structure** indicating that a new mode shape exists at 862 Hz.

The remaining mode shapes each have a **high MAC value** with one of the modes of the ***unmodified* structure**, meaning that **those modes were not affected** by the Axial Spring.




*862 Hz Mode Shape Showing Influence of the Axial Stiffener*

## TRUNCATED MODAL MODEL

The **Modal Model** that was used to model the dynamics of the ***unmodified*** **structure** had only 10 modes in it, yet it was assumed to represent the **entire dynamics of the unmodified structure**.

The real-world Jim Beam structure has more than 10 modes, ideally an **infinite number of modes**.

A **Modal Model** with only 10 modes in it is called a **truncated Modal Model** because the higher frequency modes of the real structure are not included in it.

When a **truncated Modal Model** is used by **SDM** to calculate the new modes of a ***modified*** **structure,** one or more of the highest frequency mode shapes in the solution are called **computational modes**. Computational modes have **unrealistic** mode shapes.

- ***Click*** on **Shape 10 (9550 Hz)** in **SHP: SDM Mode Shapes**

The animated display of **Shape 10 does not exhibit the effect of the Axial Spring**. It is clearly a computational mode.

A **truncated Modal Model** is **not a complete dynamic model** of the ***unmodified*** structure

The highest frequency modes in an **SDM** solution **typically have unrealistic mode shapes** and **much higher frequencies** than the rest of the mode shapes

Higher frequency modes in an **SDM** solution account for the **absence of the higher frequency modes** of the real-world structure

The higher frequency **SDM** modes **absorb the effects of the modification** that would **normally be absorbed by the modes not contained in the truncated Modal Model**

**SDM** still provides **useful solutions for the lower frequency modes**, even when a **truncated Modal Model** is used to model the dynamics of the ***unmodified*** **structure**.

## STEP 4 - 3D STIFFENER BETWEEN THE TOP & BOTTOM PLATES

- ***Press*** **Hotkey 4 SDM with the 3D Stiffener**

When **Hotkey 4 is *pressed*** **SDM** will calculate the new modes of the Jim Beam with a **stiff 3D Stiffener** attached between the top & bottom plates, and save the new mode shapes in the Shape Table **SHP: SDM Mode Shapes**.

The 3D Stiffener applies stiffness in **all three directions (X, Y, Z)** at its end points.

The **UMM** mode shapes of the Jim Beam contain DOFs in **three directions (X, Y, Z)** at the end points of the 3D Stiffener, **SDM** will use the 3D mode shape data to calculate the new mode shapes.

Sweep animation will begin through the new modes in **SHP: SDM Mode Shapes**, displaying each shape with **several cycles of sine dwell animation**. Each new mode shape is displayed side-by-side with its ***closest-matching*** mode shape from among the modes of the ***unmodified*** **structure** in **SHP: UMM Mode Shapes**.

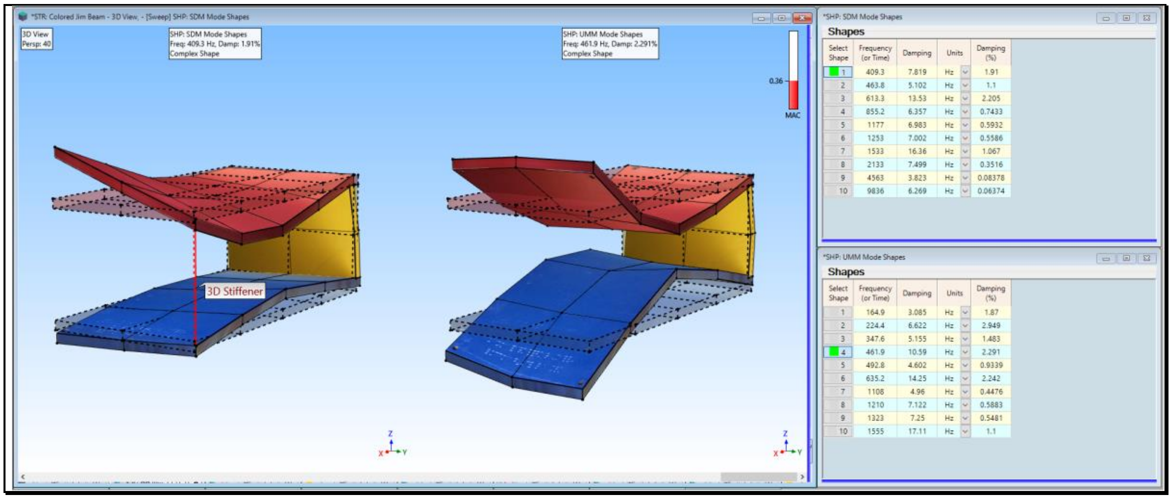
The **lowest frequency** mode shape of the ***modified*** **structure** is at **409 Hz**.

The ***closest-matching*** mode shape of the ***unmodified*** **structure** to the new **409 Hz** mode was the **462 Hz** mode shape, with **MAC → 0.36**.

The mode shapes of (**Shapes 3, 5, & 7**) have **MAC → 0.90**. They are the ***closest-matching*** shapes with those of the ***unmodified*** **Jim Beam**. Their frequencies also ***closely match*** the frequencies of the ***unmodified*** **structure**.

The remaining new modes have **MAC →** ***less than*** **0.90**, meaning that **none of those new modes matches well** with one of the modes of the ***unmodified*** **structure**.

**All modes** of the ***unmodified*** **structure** were **more heavily affected by the 3D Stiffener** than by the **Axial Spring**.




*409 Hz Mode Shape Showing Influence of the 3D Stiffener.*

## STEP 5 - REVIEW STEPS

To review the previous steps of this App Note,

- ***Press* Hotkey 5 Review Steps**