



MEscope Application Note 13

Introduction to Modal Curve Fitting

The steps in this Application Note can be carried out using any MEscope package that includes the **VES-4000 Modal Analysis** option. Without this option, you can still carry out the steps in this App Note using the **AppNote13** project file. These steps might also require MEscope software with a *more recent release date*.

APP NOTE 13 PROJECT FILE

- To retrieve the Project for this App Note, [click here](#) to download **AppNote13.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

Modal curve fitting is the process used to obtain a set of *modal parameters (frequency, damping & mode shape)* for each of the modes of vibration of a structure from experimental data.

MEscope contains several *FRF-based curve fitting* methods. Each has merit in specific situations. Modal curve fitting is done in three steps,

1. Determine the **number of modes** in the bandwidth of the measurements
2. Estimate **modal frequency & damping** for each mode
3. Estimate **modal residues** for each mode and save them as a mode shape

Different methods can be used for each of the three steps, but the same basic steps are used to extract a set of modal parameters from a set of measurements.

MEscope contains a *Quick Fit* command which curve fits a set of measurements with minimum user intervention. All three curve fitting steps are applied at the press of a single *Quick Fit* button. *Quick Fit* can also use different curve fitting methods, defined by your selections during curve fitting, and can be used in with narrow bands of data.

COMMON MODAL TESTS

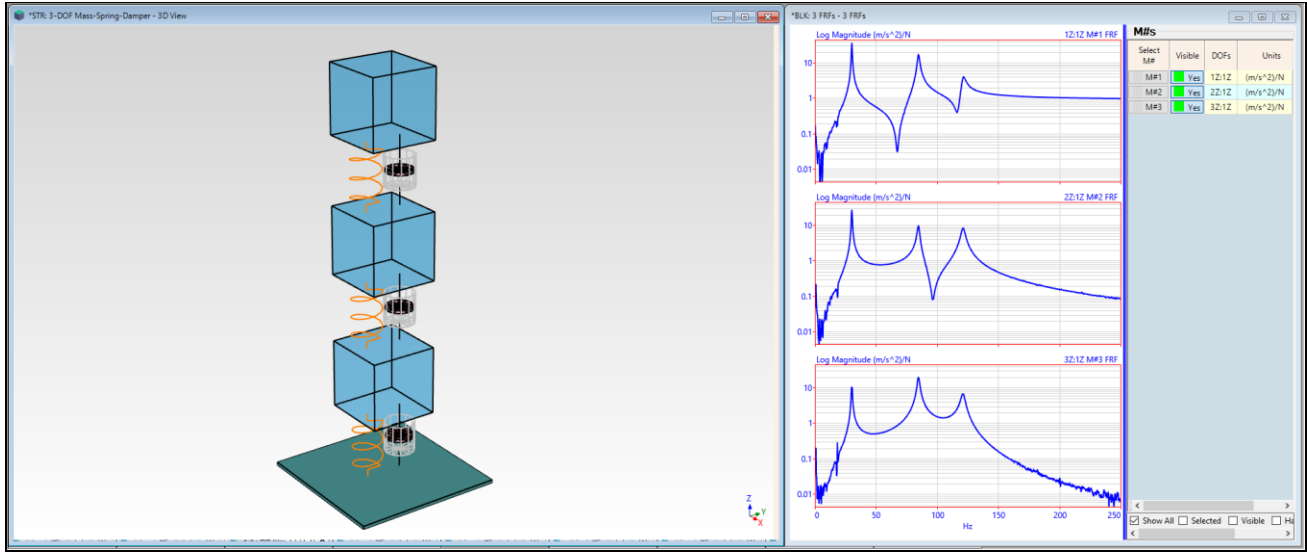
The most common type of modal test is called a **Single Reference Roving Impact Test**. In this test, a single accelerometer is *attached at a fixed DOF* (point & direction called a *degree-of-freedom*) on the structure, and the structure is impacted at multiple DOFs with an instrumented hammer.

In a **Single Reference Shaker Test**, the structure is excited by a shaker *attached at a fixed DOF*, and acceleration responses are acquired at different DOFs of the structure.

In a **Multiple Reference Impact Test**, *multiple fixed accelerometers* are attached to the structure. In a **Multiple Reference Shaker Test**, *multiple shakers* are attached to the structure.

- With the **VES-4600 Advanced Modal Analysis** option, either multiple reference sets of data or *output-only* (Auto & Cross spectra or ODS FRFs) can be curve fit using FRF-based curve fitting

The **AppNote13** Project file contains a 3D model of the **mass-spring-damper** system shown below together with FRFs that were calculated from data acquired at its three masses. This test article was impacted at the top mass, and its acceleration response was acquired at each mass



3-DOF Mass-Spring-Damper and its FRFs.

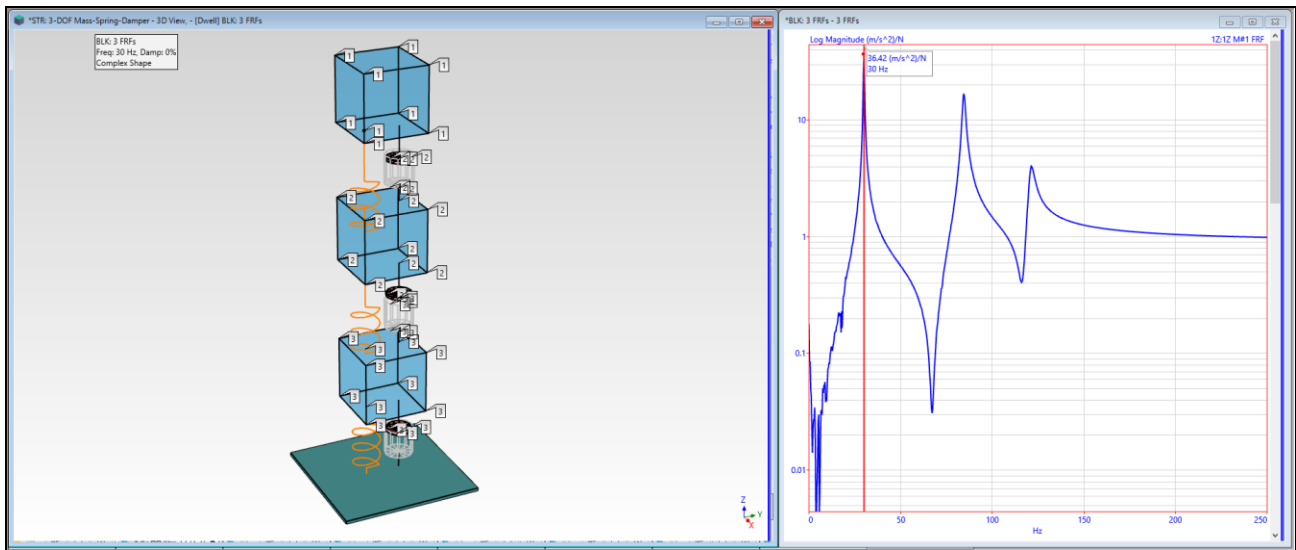
STEP 1 - FREQUENCY-BASED ODS

- **Press Hotkey 1 Frequency-Based ODS**

Operating Deflection Shapes (ODS's) are displayed on the 3D model of the structure directly from its **FRFs**. This allows you to observe *a close approximation* of each mode shape directly from the FRFs before curve fitting them.

Shape animation is initiated in the **STR: 3-DOF Mass-Spring-Damper** window.

- The ODS at the **Line cursor position** in **BLK: 3 FRFs** is displayed on the model
- **Click near** a peak in the FRFs to display the **frequency-based ODS** at the **Line cursor position**



Frequency-Based ODS at a Resonance Peak.

When **Hotkey 1** is pressed, the FRFs (M#s) are linked to the numbered points & directions on the model and shape animation was initiated in the **STR: 3-DOF Mass-Spring-Damper** window. The frequency-based ODS at the *cursor position* in **BLK: 3 FRFs** is displayed in animation on the model.

- The **masses & dampers deflect correctly** because they have numbered points on them
- The **interior Points** on the springs **do not deflect** because they are not numbered, hence **no M# Links** were created for them

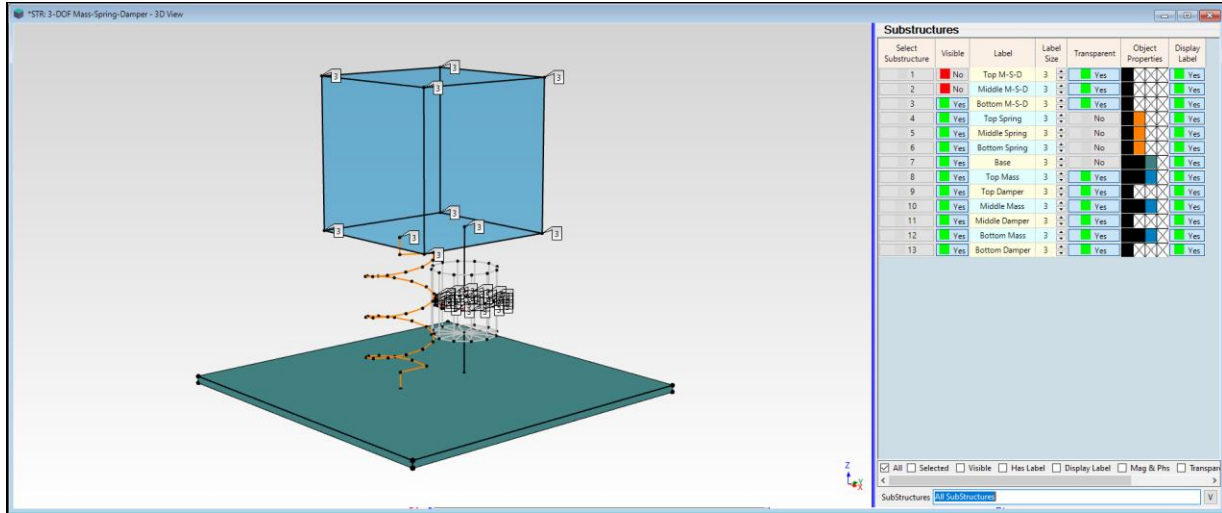
M# LINKS

Each FRF *must be linked* to a point & direction on the model to display ODS's from the FRFs.

- An **M# Link** is created for each point & direction on the model if it matches the Roving DOF of an FRF.

Each **mass Point Label** is numbered (1, 2, or 3). The top & bottom end-Points of the Springs & Dampers are also numbered with the same three numbers (1, 2, or 3). Each Point number matches the point number in the Roving DOF of an **FRF**.

- The Points on the rectangular Base are **fixed**
- The Bottom of the **Bottom Spring** is **fixed**
- The **Cylinder** of the **Bottom Damper** is **fixed**

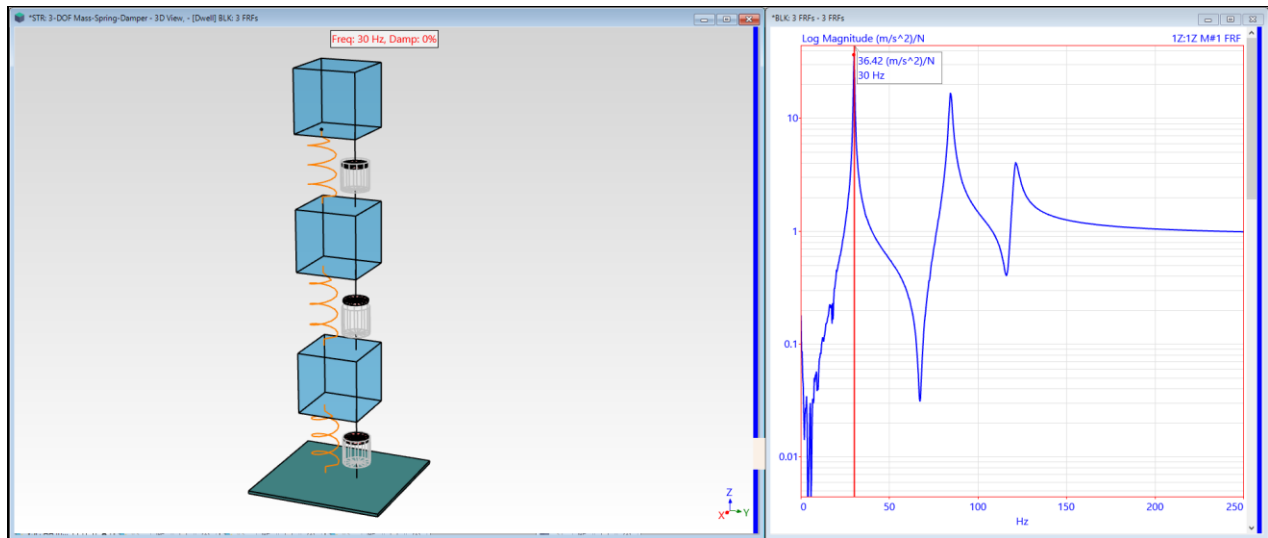


Bottom Mass Points & Plunger of the Bottom Damper are Numbered.

STEP 2- INTERPOLATED M# LINKS FOR THE SPRINGS

- **Press Hotkey 2** Interpolate Springs

When **Hotkey 2** is **pressed**, **Interpolated M# Links** are created for the interior spring Points using the **Measured M# Links** that were already created for the end-Points of the springs.



30 Hz ODS of the 3-DOF with the Spring Midpoints Interpolated.

A 3-Mass (3-DOF) structure only has **three modes of vibration**.

- At the **30 Hz** peak, the ODS is **“dominated”** by the 30 Hz mode shape. The three masses move **in-phase** with each other at this frequency
- At the **84 Hz** peak, the top & bottom masses **move out-of-phase** with each other
- At the **121 Hz** peak, the top & bottom masses **move in-phase** with each other, while the middle mass **moves out-of-phase** with the other two masses

THREE STEPS OF MODAL CURVE FITTING

Curve fitting is a **data reduction process** that converts the dynamic information from a set of FRFs into a set of **modal parameters**. Each mode is defined by its modal **frequency, damping & mode shape**. The curve fitting process is carried out in three steps.

1. Determine **how many modes** are represented in a set of FRFs. This is done by counting resonance **peaks** on a **Mode Indicator Function** calculated from **all** (or **selected**) FRFs. **Each peak is evidence of at least one mode**
2. Estimate the modal **frequency & damping** of each mode. Modal frequency & damping are **global properties**, meaning that they can be estimated from **any or all** FRFs. These **global properties** are found by curve fitting all (or **selected**) FRFs
3. Estimate the **residue** for each mode in each FRF. A Residue is a measure of the **height (or strength) of the resonance** in each FRF. A Residue is also a **component of a mode shape** called a **Residue mode shape**. Each Residue is estimated by curve fitting each FRF using the frequency & damping of each mode

STEP 3 - QUICK FIT

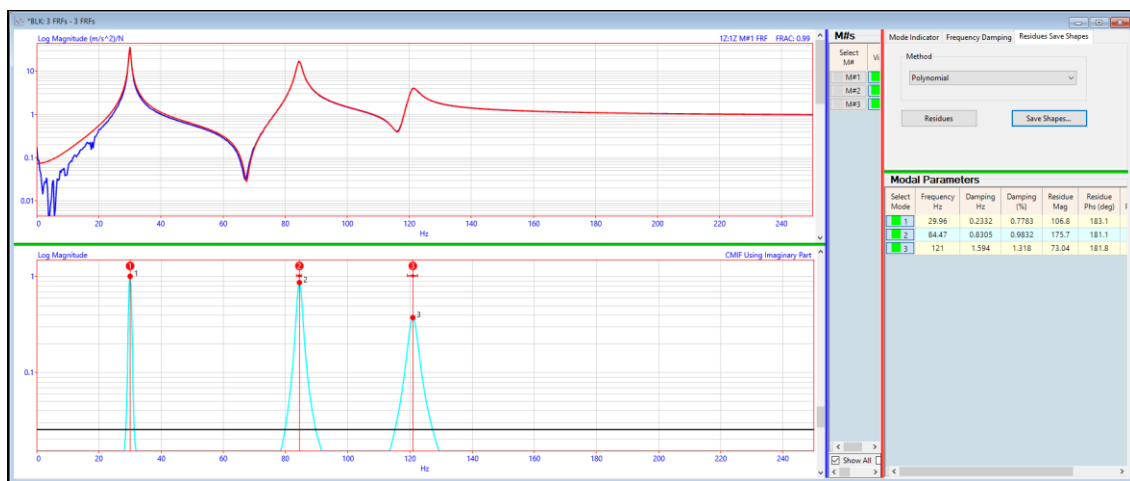
- **Press Hotkey 3 Quick Fit**

The Quick Fit command applies **all three modal curve fitting steps** in sequence to a set of FRFs. Quick Fit carries out the following steps,

- A **Mode Indicator** function is calculated, and **resonance peaks** that lie **above a noise threshold** are counted
- **Modal Frequency & Damping** are estimated **for the number of resonance peaks counted**
- **Modal Residues** are estimated by curve fitting each FRF using the estimated modal **Frequency & Damping**

Following a Quick Fit, several changes occurred in the **BLK: 3 FRFs** window.

- The modal parameter estimates are listed in the **Modal Parameters** spreadsheet **on the lower right**
- The **Mode Indicator** function is displayed below the FRFs, and each numbered resonance peak has a **Red Dot**
- **Two red lines** are displayed on the **Mode Indicator** for each mode identified from the Quick Fit. The **vertical line** is at the estimated **modal frequency** and the **horizontal line** is the **half-power point damping**
- A **Red Fit Function** is overlaid on each FRF



Quick Fit of the Three FRFs of the 3-DOF Structure.

- Use the scroll bar to the **right of the FRFs** to scroll through each FRF overlaid with its **Fit Function**
- **Close agreement** between an FRF and its **Fit Function** indicates a successful curve fit
- Execute **Display | M#s | Real, Imaginary, Magnitude, Phase, Bode or CoQuad** to compare each FRF with its corresponding **Fit Function** in a different format

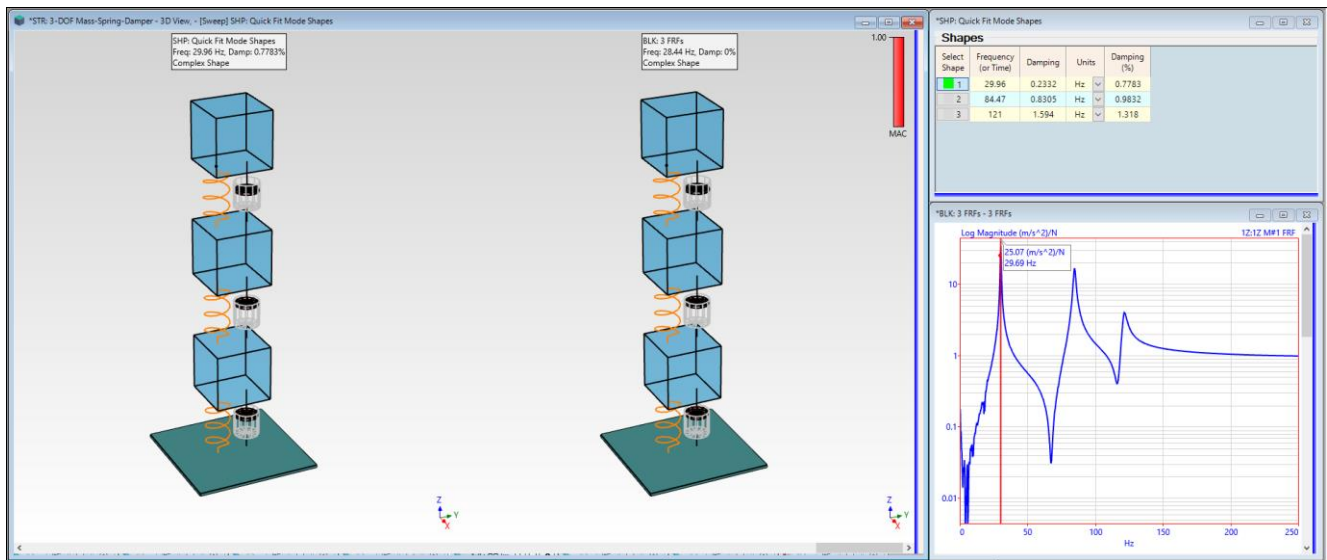
As you scroll through the FRFs, the global Frequency & Damping estimates remain the same, but the Residues change with the display of each FRF.

STEP 4 - MODE SHAPE VERSUS ODS

- **Press Hotkey 4 Mode Shape vs ODS**

When **Hotkey 4 is pressed**, each mode shape is displayed side-by-side in animation with its **closest matching ODS**.

- Each mode shape is displayed **on the left** and its **closest matching ODS** is displayed **on the right** from the cursor position in **BLK: 3 FRFs**



Mode Shape on the Left Versus Closest Matching ODS on the Right.

MODAL ASSURANCE CRITERION (MAC)

The **closest matching ODS** is the one that has the **Maximum MAC** with the mode shape.

- **MAC** is a measure of the **co-linearity** of two shape vectors
- **MAC** has values **between 0 & 1**
- **MAC greater than 0.9** → the shapes are similar (linearly dependent and only different by a scale factor)
- **MAC less than 0.9** → the shapes are different (not co-linear)

CURVE FITTING PROBLEMS

The **Polynomial** curve fitting method is the **default method** used by the **Quick Fit** command. One of **unique strengths** of the Polynomial method is that it can be used with **narrow bands of data**. This is particularly useful in the following problem situations,

- The FRFs **contain noise peaks** and other anomalies that are of no interest
- **Mass loading** (or other non-stationary behavior) occurred during data acquisition from the test article

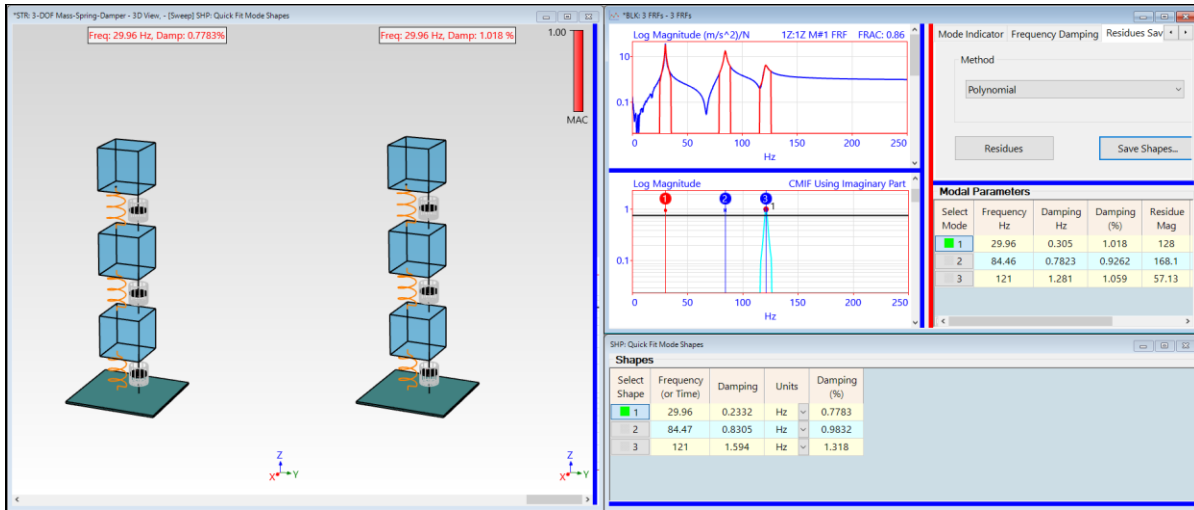
These curve fitting problems **often arise** with real-world test data. To overcome these problems, the **Quick Fit** command can be **used with narrow bands** of FRF data and also as a **local curve fitter**.

STEP 5 - QUICK FIT IN NARROW BANDS

- **Press Hotkey 5 Quick Fit in Three Bands**

When the **Band cursor** is displayed, the **Quick Fit** command estimates the modal parameters of each mode using the data **only in a narrow cursor Band**.

- For best results Quick Fit should be used with the Band cursor *surrounding one or more resonance peaks*



Quick Fit in Three Cursor Bands Surrounding Each Resonance Peak.

When **Hotkey 5 is pressed** three Quick Fits are performed in succession, using a narrow band of data surrounding each resonance peak.

With curve fitting still open in the **BLK: 3 FRFs** window, the mode shapes obtained from curve fitting narrow bands of data are compared side-by-side in animation with the mode shapes in **SHP: Quick Fit Mode Shapes**.

MASS LOADING

When there are not enough sensors or acquisition channels to *simultaneously acquire* all channels of data, the sensors must be moved during a modal test. This is called a **Roving Response test**. If the mass of the sensors is significant compared to the mass of the test article and the sensors are moved during a test, the distributed mass of the structure becomes **non-stationary**. This problem is referred to as **mass loading**.

- **Global curve fitting** methods assume that the resonance peak for each mode *occurs at the same frequency* in all measurements

If mass loading occurs during data acquisition, a **Local curve fitting** method will usually provide better results.

LOCAL CURVE FITTING

- A **Local curve fitting** method obtains a *local frequency & damping estimate* by curve fitting *each FRF separately*
- Local frequency & damping estimates are then used during residue curve fitting of each FRF to obtain *better mode shape estimates*

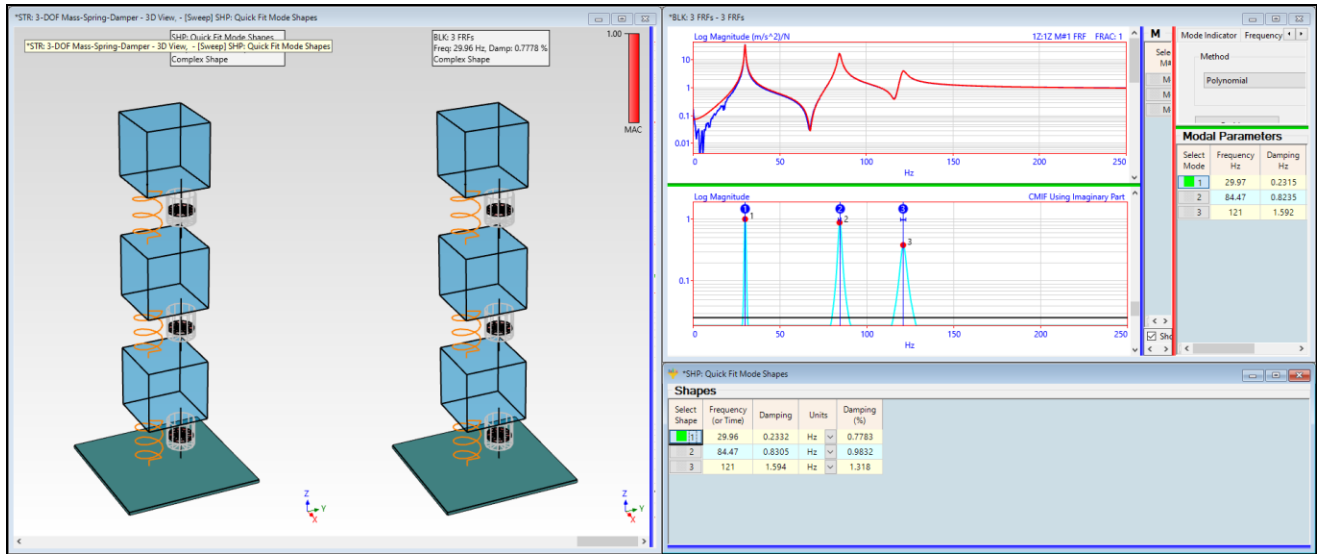
STEP 6 - LOCAL CURVE FITTING

- **Press Hotkey 6 Local Quick Fit**

When **Hotkey 6 is pressed** the three curve fitting steps are carried out in **BLK: 3 FRFs**,

1. A **Mode Indicator** is calculated, and its *resonance peaks are counted*
2. **Local frequency & damping** are estimated from each FRF
3. **Residues** are estimated for each FRF *using the local frequency & damping estimates* for each mode

With curve fitting still open in the **BLK: 3 FRFs** window, the mode shapes obtained from local curve fitting are compared side-by-side in animation with the mode shapes in **SHP: Quick Fit Mode Shapes**.



Mode Shapes from Local Curve Fitting Compared with Mode Shapes from Global Curve Fitting.

- Scroll through the FRFs and observe the **local frequency & damping** estimates for each FRF

These FRFs have no mass loading effects in them, so the local frequency & damping estimates change little as you scroll through the display of the FRFs.

- If there were significant mass loading effects, the local frequency & damping estimates would change substantially from FRF to FRF

WEIGHTED GLOBAL AVERAGES

In this case, each mode shape from **Local curve fitting** *closely matched* with each mode shape from **Global curve fitting**. Also, with **Local curve fitting**,

- When the modal parameters from **Local curve fitting** are saved into a Shape Table, the local frequency & damping estimates are saved as **Global average** values
- Each Local estimate is **weighted by the magnitude of its residue** when the **Global average** value is calculated

STEP 7 - REVIEW STEPS

To review the steps of this App Note,

- **Press Hotkey 7 Review Steps**