



MEscope Application Note 40

Multi-reference Curve Fitting to Extract Local Modes

The steps in this Application Note can be carried out using any MEscope package that includes the **VES-3600 Advanced Signal Processing** & **VES-4600 Advanced Modal Analysis** options. Without these options, you can still carry out the steps in this App Note using the **AppNote40** project file. These steps might also require a *more recent release date* of MEscope.

APP NOTE 40 PROJECT FILE

- To retrieve the Project for this App Note, [click here](#) to download **AppNote40.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

In this Application Note, a set of **Multi-reference FRFs** is curve fit using a **Multi-reference** FRF-based curve fitting method. This data was obtained by impact testing a grating from a water treatment plant, shown in the figures below.





WHEN IS MULTI-REFERENCE MODAL TESTING NECESSARY?

Multi-reference Modal Analysis is necessary when a structure has resonances that occur under one of the following conditions,

Closely-coupled Modes: Two or more modes are represented by *only one resonance peak*

Repeated Roots: Two or more modes have the *same natural frequency but different mode shapes*

Local Modes: Resonance peaks are *small or missing* in FRFs for some reference DOFs

In each of the above cases, **multi-reference curve fitting** is required to properly identify all modal parameters from a set of **multi-reference FRFs**.

SINGLE-REFERENCE VERSUS MULTI-REFERENCE FRFs

In a **single-reference modal test**, FRFs are calculated from data that was acquired using *one reference sensor*, either **one fixed excitation sensor** or **one fixed response sensor**.

A **single-reference modal test** is the *minimum requirement* for extracting experimental modal parameters from FRFs

A **single-reference modal test** is *not sufficient* for extracting **closely-coupled modes, repeated roots, or local modes** of a structure

In a **multi-reference modal test**, FRFs are calculated from data that was acquired using *two or more reference sensors*, either **multiple fixed excitation sensors** or **multiple fixed response sensors**.

A **multi-reference modal test** is *required* for extracting **closely-coupled modes, repeated roots, or local modes** of a structure

A **multi-reference modal test** is *useful* for extracting modes when a structure *has high modal density* (many resonance peaks in small frequency bands)

MULTI-REFERENCE IMPACT TEST

In the **multi-reference impact test** of the grating, *multiple roving response sensors* were used, and the structure was *excited in one (fixed) DOF at a time* with an impactor.

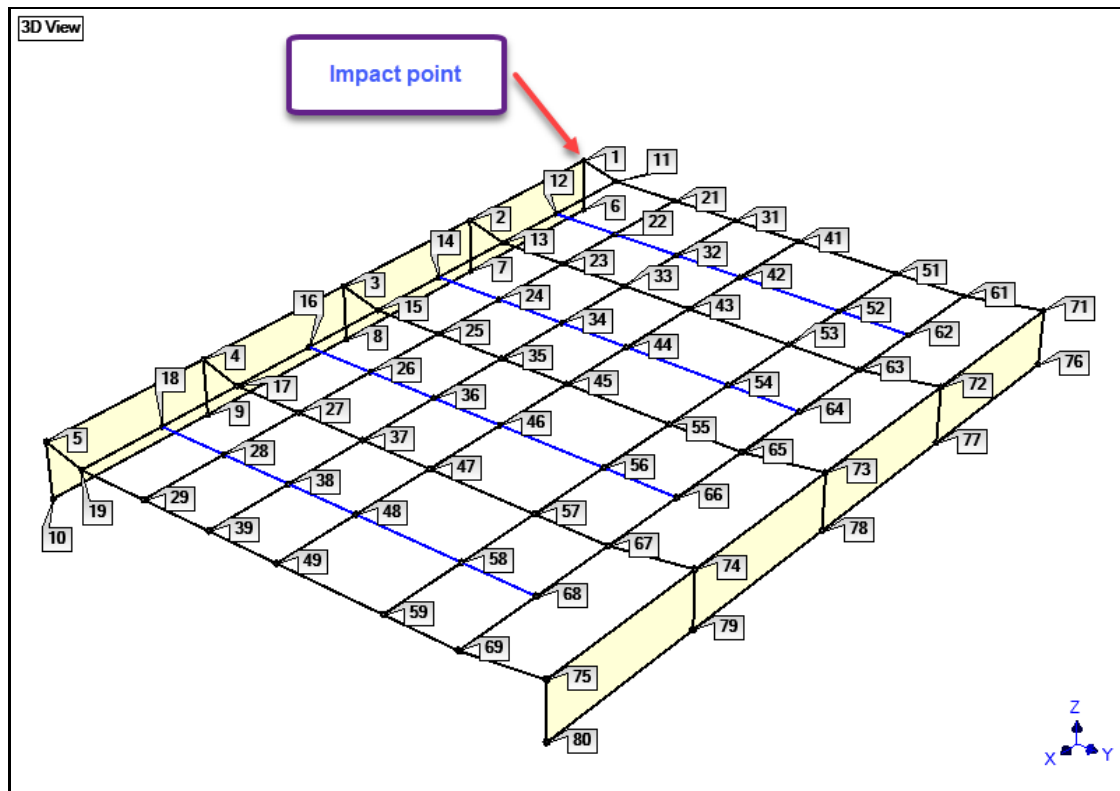
This **multi-reference impact test** is the *same as performing multiple single-reference impact tests*.

The figures above depict the **multi-reference impact test** performed on the water treatment plant grating. It was impacted at one corner, *in the X, Y, & Z directions*.

Response data was acquired using **10 tri-axial accelerometers** and a **32-channel acquisition system**

After impacting in the **1X, 1Y, & -1Z** directions, the **10 tri-axial accelerometers** were moved to a different set of 10 points on the structure. *This was done 8 times* so response data was acquired at **a total of 80 response points**

Bad data from the **last 6 numbered test points** was not used. Therefore, with **74 response points** and **3 impact DOFs** per response point, **a total of 666 FRFs** were calculated from the acquired data



Model of the Grating Showing Single Impact Point & 80 Response Points.

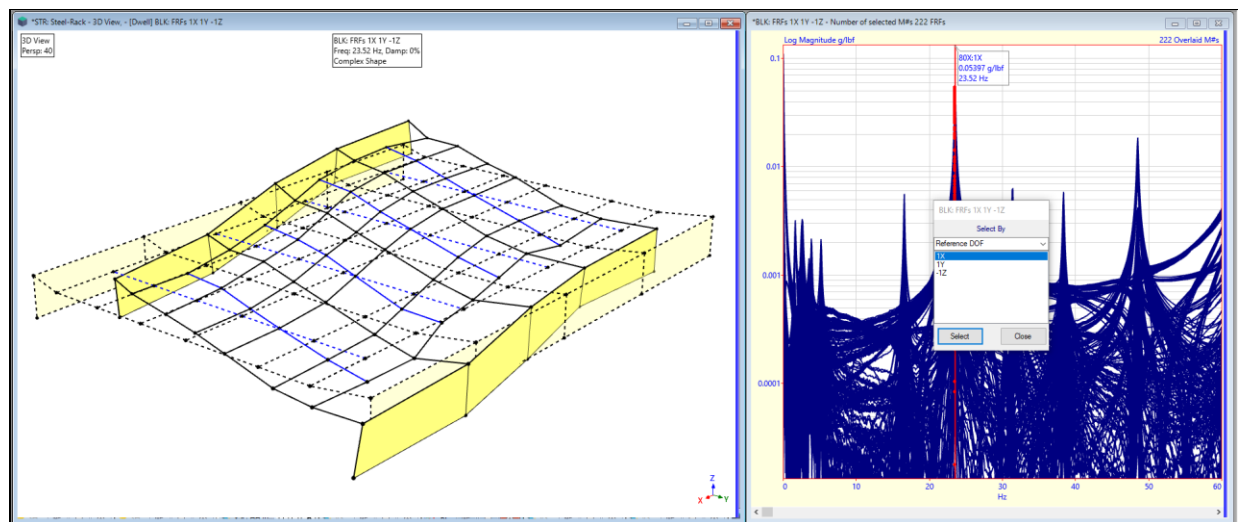
STEP 1 - MULTI-REFERENCE ODS ANIMATION

- Press Hotkey 1 Multi-reference ODS Animation

When **Hotkey 1** is *pressed*, deflection of the **ODS** from the cursor position in the Data block **BLK: FRFs 1X 1Y - 1Z** is displayed on the 3D model. The **ODS** values are the *magnitude & phase* of the *selected FRFs*

Because the **FRFs** in **BLK: FRFs 1X 1Y -1Z** have three reference DOFs, the **Reference DOF selection box** has also opened, as shown below.

- *Select* each Reference DOF in the **Reference DOF selection** box to display the **ODS** for that reference
- Drag the **Line** cursor *near the peaks at 23, 41, 38, & 48 Hz* to display the **ODS**



If an **ODS does not change** when displayed from *one reference DOF versus another*, this is evidence that the **ODS is dominated by a single mode shape**.

If an **ODS changes** when displayed from *one reference DOF versus another*, this is evidence that **two or more mode shapes are participating** in the **ODS**.

Some mode shapes are better defined (the *participate more strongly*) in one reference than in another.

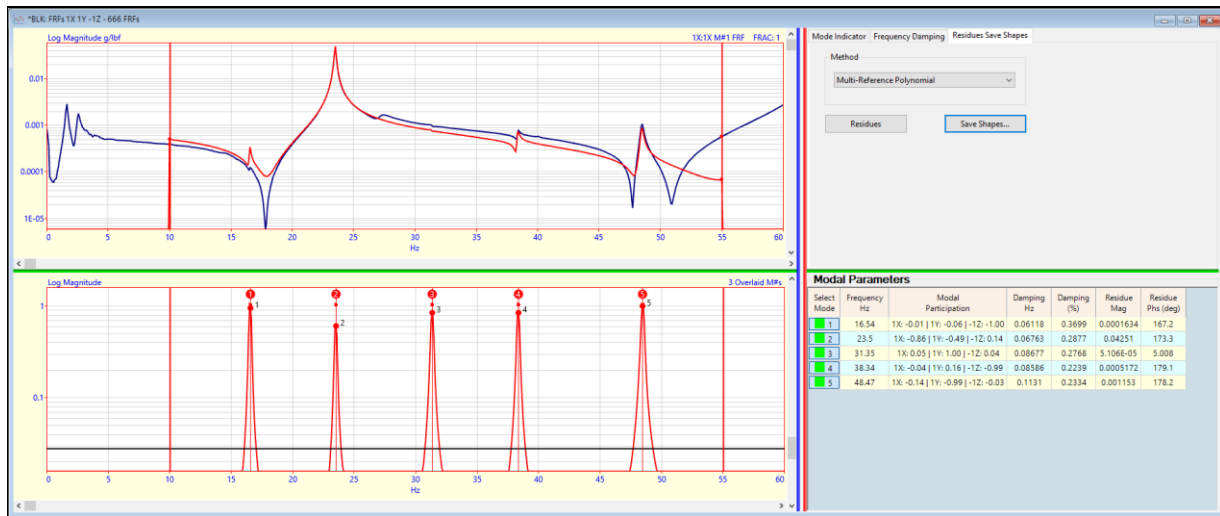
If a **reference DOF** is *at or near a nodal point* of a mode shape, its **resonance peaks are small** in all the **FRFs** compared to the resonance peaks of other modes.

STEP 2 - MULTI-REFERENCE QUICK FIT

- Press Hotkey 2 Multi-reference Quick Fit

When **Hotkey 2** is *pressed* a **multi-reference Quick Fit** is performed on the **multi-reference FRFs**.

The **Quick Fit** command completes curve fitting in one step by *successively executing* commands on the **Mode Indicator**, **Frequency Damping**, and **Residues Save Shapes** tabs using the methods selected on each of those tabs.



Multi-Reference Quick Fit of Multi-reference FRFs

Before **Quick Fit** was executed, the **Multi-reference CMIF Mode Indicator** was chosen by the script for **Hotkey 2**

When a **Multi-reference Mode Indicator** is *selected*, the **Multi-reference Polynomial** curve fitting method is used for both the **Frequency & Damping** and **Residues** curve fitting steps

As you scroll through the **FRFs** display, notice that many of the **FRFs have no or very small resonance peaks**. This is evidence of **Local Modes**.

Multi-reference curve fitting a set of **multi-reference FRFs** will recover the mode shapes of **Local Modes**.

The mode shape of a **Local Mode** has a **nodal point (zero value)** *at or near* a **reference DOF** in a set of **multi-reference FRFs**.

When a **Local mode** has a **nodal point at or near** a **reference DOF**, its resonance peaks *will be small or will not appear in all multi-reference FRFs* for that reference.

MODAL PARTICIPATION

As part of the **Multi-reference Mode Indicator** calculation, the **Modal Participation** of each mode in each reference of FRF data is also calculated.

In multi-reference curve fitting, Modal Participation is used to *weight the FRF data* during curve fitting, and to *weight the Residue estimates* that result from Residue curve fitting.

Modal Participation has absolute values between **0 & 1**

If its Modal Participation is *near zero “0”* for a reference, the *resonance peaks for that mode are small* and it *does not participate* in the **FRF** data for that reference

If its Modal Participation is *near one “1”* for a reference, that mode *participates strongly* and its *resonance peaks are large* in the **FRF** data for that reference

The Modal Participation of each mode is listed in the Modal Parameters spreadsheet as shown below.

Mode #2 participates strongly in two references 1X & 1Y

Modes #1, #3, #4, & #5 participate strongly in only one reference

Select Mode	Modal Participation	Frequency Hz	Damping Hz	Damping (%)
1	1X: -0.01 1Y: -0.06 -1Z: -1.00	16.5	0.0612	0.37
2	1X: -0.86 1Y: -0.49 -1Z: 0.14	23.5	0.0676	0.288
3	1X: 0.05 1Y: 1.00 -1Z: 0.04	31.3	0.0872	0.278
4	1X: -0.04 1Y: 0.16 -1Z: -0.99	38.3	0.086	0.224
5	1X: -0.14 1Y: -0.99 -1Z: -0.03	48.5	0.113	0.234

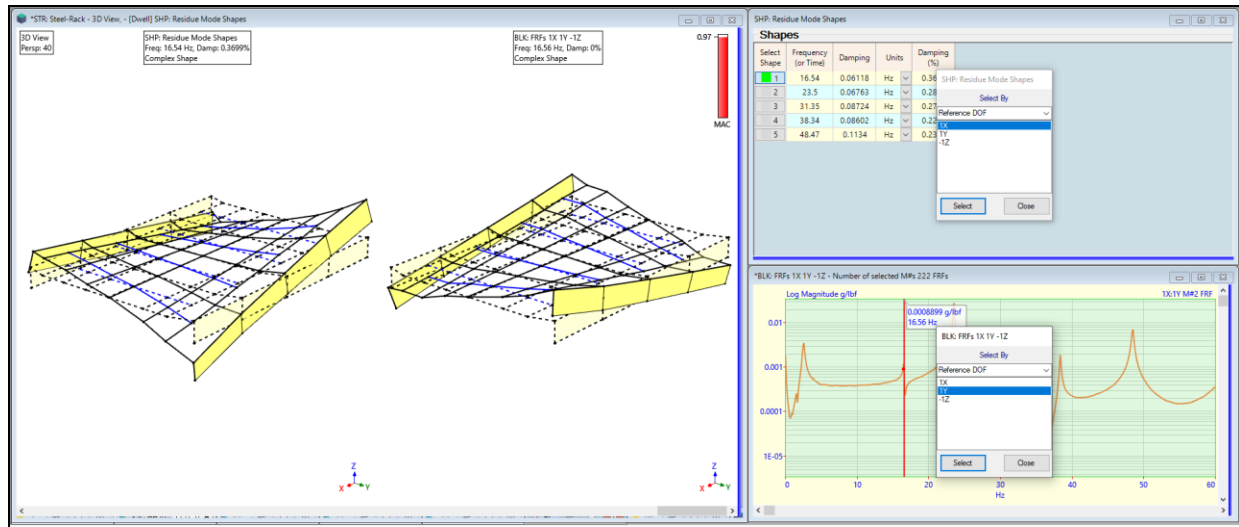
strong participation
in a single reference

STEP 3 - COMPARING MULTI-REFERENCE MODE SHAPES WITH ODS's

- **Press Hotkey 3 Compare Multi-Reference Mode Shapes & ODS's**

Side-by-side animation will begin with a mode shape & ODS pair with **Maximum MAC** displayed together, as shown below.

- **Select** a mode shape and **reference DOF** from **SHP: Residue Mode Shapes**
- Then **select** a **reference DOF** from **BLK: FRFs 1X 1Y -1Z**



Multi-Reference Mode Shape & Closest Matching ODS Side-by-Side.

MODAL ASSURANCE CRITERION (MAC)

MAC is used to correlate a pair of shapes. In this case, it is used during animation to display a mode shape and an ODS pair that has the **Maximum (highest) MAC** value.

MAC measures the *co-linearity* (or *linear dependence*) between two shapes

MAC has values *between 0 & 1*

MAC → *great than 0.9* → two shapes are *co-linear*, or *strongly correlated*

The **Reference DOF** with a **high Modal Participation** during curve fitting is the reference DOF that matches that mode shape with the ODS that has **Maximum MAC** with the mode shape during side-by-side animation.

STEP 4 - REVIEW STEPS

To review all the steps of this App Note,

- **Press Hotkey 4 Review Steps**

CONCLUSION

Many structures have **Local Modes** in them. Either energy is trapped within a local region of the structure and may not be excited during a modal test, or the choice of references is such that certain modes do not appear as resonance peaks in the FRF data. The five modes of interest in this App Note were examples of **Local Modes**. Each one did not have resonance peaks in all three references (**1X, 1Y, -1Z**) of the FRF data.

In this App Note, **Multi-reference** curve fitting was used to extract **Local Modes** from **Multi-reference FRFs**. During the multi-reference curve fitting, a **Multi-reference Mode Indicator** was used to calculate the **Modal Participation** of each mode in each reference of the **FRFs**. Modal Participation was then used to obtain mode shapes for all *five* **Local Modes** and all three references of the grating.

In **App Note 14**, Multi-reference curve fitting is used to extract **Repeated Roots**

In **App Note 15**, Multi-reference curve fitting is used to extract **Closely-coupled Modes**