MEscope Application Note 54

Rapid Impact Test™ Using 2-Channel Data Acquisition

The Steps in this Application Note can be carried out using any MEscope Package that includes the **VES-3600 Advanced Signal Processing, VES-708 Multi-Channel Acquisition** & **VES-4000 Modal Analysis** options Without these options, you can still carry out the Steps in this App Note using the **AppNote54** project file. These Steps might also require MEscope software with a ***more recent release date***.

PROJECT FILE & PDFs

- To retrieve the MEscope Project for this App Note, **click here** to download **AppNote54.zip**

INTRODUCTION

In a conventional **Roving Impact Test**, the **reference sensor** (usually an accelerometer) **must remain fixed** while the structure is impacted at different points & directions (**DOFs**). In a conventional **Roving Response Impact Test**, the structure **must be impacted at the same DOF** while one or more accelerometers are moved to different **DOFs**.

In a **Rapid Impact Test™**, both the impact DOF and the accelerometer location can be changed between acquisitions. There are two reasons why a **Rapid Impact Test™** is beneficial for impact testing,

1. If the reference accelerometer is **connected by a wire** to the data acquisition system, **only a short wire** is required when testing large structures
2. **Better quality signals** are possible if each **impact force is applied closer to the reference accelerometer**

An MEscope **Rapid Impact Test™** is faster and easier to perform on **any size structure** because it does not require a **long wire connected to the fixed reference sensor** throughout the test.

In a **Rapid Impact Test™**, both the impact DOF and the accelerometer location can be changed between acquisitions.

During a **Rapid Impact Test™**,

1. A chain of force & impact pairs is acquired based on their DOFs
2. A chain of **FRFs** is calculated from the chain of force & impact pairs
3. The FRFs are curve fit to obtain a chain of modal residues
4. The modal residues are processed using the **Tools | Scaling | Rapid Test Residues to Mode Shapes** command in the residues Shape Table to obtain mode shapes

An FRF chain is a set of **multiple-reference FRFs**. But unlike a single-reference set of FRFs, the modal residues resulting from curve fitting an FRF chain are not mode shapes. Residues from curve fitting an FRF chain must be further processed to obtain mode shapes.

A Rapid Impact Test like this simulated Rapid Impact Test could be performed on any test article using an **impact hammer**, a **uni-axial accelerometer**, and a **2-channel acquisition system**.

MODAL RESIDUES & MODE SHAPES

Each FRF measurement has **two DOFs** associated with it, the DOF where the force was applied and the DOF where the response caused by the force was measured. Each modal residue obtained by curve fitting an FRF has the same two DOFs associated with it.

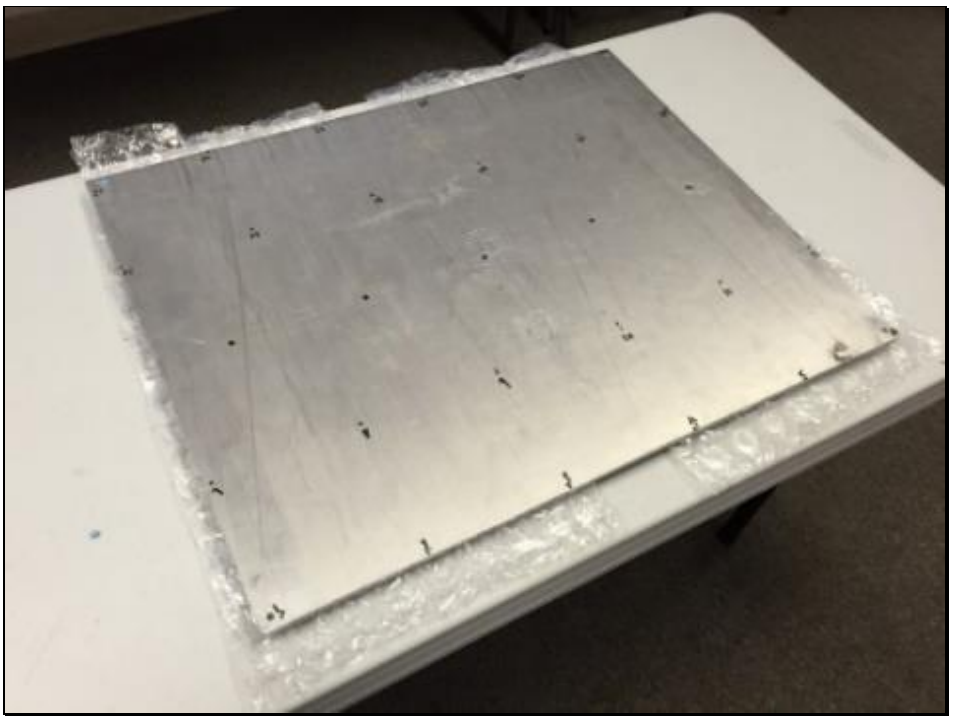
On the other hand, a mode shape only has **one DOF** associated with it, the DOF which defines the deflection of a structure at the natural frequency of the resonance.

SINGLE-REFERENCE IMPACT TEST

In this App Note, a set of **scaled mode shapes** will be used to define the dynamic properties of the aluminum plate shown in the figure below. To obtain those mode shapes, a conventional **single-reference roving impact test** was performed on the aluminum plate with the accelerometer fixed at one corner of the plate.

FRFs were calculated and curve fit, and the mode shapes of the plate were then scaled to **Unit Modal Masses**, called **UMM** mode shapes, and used during the simulated **Rapid Impact Test™** to define the Input-Output dynamics of the plate.

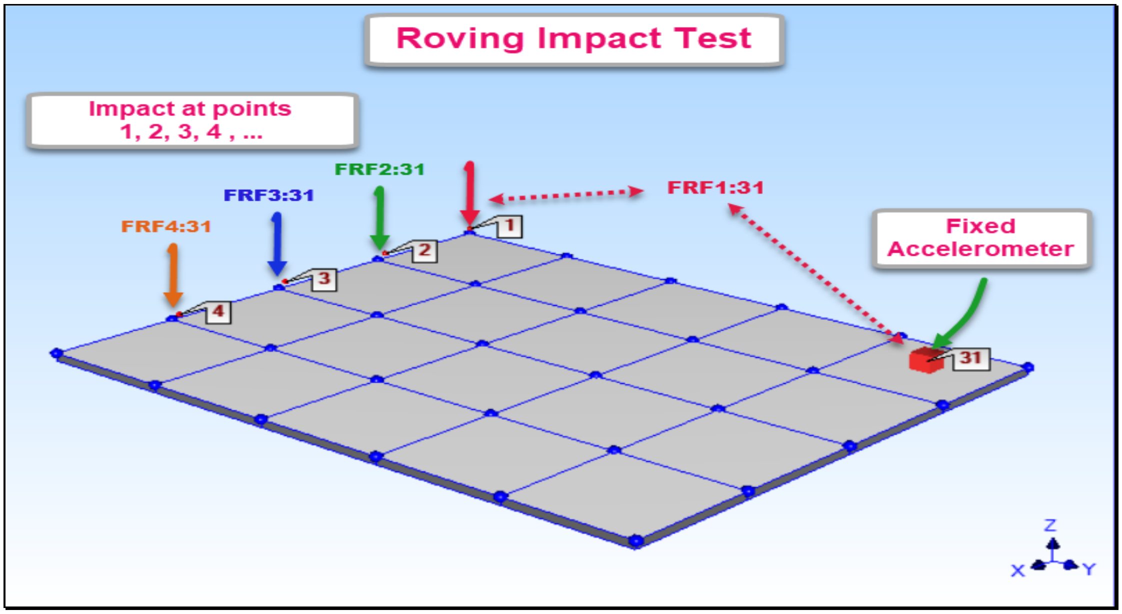
To capture its mode shapes, a **single-reference Roving Impact Test** was performed on the aluminum plate with an accelerometer attached at one corner (**DOF 1Z**), and the plate was impacted at a grid of 30 points in the vertical direction (**DOFs 1Z through 30Z**). **FRFs** were calculated between each impact DOF and the fixed reference response **DOF 1Z**.



3/8th Inch Thick Aluminum Plate Test Article.

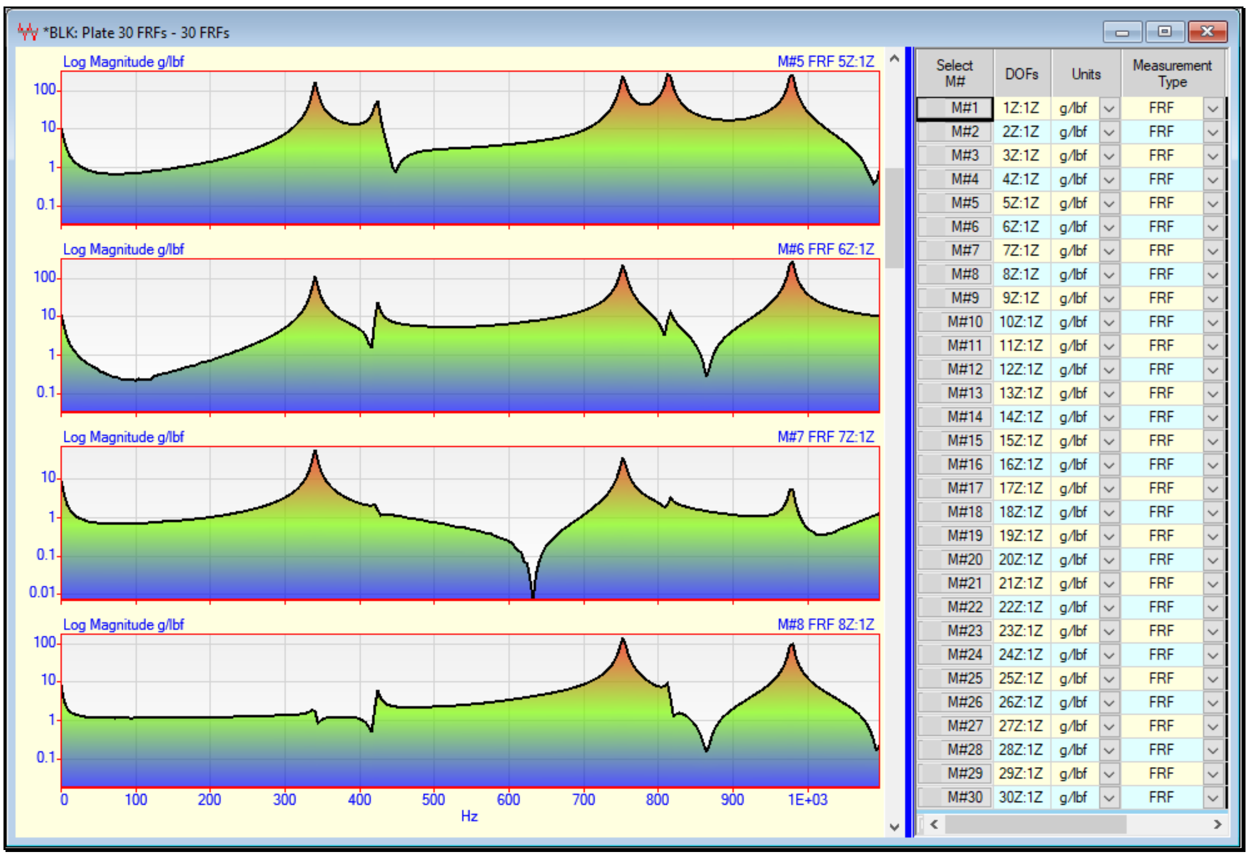
In a single-reference **Roving Impact Test**, ***only the roving impact*** **DOFs** define the mode shapes. The fixed reference sensor (accelerometer) ***can be attached anywhere*** on the test article.

However, to scale the residues from a single-reference Impact Test to **Unit Modal Masses (UMM)** mode shapes), a **driving point residue** is required. In this case, driving point residues were obtained by curve fitting **FRF 1Z:1Z**.



Single-Reference Roving Impact Test.

The log magnitudes of several **FRFs** derived from the **single-reference Roving Impact Test** are shown below. The properties of the single-reference **FRFs** are also listed in the **M#s** spreadsheet ***to the right***. The **FRFs** have engineering units of (**g/lbf**). The peaks in the log magnitudes of the FRFs indicate that five modes of vibration were excited over a frequency span of **1096 Hz**.



Select M#	DOFs	Units	Measurement Type
M#1	1Z:1Z	g/lbf	FRF
M#2	2Z:1Z	g/lbf	FRF
M#3	3Z:1Z	g/lbf	FRF
M#4	4Z:1Z	g/lbf	FRF
M#5	5Z:1Z	g/lbf	FRF
M#6	6Z:1Z	g/lbf	FRF
M#7	7Z:1Z	g/lbf	FRF
M#8	8Z:1Z	g/lbf	FRF
M#9	9Z:1Z	g/lbf	FRF
M#10	10Z:1Z	g/lbf	FRF
M#11	11Z:1Z	g/lbf	FRF
M#12	12Z:1Z	g/lbf	FRF
M#13	13Z:1Z	g/lbf	FRF
M#14	14Z:1Z	g/lbf	FRF
M#15	15Z:1Z	g/lbf	FRF
M#16	16Z:1Z	g/lbf	FRF
M#17	17Z:1Z	g/lbf	FRF
M#18	18Z:1Z	g/lbf	FRF
M#19	19Z:1Z	g/lbf	FRF
M#20	20Z:1Z	g/lbf	FRF
M#21	21Z:1Z	g/lbf	FRF
M#22	22Z:1Z	g/lbf	FRF
M#23	23Z:1Z	g/lbf	FRF
M#24	24Z:1Z	g/lbf	FRF
M#25	25Z:1Z	g/lbf	FRF
M#26	26Z:1Z	g/lbf	FRF
M#27	27Z:1Z	g/lbf	FRF
M#28	28Z:1Z	g/lbf	FRF
M#29	29Z:1Z	g/lbf	FRF
M#30	30Z:1Z	g/lbf	FRF

***FRFs** Calculated from a Roving Impact Test of the Aluminum Plate.*

RAPID IMPACT TEST ROUND TRIP

To simulate a **Rapid Impact Test™**, a sequence of three random impact forces was created as a **TWF** for each impact DOF of the plate. Each **TWF** of three random impact forces was then used as an **Input**, together with the **UMM** mode shapes, to calculate a **TWF** of three acceleration responses.

A Rapid Impact Test like this simulated Rapid Impact Test could be performed on any test article using an **impact hammer**, a **uni-axial accelerometer**, and a **2-channel acquisition system**.

A **"round trip"** is completed in the App Note by comparing the mode shapes obtained from the simulated **Rapid Impact Test™** with the original **UMM** mode shapes used to model the Input-Output dynamics of the plate.

The **UMM** mode shapes are used by the **Transform | Outputs** command to define the Input-Output dynamics of the plate.

The **Transform | Outputs** command calculates acceleration **Outputs** caused by the impact force **Inputs** applied to the plate.

The **UMM** mode shapes are used to synthesize the **FRF** that defines the Input-Output dynamics between each impact force & acceleration response pair.

UMM MODE SHAPES

The single-reference **FRFs** acquired from the aluminum plate were curve-fit in MEscope to obtain modal residues for each of its five modes. The **FRFs** were calibrated so the modal residues preserved the Input-Output dynamic properties of the structure. The modal residues were converted to **Unit Modal Mass (UMM)** mode shapes using the **Tools | Scaling | Residue to UMM Shapes** command in the Shape Table with modal residues in it.

UMM mode shapes **preserve the dynamic properties** of a structure if they are calculated from **calibrated modal residues** which are extracted from curve fitting **calibrated FRFs**.

The **UMM** mode shapes shown in Shape Table below are used in this App Note to model the Input-Output dynamics of the aluminum plate during the simulated Rapid Impact Test.

SHP: UMM Mode Shapes

Shapes

Select Shape	Frequency (or Time)	Damping	Units	Damping (%)
1	339.978	2.33343	Hz	0.68633
2	423.021	2.06981	Hz	0.489287
3	752.604	2.73988	Hz	0.364051
4	813.769	2.61037	Hz	0.320774
5	978.21	2.26582	Hz	0.231629

M#s

Select M#	DOFs	Units	Measurement Type	Label	Shape 1		Shape 2	
					Magnitude	Phase	Magnitude	Phase
M#1	1Z	in/lbf-sec	UMM Mode Shape	Poly	30.3916	359.509	15.2329	0.726751
M#2	2Z	in/lbf-sec	UMM Mode Shape	Poly	15.8597	359.911	19.451	0.887658
M#3	3Z	in/lbf-sec	UMM Mode Shape	Poly	0.180163	18.2835	21.2999	0.736397
M#4	4Z	in/lbf-sec	UMM Mode Shape	Poly	16.0134	179.454	20.1361	0.368147
M#5	5Z	in/lbf-sec	UMM Mode Shape	Poly	29.4474	179.491	15.418	0.362676
M#6	6Z	in/lbf-sec	UMM Mode Shape	Poly	19.8876	179.459	5.64266	180.635
M#7	7Z	in/lbf-sec	UMM Mode Shape	Poly	10.3022	179.528	0.234846	4.81111
M#8	8Z	in/lbf-sec	UMM Mode Shape	Poly	0.277678	178.323	1.3111	359.468
M#9	9Z	in/lbf-sec	UMM Mode Shape	Poly	10.0976	359.592	0.213248	169.458
M#10	10Z	in/lbf-sec	UMM Mode Shape	Poly	20.0187	359.778	5.73434	180.014
M#11	11Z	in/lbf-sec	UMM Mode Shape	Poly	6.46067	359.471	19.0478	180.296
M#12	12Z	in/lbf-sec	UMM Mode Shape	Poly	3.27595	359.355	12.5851	180.135
M#13	13Z	in/lbf-sec	UMM Mode Shape	Poly	0.250301	179.722	10.5195	179.905
M#14	14Z	in/lbf-sec	UMM Mode Shape	Poly	3.725	179.089	12.4231	180.278
M#15	15Z	in/lbf-sec	UMM Mode Shape	Poly	6.90233	179.242	18.7097	179.876

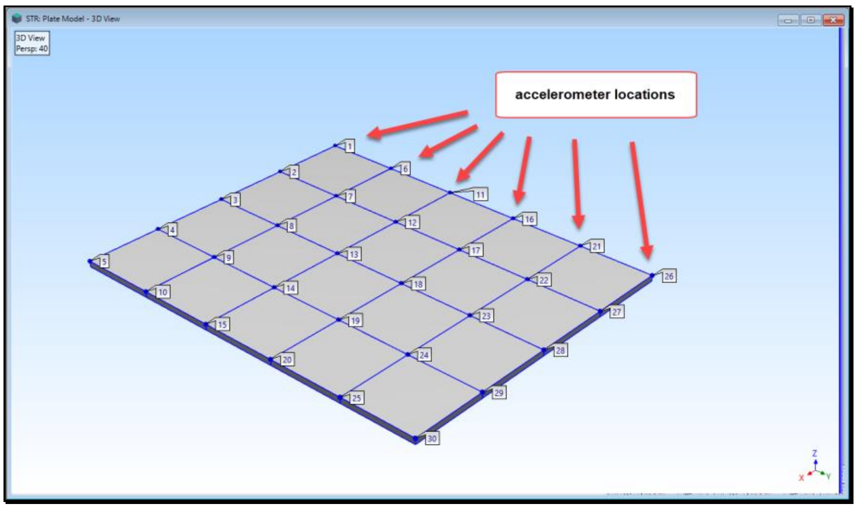
UMM Mode Shapes of the Aluminum Plate

The rigid-body mode shapes and higher frequency flexible-body mode shapes of the plate are not included in the set of **UMM** mode shapes used for this simulated Rapid Impact Test. Nevertheless, this **truncated model** preserves enough of the Input-Output dynamics of the plate to calculate its response to random hammer impacts and use the impact & response pair TWFs to calculate multiple-reference FRFs. The multiple-reference FRFs are then curve-fit to obtain multiple-reference modal residues, which are then used to calculate the **UMM** mode shapes of the plate.

CHOOSING ACTIVE ACCELEROMETER LOCATIONS.

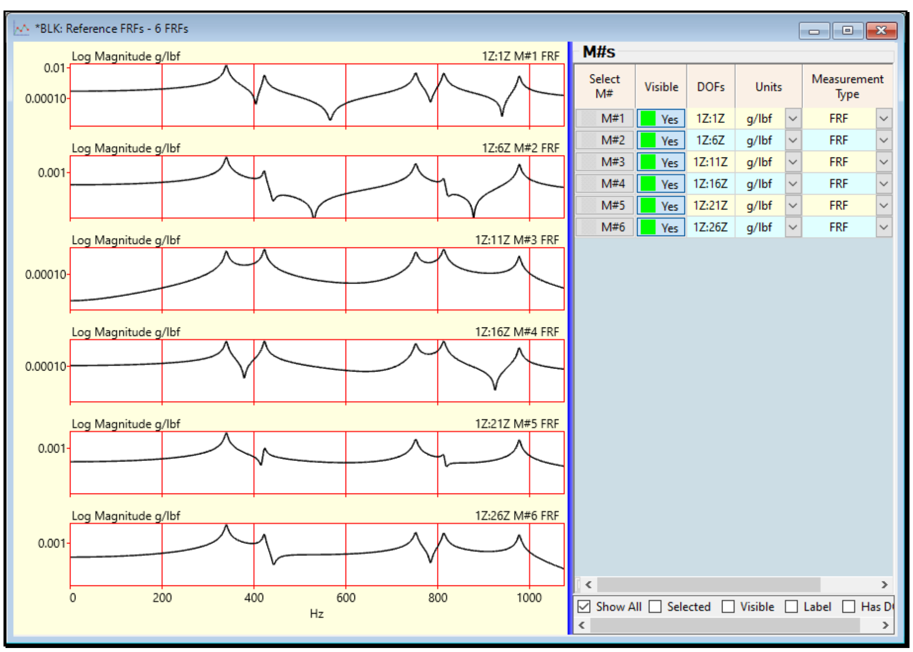
To obtain valid mode shapes from a Rapid Impact Test™, it is necessary to choose accelerometer locations where all the modes of interest exhibit peaks in an FRF made at each point.

In this simulated test the accelerometer will be moved along one edge of the plate, from **point 1** to **point 6**, to **point 11**, to **point 1**6 to **point 2**1, to **point 26**. Then impacts are simulated at each point in each row of points using the accelerometer in that row as the reference.



Accelerometer Location for Each Row of Impacts

The FRFs between DOF 1Z and each of the other reference points are shown in the figure below.



FRFs for all all the Accelerometer Locations

All five modes have peaks in each of these FRFs, meaning that they are good reference points for attaching the accelerometer. When the accelerometer is attached at a reference point, FRF measurements will be acquired by impacting at all the remaining points in the row of points where the accelerometer in attached.

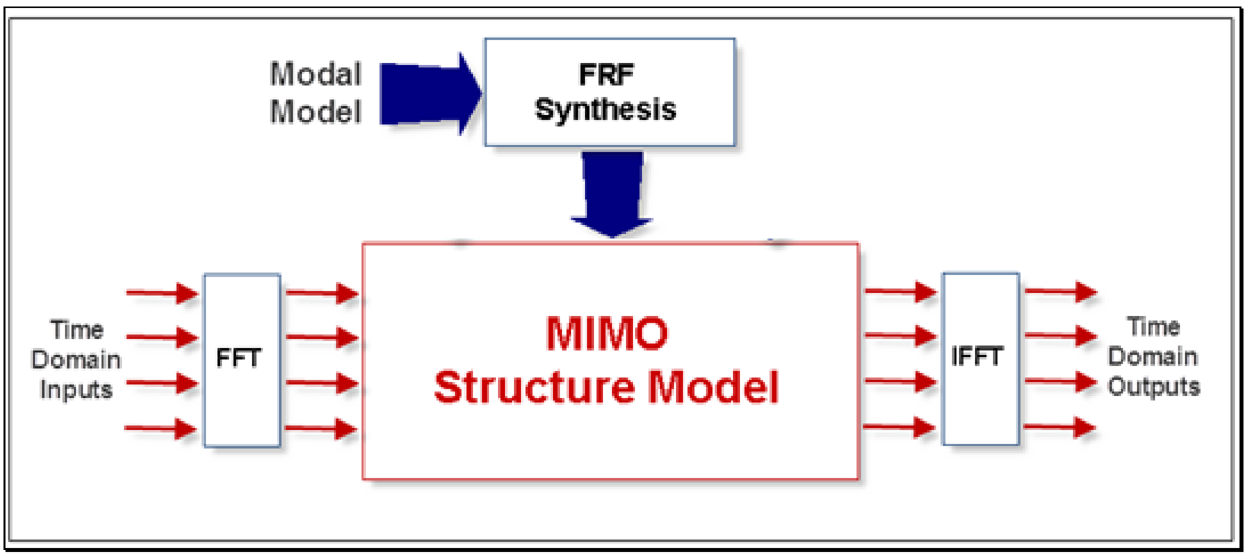
RAPID IMPACT™ ACQUISITION STEPS

During a Rapid Impact Test, acquisitions can be made in ***any desired manner*** provided that a **chain of FRFs** can be calculated from the acquired data.

An FRF chain is formed when each FRF has the same Roving or Reference DOF as another FRF in the chain.

The **Rapid Impact Test™** is simulated using the following steps,

1. A sequence of **three random impact force TWFs** is calculated and stored in a Data Block. To simulate a real-world roving impact test, a different sequence of random impacts is applied to each point on the plate.
2. The **Transform | Outputs** command is used to calculate responses (**Outputs**) to each impact force (**Input**). Calculation of the **Output TWFs** is depicted in the diagram below. This calculation uses the **UMM** mode shapes (a **Modal Model**) to synthesize FRFs which represent the Input-Output dynamics between the impact DOF and the accelerometer DOF of the plate.
3. Each pair of impact & response **TWFs "is acquired"** from a Data Block by the Acquisition window in MEscope. Each pair is defined by its **[Measurement Set number]**.



*Block Diagram of the **Transform | Outputs** Command.*

The **Transform | Outputs** command carries out the following sequence of calculations,

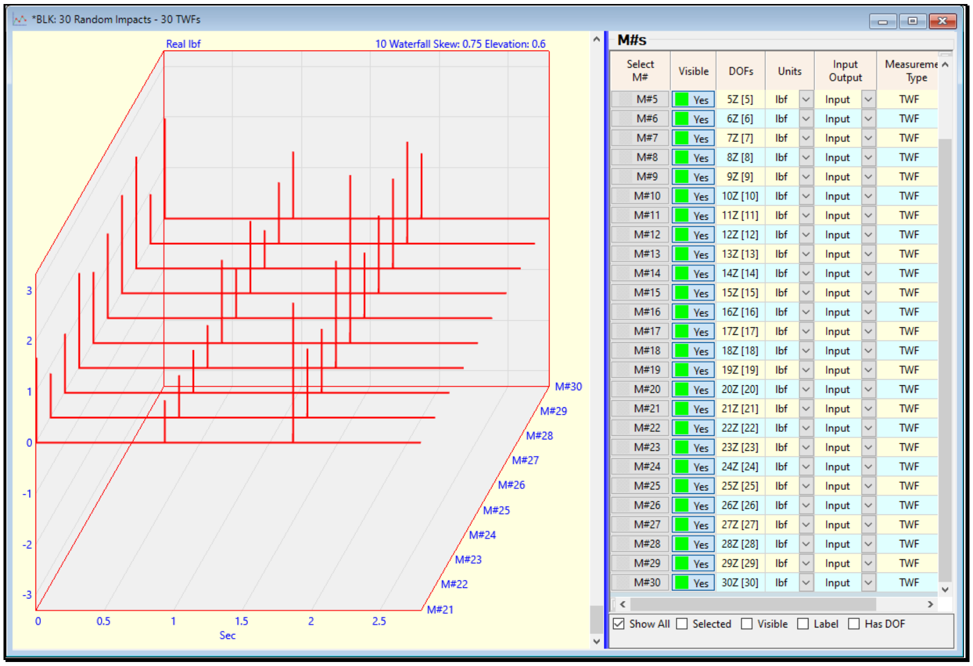
1. The **UMM** mode shapes are used to **synthesize FRFs** between each force **Input DOF** and each response **Output DOF**
2. The **TWF** of each force (**Input**) is **Fourier Transformed** to its **Digital Fourier Spectrum (DFT)**
3. The **DFT** of each force **Input is multiplied by** the appropriate synthesized **FRF** to obtain the **DFT** of each response **Output**
4. The **DFT** of each response is **Inverse Fourier Transformed** to obtain its **Output TWF**

STEP 1 - RANDOM IMPACT FORCES

- ***Press* Hotkey 1 Random Impacts**

When **Hotkey 1 is *pressed***, 30 random impact forces are calculated and displayed in a Data Block (**BLK: Random Impacts**) as shown below.

> Each **M#** contains **6144 samples** of time waveform data, enough to calculate **three DFTs** with **1024 samples** in each **DFT**.



The M# of Each Force (Input) Contains Three Random Impact Time Waveforms.

The properties of each Force (**Input**) **M#** are shown in the **M#s** spreadsheet ***on the right*** above

- Each **M# DOF** is the ***point number & direction*** on the plate where the impact will be applied
- The engineering units are ***units of force***
- Each **M#** is designated in the **Input Output** column as an **Input**

STEP 2 - RAPID IMPACT TEST PAIRS

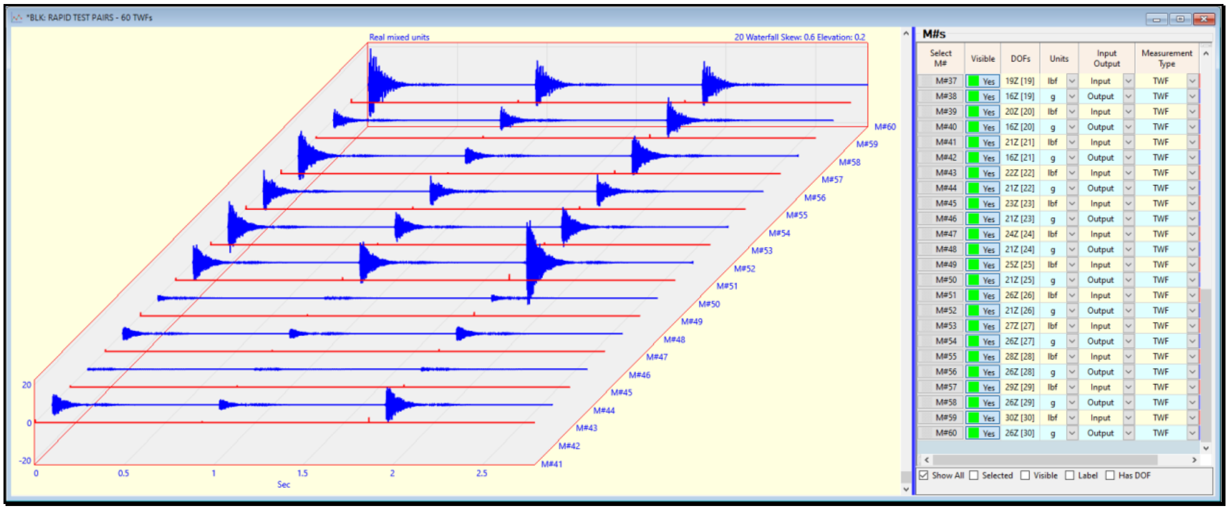
- ***Press* Hotkey 2 Rapid Test Pairs**

When **Hotkey 2 is *pressed***, the **Transform | Outputs** command is executed to calculate a response (**Output**) to each force (**Input**) in each row of point on the plate.

> To form a chain of impact measurements, the accelerometer point in the next row is impacted before moving the accelerometer to the next row.

When the Step 2 calculation is completed, a waterfall of impact & response TWF pairs is displayed in a waterfall as shown below. Each Impact **force M# is in red** followed by its **paired response M# in blue**. The **M#s** spreadsheet ***on the right*** shows the properties of each **M#**.

- Each impact & response pair has a **[Measurement Set number]** added to its DOF
- Each response is designated as an **Output** and has **acceleration units of g's**



Impact & Response TWF Pairs.

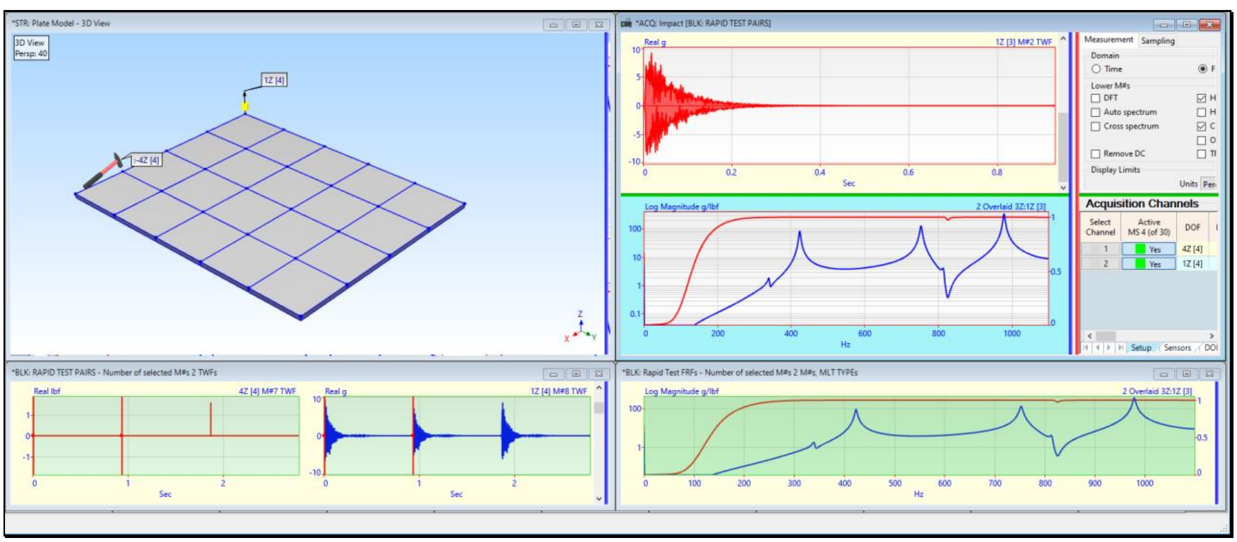
STEP 3 - ACQUIRE RAPID IMPACT FRFs

- ***Press* Hotkey 3 Acquire FRFs**

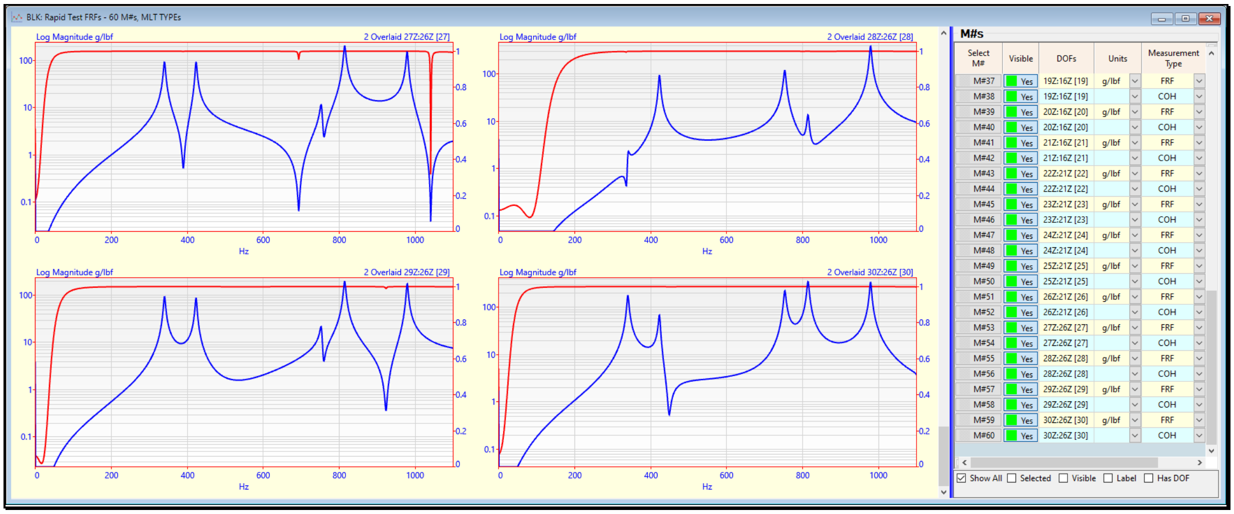
When **Hotkey 3 is *pressed***, the MEscope Acquisition window is connected to **BLK: RAPID TEST PAIRS** and **TWFs** each Measurement Set of an impact & response pair **"is acquiring"** from the Data Block. Three spectral estimates corresponding to the three impacts are averaged together using **Stable (Linear) Averaging**. **Coherence** is calculated and is displayed in Overlaid format with each **FRF**.

At TWF is acquired, each impact point is depicted with a hammer on the plate model . Each accelerometer location is depicted with a cylinder and an arrow indicating the direction of the accelerometer response.

Before processing the FRFs, all negative directions are removed from the DOFs, so accelerometers can be mounted in plus or minus directions and impact forces applied in plus or minus directions.



Acquisition of Rapid Impact FRFs



*Rapid Impact **FRFs**.*

When all 30 Measurement Sets of data have been **“acquired”**, the Rapid Impact **FRFs** are displayed as shown above.

- Each **FRF** magnitude is colored in **blue**
- Each corresponding **Coherence** is colored in **red** and is overlaid on its **FRF**

The **M#s** spreadsheet ***on the right side*** of the **FRF & Coherence** graphics contains the following properties for each **M#**.

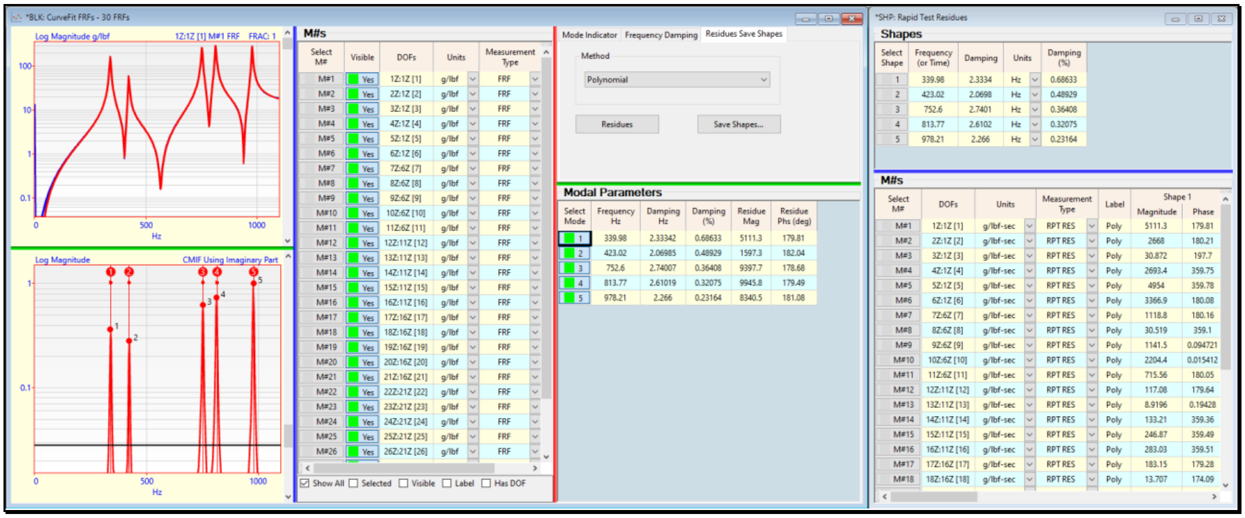
- There are **60 M#s** in the Data Block, **30 FRF & Coherence pairs**
- No special time domain windowing was required because the impact & response signals are both **completely contained** within each sampling window (**2048 samples**) of TWF data
- All **Coherence** values are **“close to 1”** because the **FRFs** are **“leakage free”**

STEP 4 - FRF CURVE FITTING

- ***Press* Hotkey 4 Curve Fit the FRFs**

When **Hotkey 4 is *pressed***, the Rapid Impact **FRFs** calculated in the previous STEP are curve fit using the **Quick Fit** method in MEscope.

When the **Quick Fit** of the **FRFs** is complete, the modal frequencies, damping, and residues are saved in a Shape Table ***on the right***, as shown below.



*Quick Fit of Rapid Test **FRFs***

- Scroll through the **FRFs** in the Data Block **BLK: Rapid Impact FRFs**.

Notice the following,

- A **red Fit Function** is overlaid on each **FRF**
- Each **Fit Function** closely matches each **FRF**, indicated by **FRAC=1**

FRAC is the frequency response version of **MAC** that measures the **co-linearity** between an **FRF** and its **Fit Function.**

- Each **Rapid Test Residue** in the Shape Table ***on the right*** has the same **DOFs** as its corresponding **FRF**
- There are **30 FRFs** in the Data Block and **30 matching Residues** in the Shape Table for each mode

MODAL RESIDUES & MODE SHAPES

A **Rapid Impact Test™** takes advantage of the mathematical relationship between modal residues and mode shapes.

Residues extracted by curve fitting **FRFs** from a **Rapid Impact Test™** must be further processed to obtain mode shapes using the following relationship

Modal residue ➔ Product of two mode shape components

The figures below show how modal **Residues** obtained by curve fitting **FRFs** from a **Rapid Impact Test™** are used to calculate mode shapes. A **starting mode shape component** is required to begin the calculation.

Residues versus Mode Shape Components

$$\text{Residues} = \begin{Bmatrix} \text{RES}(1:2) \\ \text{RES}(1:3) \\ \text{RES}(2:3) \end{Bmatrix} \qquad \text{Mode Shape} = \begin{Bmatrix} \text{MSC}(1) \\ \text{MSC}(2) \\ \text{MSC}(3) \end{Bmatrix}$$

RES(1:1) = MSC(1) x MSC(1)

RES(1:2) = MSC(1) x MSC(2)

RES(1:3) = MSC(1) x MSC(3)

RES(2:3) = MSC(2) x MSC(3)

Single-Reference Modal Test

$$\text{Residue Mode Shape} = \begin{Bmatrix} \text{RES}(1:1) \\ \text{RES}(2:1) \\ \text{RES}(3:1) \end{Bmatrix} = \begin{Bmatrix} \text{MSC}(1) \times \text{MSC}(1) \\ \text{MSC}(2) \times \text{MSC}(1) \\ \text{MSC}(3) \times \text{MSC}(1) \end{Bmatrix}$$

Converting Rapid Test Residues to a Mode Shape

Starting with a Driving Point Residue

$$\text{MSC}(1) = \sqrt{\text{RES}(1:1)} = \sqrt{\text{MSC}(1) \times \text{MSC}(1)}$$

MSC(2) = RES(1:2) / MSC(1)

MSC(3) = RES(1:3) / MSC(1)

MSC(3) = RES(2:3) / MSC(2)

MSC(4) = RES(3:4) / MSC(3) = RES(4:3) / MSC(3)

Starting with Triangle Point Residues

$$\text{MSC}(1) = \sqrt{\frac{\text{RES}(1:2) \times \text{RES}(1:3)}{\text{RES}(2:3)}} = \sqrt{\frac{\text{MSC}(1) \times \text{MSC}(2) \times \text{MSC}(1) \times \text{MSC}(3)}{\text{MSC}(2) \times \text{MSC}(3)}}$$

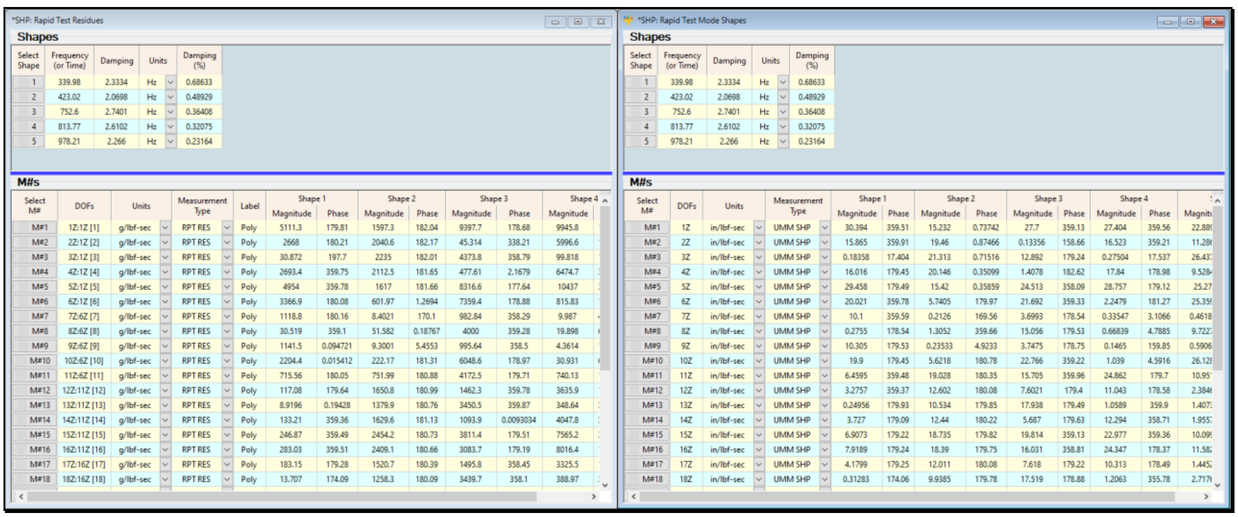
Modal Residues used to Calulate Mode Shapes

STEP 5 - CALCULATING MODE SHAPES FROM RESIDUES

- ***Press* Hotkey 5 Residues to UMM Mode Shapes**

When **Hotkey 5 is *pressed***, the **Tools | Scaling | Rapid Test Residues to Mode Shapes** command is executed in the **SHP: Rapid Test Residues** Shape Table to calculate **UMM** mode shapes. The **UMM** mode shapes are saved into the **SHP: Rapid Test Mode Shapes** Shape Table.

The **SHP: Rapid Test Residues** Shape Table is displayed ***on the left***, and the **SHP: Rapid Test Mode Shapes** Shape Table is displayed ***on the right***, as shown below.



*SHP: Rapid Test Residues

Shapes

Select Shape	Frequency (or Time)	Damping	Units	Damping (%)
1	339.98	2.3334	Hz	0.68633
2	423.02	2.0698	Hz	0.48929
3	752.6	2.7401	Hz	0.36408
4	813.77	2.6102	Hz	0.32075
5	978.21	2.266	Hz	0.23164

M#s

Select M#	DOFs	Units	Measurement Type	Label	Shape 1		Shape 2		Shape 3		Shape 4
					Magnitude	Phase	Magnitude	Phase	Magnitude	Phase	Magnitude
M#1	1Z:1Z [1]	g/lbf-sec	RPT RES	Poly	5111.3	179.81	1597.3	182.04	9397.7	178.68	9945.8
M#2	2Z:1Z [2]	g/lbf-sec	RPT RES	Poly	2668	180.21	2040.6	182.17	45.314	338.21	5996.6
M#3	3Z:1Z [3]	g/lbf-sec	RPT RES	Poly	30.872	197.7	2235	182.01	4373.8	358.79	99.818
M#4	4Z:1Z [4]	g/lbf-sec	RPT RES	Poly	2693.4	359.75	2112.5	181.65	477.61	2.1679	6474.7
M#5	5Z:1Z [5]	g/lbf-sec	RPT RES	Poly	4954	359.78	1617	181.66	8316.6	177.64	10437
M#6	6Z:1Z [6]	g/lbf-sec	RPT RES	Poly	3366.9	180.08	601.97	1.2694	7359.4	178.88	815.83
M#7	7Z:6Z [7]	g/lbf-sec	RPT RES	Poly	1118.8	180.16	8.4021	170.1	982.84	358.29	9.987
M#8	8Z:6Z [8]	g/lbf-sec	RPT RES	Poly	30.519	359.1	51.582	0.18767	4000	359.28	19.898
M#9	9Z:6Z [9]	g/lbf-sec	RPT RES	Poly	1141.5	0.094721	9.3001	5.4553	995.64	358.5	4.3614
M#10	10Z:6Z [10]	g/lbf-sec	RPT RES	Poly	2204.4	0.015412	222.17	181.31	6048.6	178.97	30.931
M#11	11Z:6Z [11]	g/lbf-sec	RPT RES	Poly	715.56	180.05	751.99	180.88	4172.5	179.71	740.13
M#12	12Z:11Z [12]	g/lbf-sec	RPT RES	Poly	117.08	179.64	1650.8	180.99	1462.3	359.78	3635.9
M#13	13Z:11Z [13]	g/lbf-sec	RPT RES	Poly	8.9196	0.19428	1379.9	180.76	3450.5	359.87	348.64
M#14	14Z:11Z [14]	g/lbf-sec	RPT RES	Poly	133.21	359.36	1629.6	181.13	1093.9	0.0093034	4047.8
M#15	15Z:11Z [15]	g/lbf-sec	RPT RES	Poly	246.87	359.49	2454.2	180.73	3811.4	179.51	7565.2
M#16	16Z:11Z [16]	g/lbf-sec	RPT RES	Poly	283.03	359.51	2409.1	180.66	3083.7	179.19	8016.4
M#17	17Z:16Z [17]	g/lbf-sec	RPT RES	Poly	183.15	179.28	1520.7	180.39	1495.8	358.45	3325.5
M#18	18Z:16Z [18]	g/lbf-sec	RPT RES	Poly	13.707	174.09	1258.3	180.09	3439.7	358.1	388.97

*SHP: Rapid Test Mode Shapes

Shapes

Select Shape	Frequency (or Time)	Damping	Units	Damping (%)
1	339.98	2.3334	Hz	0.68633
2	423.02	2.0698	Hz	0.48929
3	752.6	2.7401	Hz	0.36408
4	813.77	2.6102	Hz	0.32075
5	978.21	2.266	Hz	0.23164

M#s

Select M#	DOFs	Units	Measurement Type	Shape 1		Shape 2		Shape 3		Shape 4	
				Magnitude	Phase	Magnitude	Phase	Magnitude	Phase	Magnitude	Phase
M#1	1Z	in/lbf-sec	UMM SHP	30.394	359.51	15.232	0.73742	27.7	359.13	27.404	359.56
M#2	2Z	in/lbf-sec	UMM SHP	15.865	359.91	19.46	0.87466	0.13356	158.66	16.523	359.21
M#3	3Z	in/lbf-sec	UMM SHP	0.18358	17.404	21.313	0.71516	12.892	179.24	0.27504	17.537
M#4	4Z	in/lbf-sec	UMM SHP	16.016	179.45	20.146	0.35099	1.4078	182.62	17.84	178.98
M#5	5Z	in/lbf-sec	UMM SHP	29.458	179.49	15.42	0.35859	24.513	358.09	28.757	179.12
M#6	6Z	in/lbf-sec	UMM SHP	20.021	359.78	5.7405	179.97	21.692	359.33	2.2479	181.27
M#7	7Z	in/lbf-sec	UMM SHP	10.1	359.59	0.2126	169.56	3.6993	178.54	0.33547	3.1066
M#8	8Z	in/lbf-sec	UMM SHP	0.2755	178.54	1.3052	359.66	15.056	179.53	0.66839	4.7885
M#9	9Z	in/lbf-sec	UMM SHP	10.305	179.53	0.23533	4.9233	3.7475	178.75	0.1465	159.85
M#10	10Z	in/lbf-sec	UMM SHP	19.9	179.45	5.6218	180.78	22.766	359.22	1.039	4.5916
M#11	11Z	in/lbf-sec	UMM SHP	6.4595	359.48	19.028	180.35	15.705	359.96	24.862	179.7
M#12	12Z	in/lbf-sec	UMM SHP	3.2757	359.37	12.602	180.08	7.6021	179.4	11.043	178.58
M#13	13Z	in/lbf-sec	UMM SHP	0.24956	179.93	10.534	179.85	17.938	179.49	1.0589	359.9
M#14	14Z	in/lbf-sec	UMM SHP	3.727	179.09	12.44	180.22	5.687	179.63	12.294	358.71
M#15	15Z	in/lbf-sec	UMM SHP	6.9073	179.22	18.735	179.82	19.814	359.13	22.977	359.36
M#16	16Z	in/lbf-sec	UMM SHP	7.9189	179.24	18.39	179.75	16.031	358.81	24.347	178.37
M#17	17Z	in/lbf-sec	UMM SHP	4.1799	179.25	12.011	180.08	7.618	179.22	10.313	178.49
M#18	18Z	in/lbf-sec	UMM SHP	0.31283	174.06	9.9385	179.78	17.519	178.88	1.2063	355.78

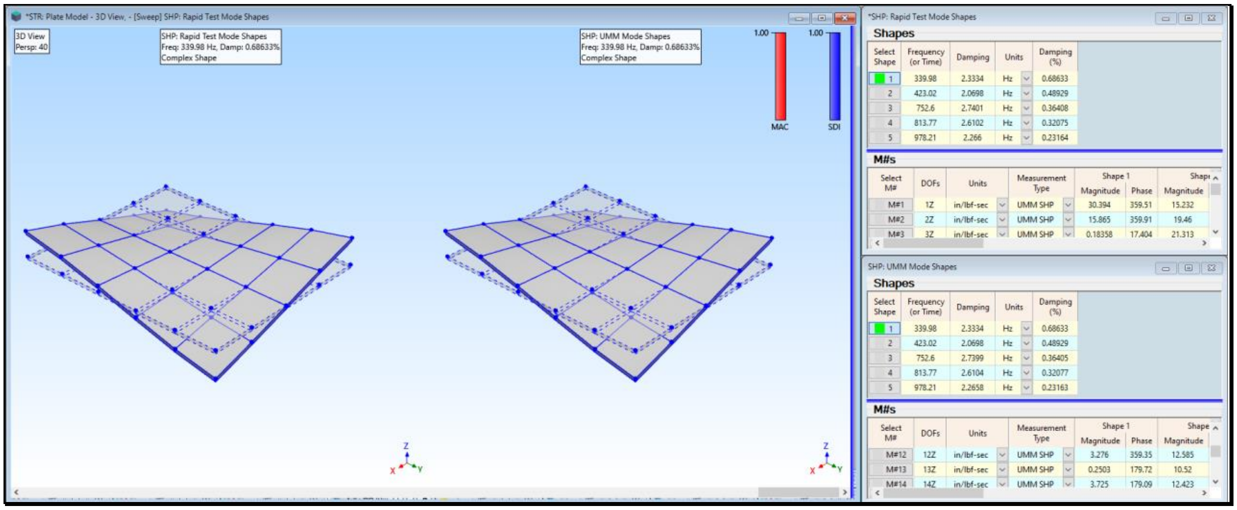
*Rapid Test Modal Residues on the Left and **UMM** Mode Shapes on the Right.*

STEP 6 - MODE SHAPE COMPARISON

To complete the **“round trip”**, the mode shapes obtained from the **Rapid Impact Test™** are compared in animation with the original **UMM** mode shapes.

- ***Press* Hotkey 6 Compare Mode Shapes**

When **Hotkey 6 is *pressed***, sweep animation displays each mode shape in **SHP: Rapid Impact Mode Shapes** side-by-side with the original UMM mode shape from **SHP: UMM Mode Shapes** that has **Maximum MAC** with it.



Rapid Test Mode Shape on the Left & Original **UMM** Mode Shape on the Right.

MAC & SDI BARS

During side-by-side animation of each mode shape pair, their **Modal Assurance Criterion (MAC)** and **Shape Difference Indicator (SDI)** bars are also displayed ***in the upper right corner***.

- **MAC** measures the **co-linearity** of two shapes
- **SDI** measures the **difference** between two shapes
- **MAC = 1.00** ➔ two shapes **are co-linear**
- **SDI = 1.00** ➔ two shapes **are identical**

The **MAC** & **SDI** values are **1.00** for all five matching shape pairs. This means that each Rapid Test Mode Shape is ***identical*** to it matching **UMM** mode shape.

Therefore, all the calculations done in the simulated **Rapid Impact Test™** starting with **UMM** mode shapes to model the Input-Output dynamics of the aluminum plate yielded the same Rapid Test mode shapes.

SUMMARY

In this App Note, a **Rapid Impact Test™** on an aluminum plate was simulated using an **impact hammer**, **uni-axial accelerometer**, and **2-channel simultaneous data acquisition**. The following Steps were carried,

- **STEP 1** - A Data Block of **30 random impact forces** was created to simulate real-world impact forces
- **STEP 2** - A Data Block of **impact & response pairs** was created using the **Transform | Outputs** command and a **Modal Model** (**UMM** mode shapes) to define the Input-Output dynamics of the aluminum plate.
- **STEP 3 - Rapid Impact FRFs** were calculated from the impact & response TWF pairs
- **STEP 4** - The **Rapid Impact FRFs** were curve fit to obtain the modal **frequency, damping, & modal residues** for five modes of the plate
- **STEP 5** – The modal residues were used by the **Tools | Scaling | Rapid Test Residues to Mode Shapes** command to calculate **UMM** mode shapes
- **STEP 6** - Each **Rapid Test** mode shape from the simulated **Rapid Impact Test™** was displayed side-by-side with its ***matching*** original **UMM** mode shape

In a **Rapid Impact Test™**, either the **impact hammer or the accelerometer can be moved** to a different DOF between acquisitions of data.

An **FRF chain** is formed when the **Roving or Reference DOF** of each **FRF** is the same as the **Roving or Reference DOF** of **another FRF**.

FRFs from a **Rapid Impact Test™** can be curve fit any curve fitting method in MEscope, but the modal residues must be post-processed using the **Tools | Scaling | Rapid Test Residues to Mode Shapes** command to recover mode shapes from them.

STEP 7 - REVIEW STEPS

To review the Steps of this App Note,

- ***Press*** **Hotkey 7 Review Steps**