MEscope Application Note 50

TRN Chain™ Test Using Two Uni-Axial Accelerometers

The steps in this Application Note can be carried out using any MEscope package that includes the **VES-3600 Advanced Signal Processing** and **VES-700 Multi-Channel Acquisition** options. Without these options, you can still carry out the steps in this App Note using the **AppNote50** project file. These steps might also require MEscope software with a ***more recent release date***.

PROJECT FILE

- To open **AppNote50.VTmax** for this App Note, **click here** to download **AppNote50.zip**
- To retrieve PDFs of the Webinar for this App Note, **click here** to download **AppNote50PPTs.pdf**

The project file **AppNote50.VTmax** 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.

INTRODUCTION`

In this Application Note, a unique measurement and post-processing capability in MEscope called **TRN Chain™** testing is illustrated. A **TRN Chain™** is formed from two uni-axial accelerometer responses acquired from an aluminum plate. Then the **TRN Chain**™ is ***"seeded"*** with an **FRF** to calculate a **set of single-reference FRFs** for the plate.

LIMITATIONS OF CONVENTIONAL MODAL TESTING

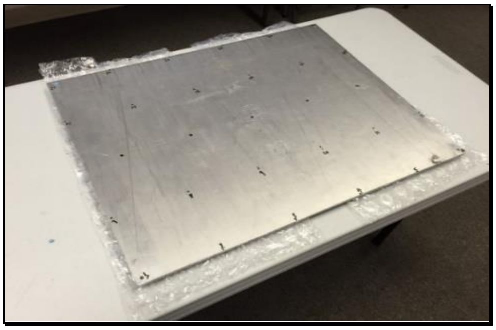
Conventional modal testing has limitations that are overcome with **TRN Chain™** testing,

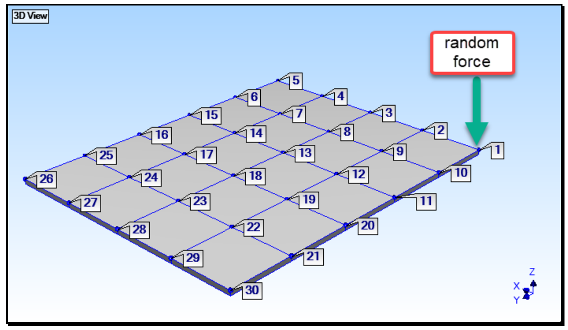
- The **reference sensor**, (the accelerometer in a roving impact test or the hammer or shaker location in a roving response test), ***must remain fixed throughout the test***.
- To test a larger structure, ***very long wires might be required*** to connect all the sensors to the data acquisition front end.
- A **TRN Chain™** test ***does not require a fixed reference sensor*** throughout the test, so it is faster and easier to perform on ***any size structure***.

ALUMINUM PLATE

In this App Note, the acceleration responses in the vertical direction at 30 points on the aluminum plate shown below are calculated by applying a pure random excitation force at one corner of the plate.

The random responses are calculated using the **Transform | Outputs** command, which is part of the **VES-3600 Advanced Signal Processing** option in MEscope. The **VES-700 Multi-Channel Acquisition** option in MEscope is then used to ***"acquire"*** and process a chain of random acceleration **TWFs** (time waveforms) to simulate using two real world uni-axial accelerometers and a 2-channel acquisition system.





WHAT IS A TRN CHAIN™?

A Transmissibility is defined as the ratio of two **DFTs** (Digital Fourier Transforms) which are calculated from two **TWFs** (time waveforms). However, a Transmissibility can be calculated in the same way as an **FRF** from Auto & Cross spectra, using Hanning windowing to reduce leakage, and spectrum averaging to reduce extraneous noise in the spectra.

- To calculate a Transmissibility, two or more **TWFs** must be ***simultaneously acquired***.
- Each Transmissibility has the same two **DOFs** (Degrees of Freedom) as the two **TWFs** used to calculate it.
- Even though a Transmissibility is calculated in the same way as an **FRF**, a Transmissibility is a ***different complex waveform*** than an **FRF**.
- Peaks in a Transmissibility ***are not resonance peaks***. Therefore, Transmissibility's ***cannot be curve fit*** to obtain experimental modal parameters.
- A **TRN Chain** is formed when each Transmissibility has the ***same* DOF *as another Transmissi*bility** in the chain.

ADVANTAGES OF A TRN CHAIN™ TEST

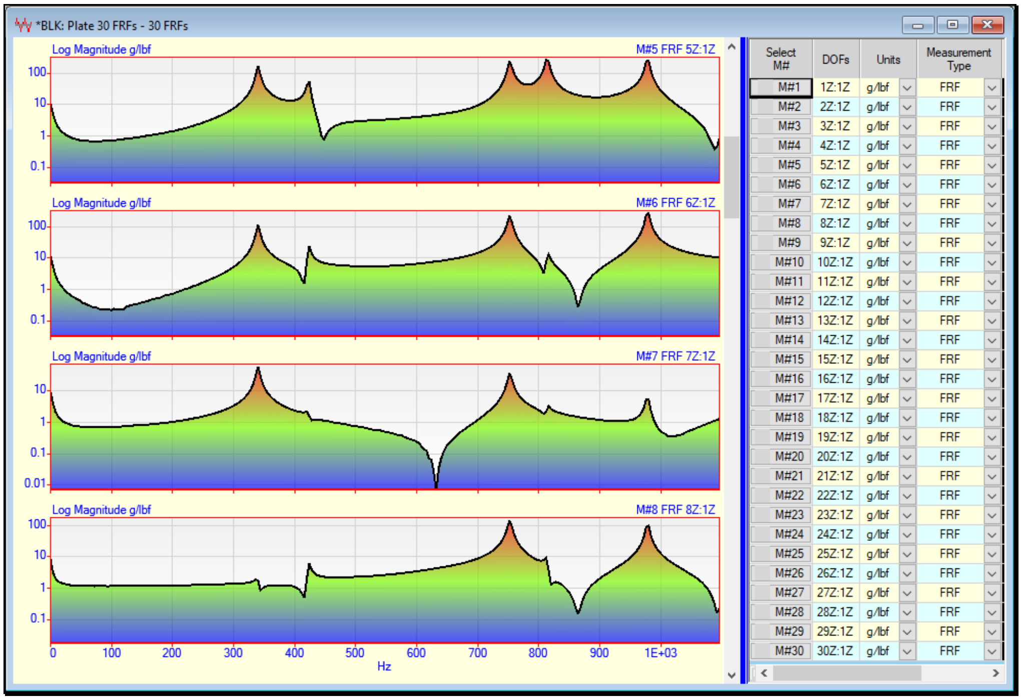
- ***Either or both accelerometers*** can be moved between acquisitions.
- One accelerometer can be ***"hopped over"*** the other one in slinky fashion.
- After a **TRN Chain** has been acquired, it can be ***"seeded"*** with an **FRF**, **Cross spectrum**, or **ODS-FRF** to calculate a set of ***single reference measurements***.
- An **FRF** calculation requires the ***simultaneous acquisition*** of a response and the excitation force that caused the response.
- When a **TRN Chain** is ***"seeded"*** with an **FRF**, a set of ***single-reference*** **FRFs** is calculated.
- A **Cross spectrum** or **ODS-FRF** calculation only requires the operational (output-only) data from two responses.
- When a **TRN Chain** is ***"seeded"*** with a **Cross spectrum**, a set of ***single-reference*** **Cross spectra** is calculated.
- When **a TRN Chain** is ***"seeded"*** with an **ODS-FRF**, a set ***of single-reference*** **ODS-FRFs** is calculated.
- Any set of ***single-reference*** **FRFs**, **Cross spectra**, or **ODS-FRFs** can be curve fit to obtain experimental mode shapes.

ROVING IMPACT TEST

To capture the dynamics of the aluminum plate, a **Roving Impact Test** was performed on it with an accelerometer attached at one corner (**DOF 1Z**). The plate was impacted at 30 points in the vertical direction (**DOFs 1Z to 30Z**), and **Plate 30 FRFs** were calculated from the ***simultaneously acquired pairs*** of force and response **TWFs**.

Each experimental **FRF** has two **DOFs**, separated by a colon (Roving **DOF** : Reference **DOF**). The first **DOF** is the roving impact **DOF** and the second **DOF** is the **fixed reference DOF 1Z**.

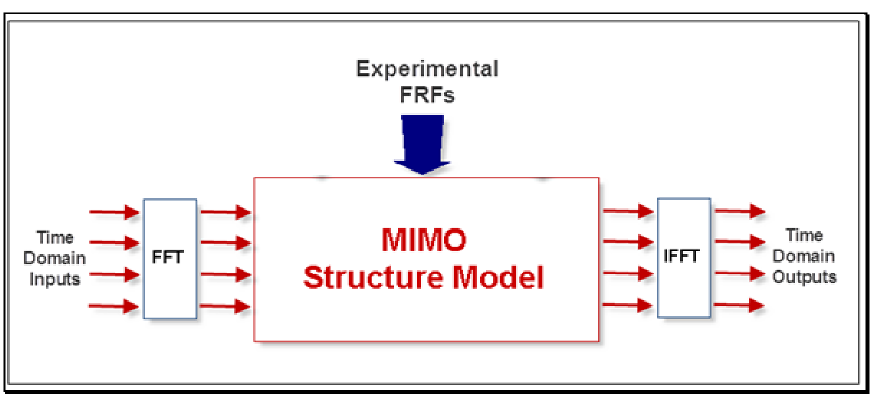
The log magnitudes of several **FRFs** derived from the impact test are shown in the figure below. The **FRFs** are stored in **BLK: Plate 30 FRFs** which is included in the **AppNote50.VTmax** project file. The properties of the **FRFs** are also listed in the **M#s** spreadsheet ***to the right*** of the log magnitudes. The peaks in the log magnitudes indicate that five resonances (modes of vibration) were excited over the frequency span of the **FRFs**.



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

STEP 1 - RANDOM RESPONSES

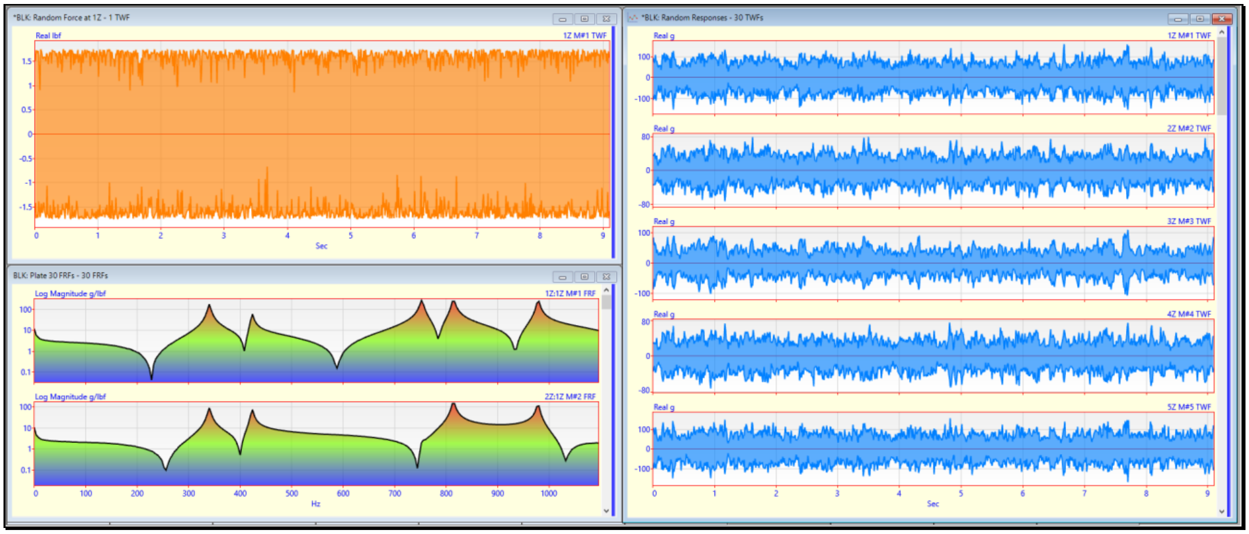
Using the experimental **FRFs** to model the Input-Output dynamics of the aluminum plate, a random excitation force is applied as an Input at **DOF 1Z** on one corner of the aluminum plate. The random Outputs, or responses of the plate at **DOFs 1Z through 30Z**, are then calculated using the **Transform | Outputs** command in MEscope. This calculation is depicted in the diagram below.



The **File | New | Data Block** command in MEscope was used to create a Data Block with a **TWF** of a random force in it as the random force Input at **DOF 1Z**. The random force **TWF** in **BLK: Random Force at 1Z** was created with **20,000 samples** it in, enough samples to calculate **ten spectral estimates** in the next Step and average them together to minimize the noise effects. **BLK: Random Force at 1Z** is included in the **AppNote50.VTmax** project file.

- ***Press* Hotkey 1 Calculate Random Responses**

When **Hotkey 1 is *pressed***, of Data Block of 30 random response **TWFs** is calculated and displayed on the right, in **BLK: Random Responses**. The random force Data Block, **BLK: Random Force at 1Z**, and the **BLK**: **Impact Test FRFs** Data Block are displayed on the left.



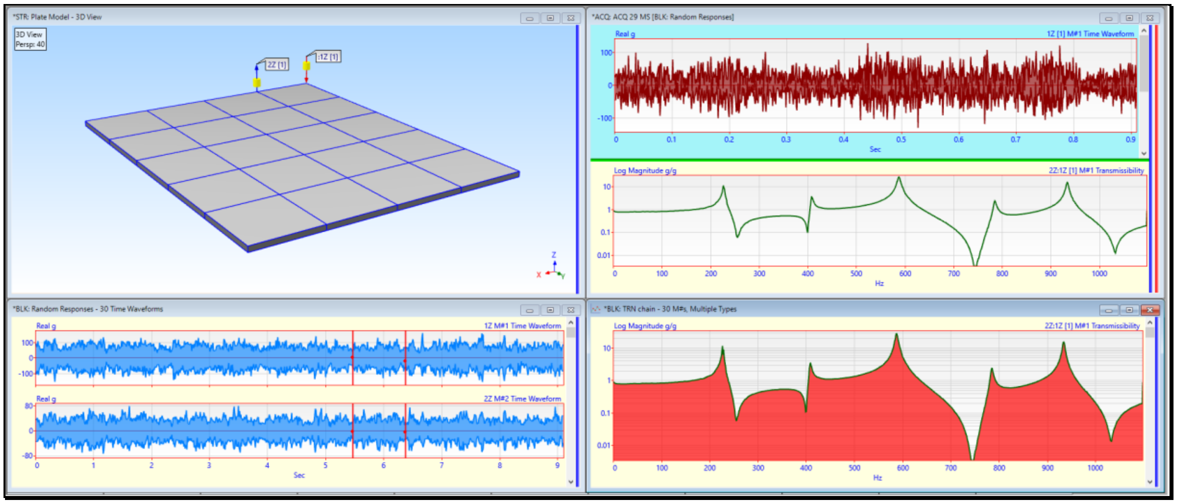
30 Random Response (Outputs) Calculated from a Random Force (Input) at 1Z.

STEP 2 - ACQUIRE A TRN CHAIN

- ***Press* Hotkey 2 Acquire a TRN Chain**

When **Hotkey 2 is *pressed***, data is *"**acquired**"* from the **BLK: Random Responses** Data Block by the Acquisition window. Acquisition from an adjacent pair of uni-axial accelerometers is ***simultaneously acquired*** from **BLK: Random Responses**.

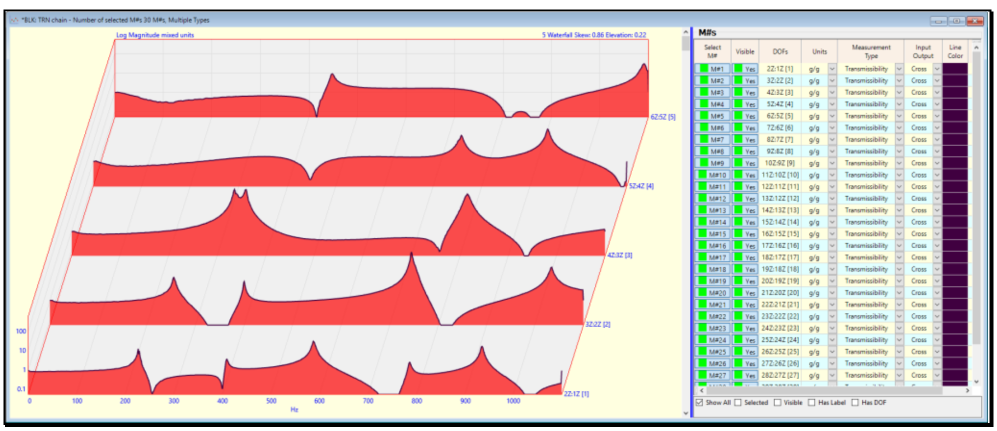
- ***Two channels*** of **TWFs** are used to calculate the Transmissibility's between each pair of adjacent points.
- A **TRN Chain** of **29 Transmissibility's** is calculated between the random acceleration responses at **29 pairs of points**.
- Each sampling window of **2000 samples** of **TWF** data is ***non-periodic*** in its sampling window, meaning that the signal is ***not completely defined*** within its sampling window.
- To ***minimize leakage effects*** in its spectra, a **Hanning window** is applied to each sampling window of **TWF** data before the **FFT** is applied to it.
- Ten response **Auto & Cross spectra** are ***averaged together*** to remove random noise from them.



THE TRN CHAIN

Some of the Transmissibility's in the **TRN Chain** are displayed below.

- A Transmissibility is a ***different complex waveform*** than an **FRF**.
- Each Transmissibility has ***units of g/g***.
- The Transmissibility's have ***different Reference*** **DOFs**.
- Each Transmissibility in a **TRN Chain** has a **DOF** that is the ***same as the*** **DOF** of another Transmissibility.
- A Transmissibility can be calculated from ***any pair of*** **TWFs** provided that all Transmissibility's are ***chained together by their*** **DOFs**.
- **Peaks** in a Transmissibility ***are not resonance peaks***.
- Transmissibility's ***cannot be curve fit*** using **FRF**-based curve fitting methods.



TRN Chain "Acquired" from ***BLK: Random Responses***

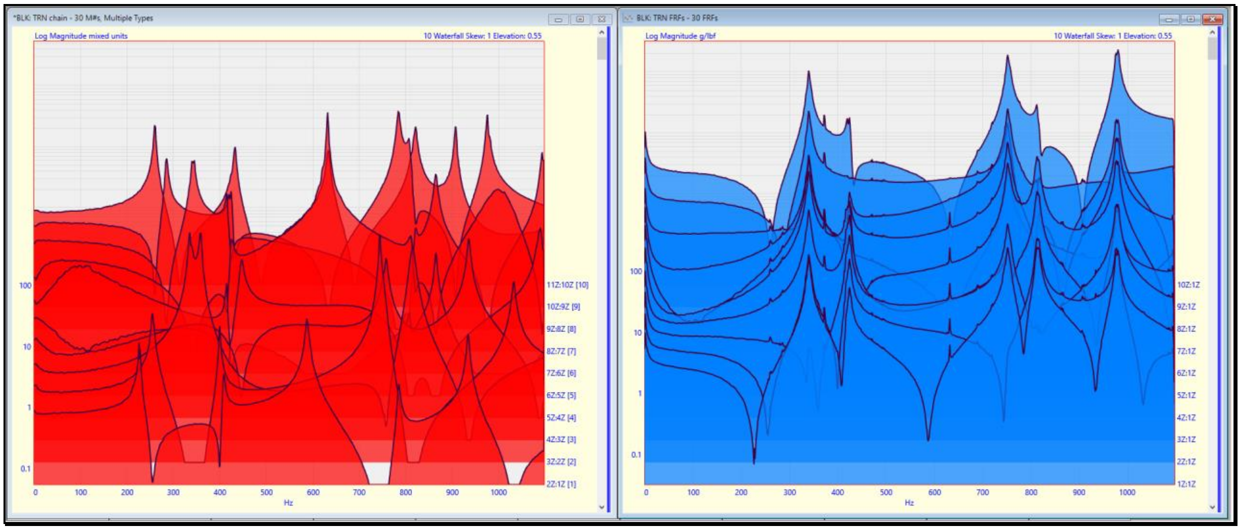
STEP 3 - SEEDING THE TRN CHAIN

- ***Press*** **Hotkey 3 Seed the TRN Chain**

In this step, a set of single-reference **FRFs** is calculated by ***"seeding"*** the **TRN Chain** obtained in the previous step with an **FRF**. The **Transform | TRN Seed** command is used in **BLK: TRN Chain** to seed the **TRN Chain**.

To seed a **TRN Chain,** the **Roving DOF** of the seed ***much match one of the*** **DOFs** in the **TRN Chain**.

When **Hotkey 3 is *pressed***, a set of single-reference **FRFs** is displayed ***in the right side*** of the MEscope window, as shown below.



*Single-Reference **FRFs** on the Right from Seeding the TRN Chain on the Left.*

- **Peaks** in the Transmissibility's ***are not evidence of resonances***. Peaks are the result of ***dividing one* DFT *by another* DFT**.
- **Peaks** in the **FRFs *are evidence of resonances***. A peak occurs ***at the same frequency*** in every **FRF**.

COMPARING FRFs

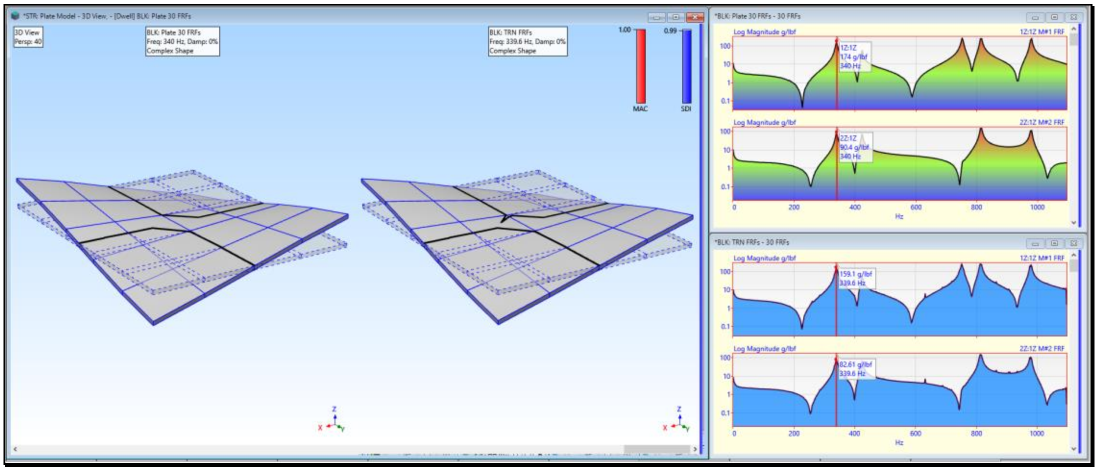
The **FRFs** derived from the **TRN Chain** can be compared with the original **Plate 30 FRFs** in three different ways,

1. **Side-by-Side ODS** display in animation with **MAC** & **SDI** values.
2. Using **Tools | Data Block Correlation** to compare ***values are each sample*** in the two Data Blocks.
3. Using **Tools | M# Pairs Correlation** to compare the ***values in each pair of* M#s** with ***matching* DOFs**.

STEP 4 - SIDE-BY-SIDE ODS DISPLAY

***Press* Hotkey 4 Side-by-Side ODS Display**

When **Hotkey 4 is *pressed***, an ODS from the Line cursor position in the original Data Block **BLK: Plate 30 FRFs** is displayed side-by-side with the **closest matching ODS** from **BLK: TRN FRFs**.



*Side-by-Side Display of ODS's With Maximum **MAC**.*

- Drag the **Line** cursor to a resonance peak in either Data Block of the **FRFs** to display a matching pair of ODS's.

When the Line cursor is moved in one Data Block, the **ODS** from the other Data Block which has a **Maximum MAC** with the ODS at the Line cursor is also displayed.

MAC & SDI

Both **MAC (Modal Assurance Criterion)** and **SDI (Shape Difference Indicator)** are also displayed in the Side-by-Side display of ODS's.

- **MAC** measures ***the co-linearity*** of two ODS's.
- **SDI** measures ***the difference*** between two ODS's.

Both **MAC & SDI** indicate a ***strong correlation*** between the ODS's at a resonant peak in each Data Block.

STEP 5 - DATA BLOCK CORRELATION

- ***Press* Hotkey 5 Data Block Correlation**

The **Tools | Data Block Correlation** command calculates **MAC** & **SDI** values between the Y-axis values ***at each sample*** in two Data Blocks ***with matching*** **DOFs**.

Tools | Data Block Correlation requires that two Data Blocks have ***the same X-Axis values***.

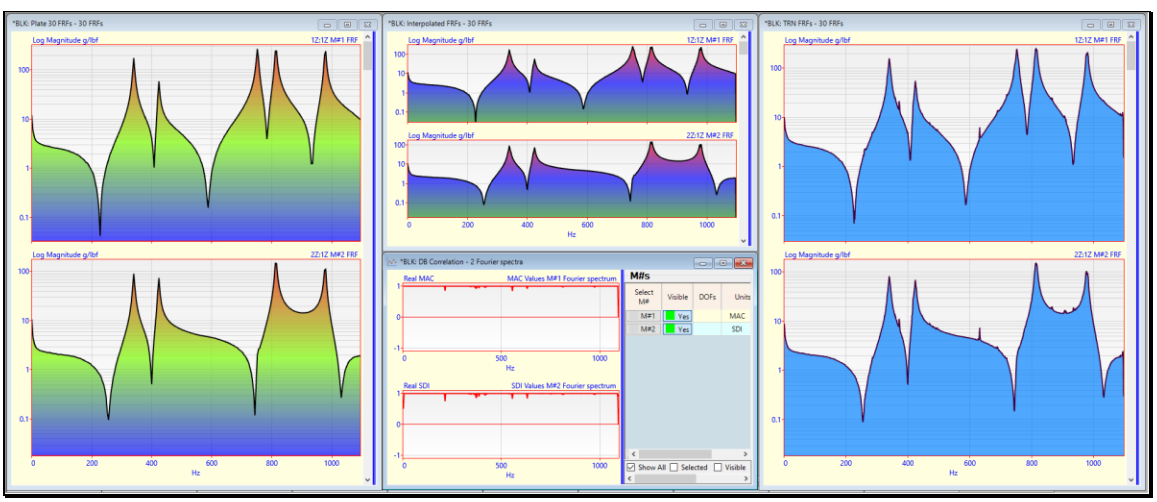
BLK: Plate 30 FRFs has **275 samples** and **BLK: TRN FRFs** has **1000 samples**.

Since the two Data Blocks have different numbers of samples in them, the **M#s | Paste from File** command is used to ***interpolate between the samples*** in **BLK: Plate 30 FRFs** so they match the samples in **BLK: TRN FRFs**.

When **Hotkey 5 is *pressed***, the following steps are carried out,

1. **BLK: Plate 30 FRFs** is pasted into **BLK: TRN FRFs** by executing the **M#s | Paste from File** command.
2. The **interpolated M#s** from **BLK: Plate 30 FRFs** are copied from **BLK: TRN FRFs** into **BLK: Interpolated FRFs**
3. **Tools | Data Block Correlation** is executed between **BLK: TRN FRFs** and **BLK: Interpolated FRFs** and the calculated **MAC & SDI** results are stored in **BLK: DB Correlation**

The new Data Block **BLK: DB Correlation** is displayed in the ***lower middle*** of the figure below.



*Data Block Correlation Between **Plate 30 FRFs & TRN Chain FRFs**.*

The **MAC & SDI** values in **BLK: DB Correlation** indicate ***a strong correlation*** over the entire frequency span between the **FRFs** in **BLK: Plate 30 FRFs** and the **FRFs** in **BLK: TRN FRFs**.

STEP 6 - M# PAIRS CORRELATION

The **Tools | M# Pairs Correlation** command is used to calculate **MAC** & **SDI** values between the Y-axis values of ***pairs of*** **M#s** ***with matching*** **DOFs** in two Data Blocks.

Tools | M# Pairs Correlation requires that two Data Blocks have ***the same X-Axis values***.

BLK: Plate 30 FRFs has **275 samples** and **BLK: TRN FRFs** has **1000 samples**.

When **Hotkey 6 is** ***pressed***, the following steps are carried out by the Script for **Hotkey 6**,

1. The **M#s | Paste from File** command is executed to paste the **M#s** from **BLK: Plate 30 FRFs** into **BLK: TRN FRFs**
2. The ***interpolated*** **M#s** from **BLK: Plate 30 FRFs** are copied into **BLK: Interpolated FRFs**
3. The **Tools | M# Pairs Correlation** command is executed between **BLK: TRN FRFs** and **BLK: Interpolated FRFs**
4. The **MAC & SDI** values ***between matching*** **M#s** in **BLK: TRN FRFs** and **BLK: Interpolated FRFs** are stored into the Shape Table **SHP: M# Correlation**

SHP: M# Correlation is displayed in the ***upper middle*** of the figure below, and the **Magnitude Ranking** of its **SDI M#s** is displayed in the ***lower middle***.

*M# Pairs Correlation Between Original **FRFs** & TRN Chain **FRFs**.*

- Scroll through the **Magnitude Ranking** in the ***lower middle***.
- Click on the **MAC** or **SDI** shape in **SHP: M# Correlation** to display its **Magnitude Ranking**

All the **MAC** & **SDI** values indicate a ***strong correlation*** between each pair of **M#s** with ***matching*** **DOFs** in **BLK: Plate 30 FRFs** and **BLK: TRN FRFs**.

SUMMARY

In this App Note, a **TRN Chain ™** test was simulated by calculating random acceleration responses to a random force applied at one corner of an aluminum plate. This new testing method created a chain of Transmissibility's called a **TRN Chain**. Then the **TRN Chain *was "seeded"*** with an **FRF** to obtain a set of single-reference **FRF**s for the aluminum plate.

A ***"round trip"*** was performed by starting with a set of single-reference **FRFs** calculated from data acquired during a **roving impact test** of the plate. The **Plate 30 FRFs** from the **roving impact test** were used by the **Transform | Outputs** command in MEscope to calculate responses at 30 points on the aluminum plate to a random excitation force applied at **DOF 1Z**.

Then the Acquisition window in MEscope was used to ***"simultaneously acquire"*** pairs of response data from the Data Block of random **TWFs** and form a **TRN Chain**.

This simulated a **TRN Chain ™ test** using **two uni-axial accelerometers** and a **two-channel spectrum analyzer**.

Finally, **MAC** & **SDI** were used in three different ways to compare the FRFs calculated from seeding the TRN Chain ™ test with the original FRFs used to calculate the random responses of the aluminum plate.

MAC & **SDI** were used to **compare ODS's**, compare the two sets of **FRFs at each frequency**, and **compare matching pairs of M#s** from the two sets of **FRFs**.

MAC & SDI

All three numerical methods used to compare the **TRN Chain FRFs** with the **Plate 30 FRFs** utilized the **MAC (Modal Assurance Criterion)** and **SDI (Shape Difference Indicator)**.

- Both **MAC & SDI** have values between **0 & 1**
- **MAC or SDI >= 0.9 ➔ strong correlation** between two shapes
- **MAC or SDI < 0.9 ➔ weak correlation** between two shapes

All three comparison methods showed a ***strong correlation*** between the **Plate 30 FRFs** and the **TRN Chain FRFs**.

STEP 7 - REVIEW STEPS

To review all the steps of this App Note,

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