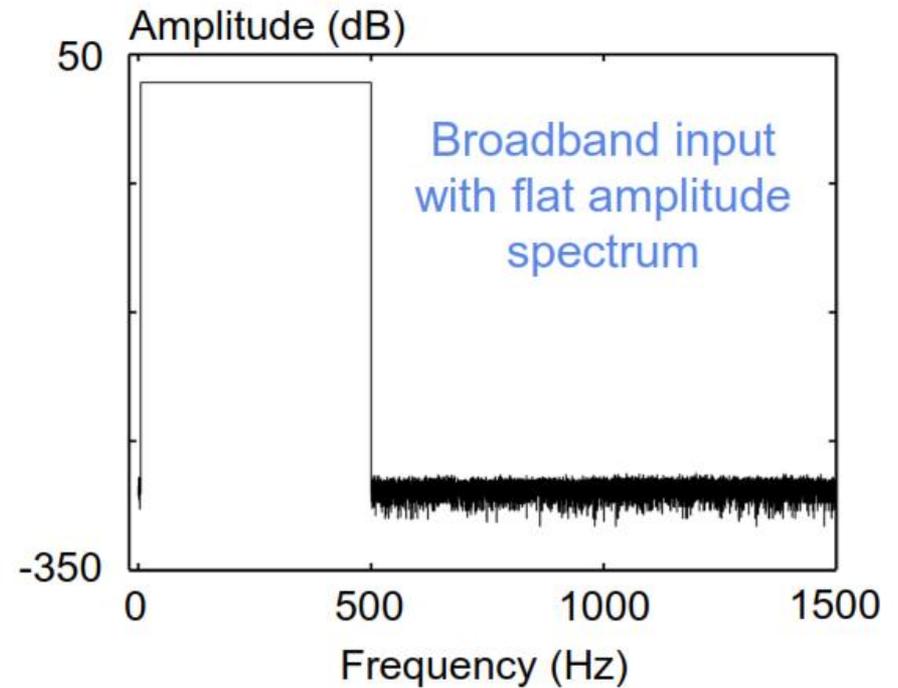
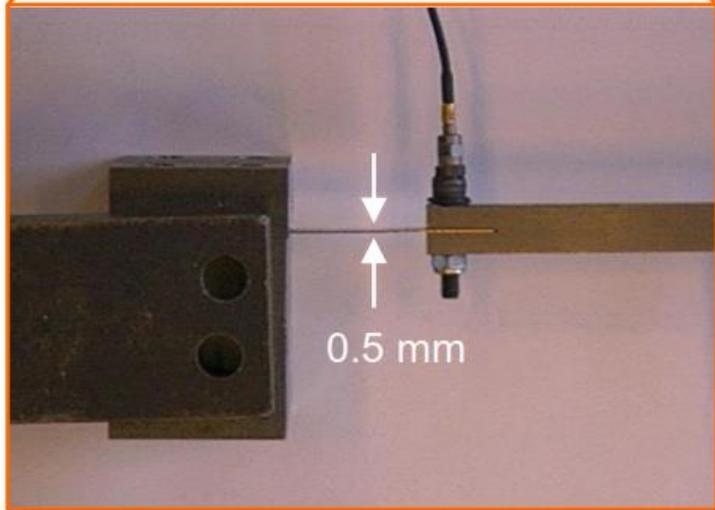
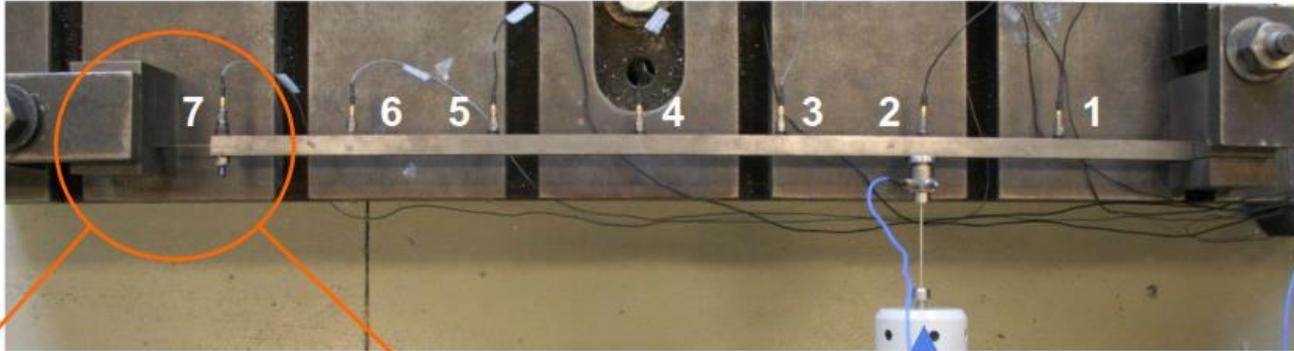


Nonlinear Vibrations of Aerospace Structures

Tutorial 09
Estimating Parameters
using FNSI



A Numerical Beam with a Geometric Nonlinearity



Create a New Model at 0.1 N based on Measured Signals

NI2D: New model

User models | Spring/mass system | MCK matrices | Finite element model | DAQ model | Measured signals

Sensor signals: [7x327680] Num.

Accelerations Displacements

Shaker(s) signal: [1x327680]

Shaker/sensor connections: 2

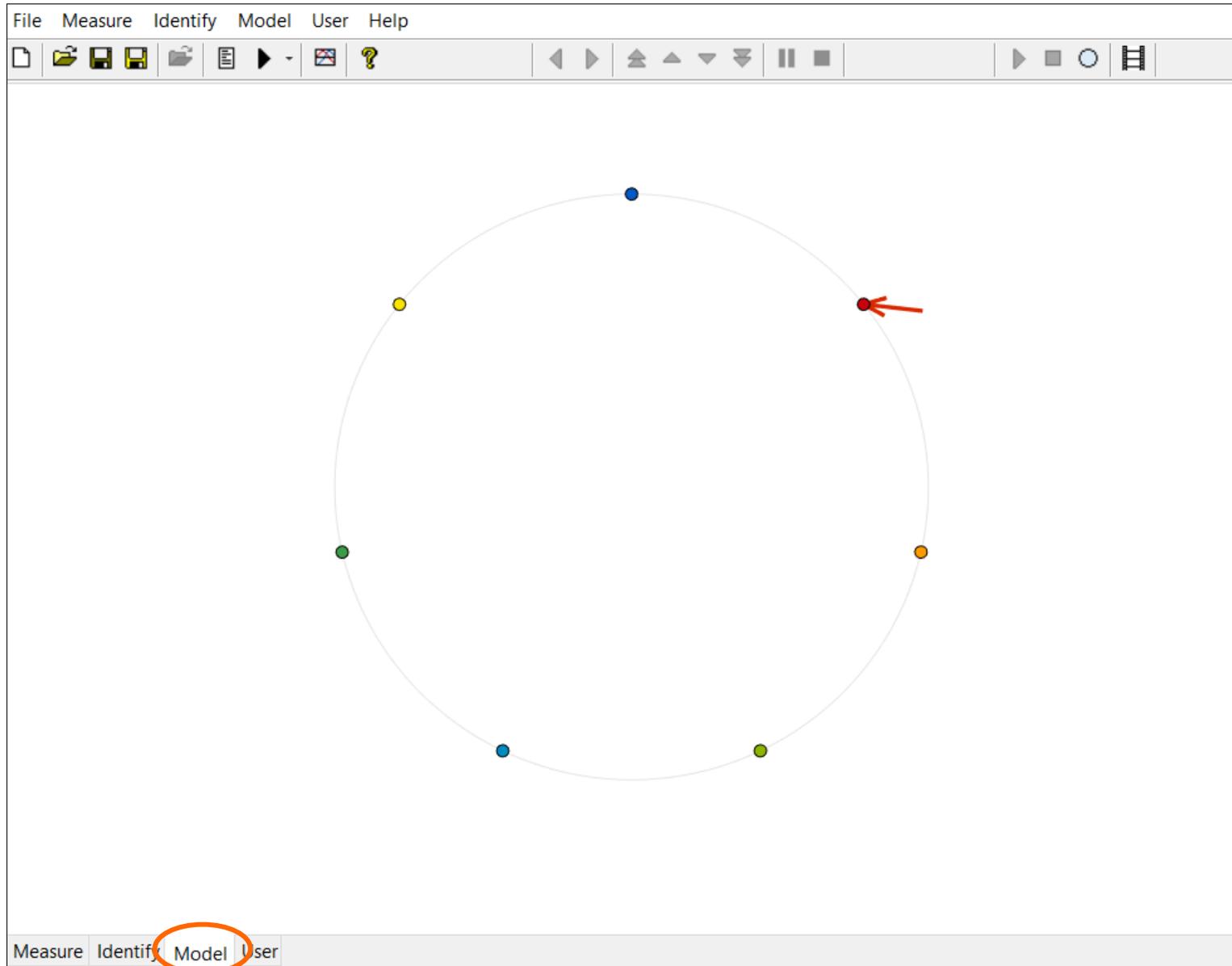
Sampling frequency: 3000 Hz

Number of points per period: 32768

Continue > Abort

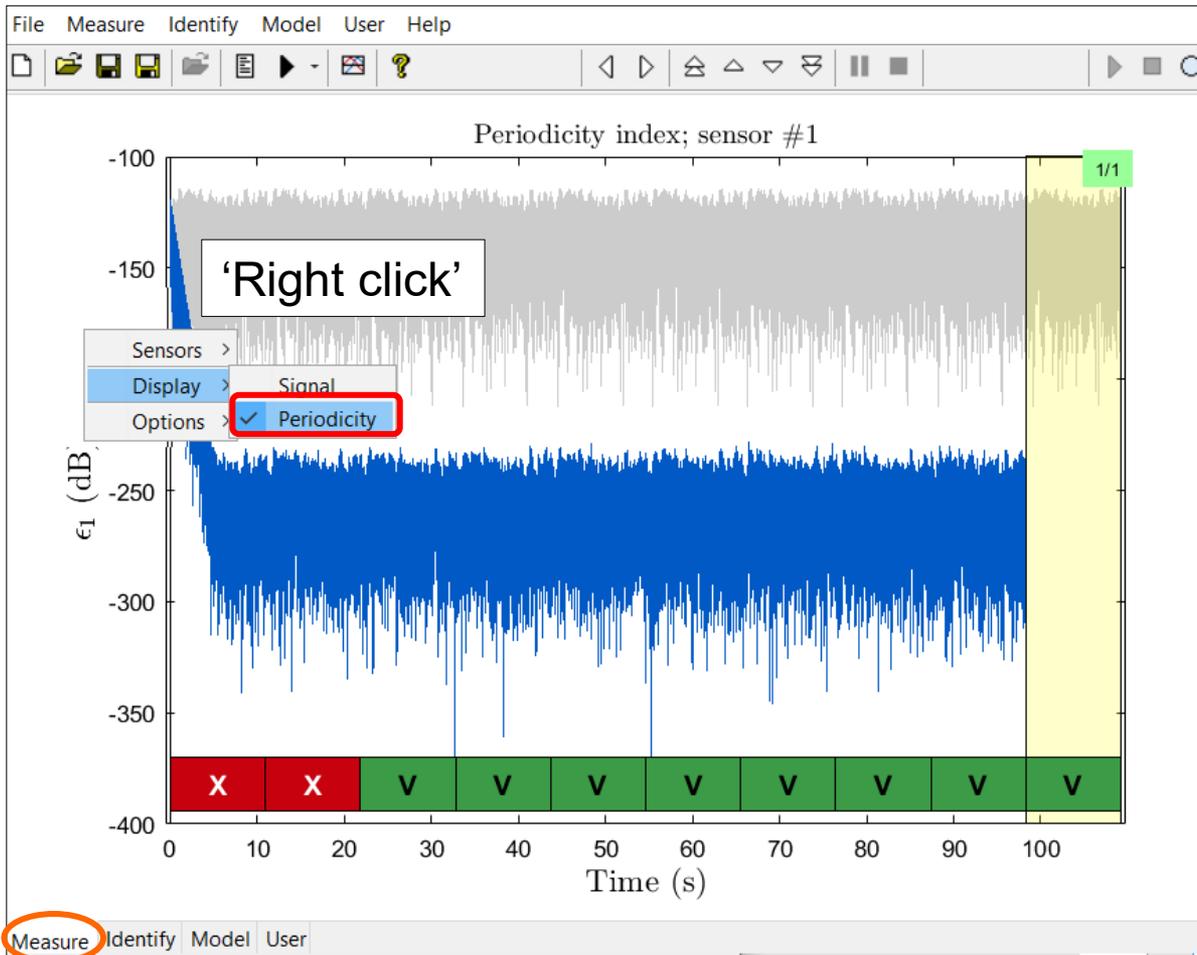
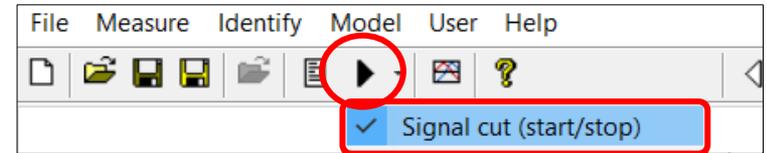
Use the FNSI data for this. Y includes the sensor signals while the shaker signal is saved in u .

7 Displacements and 1 Shaker are Represented



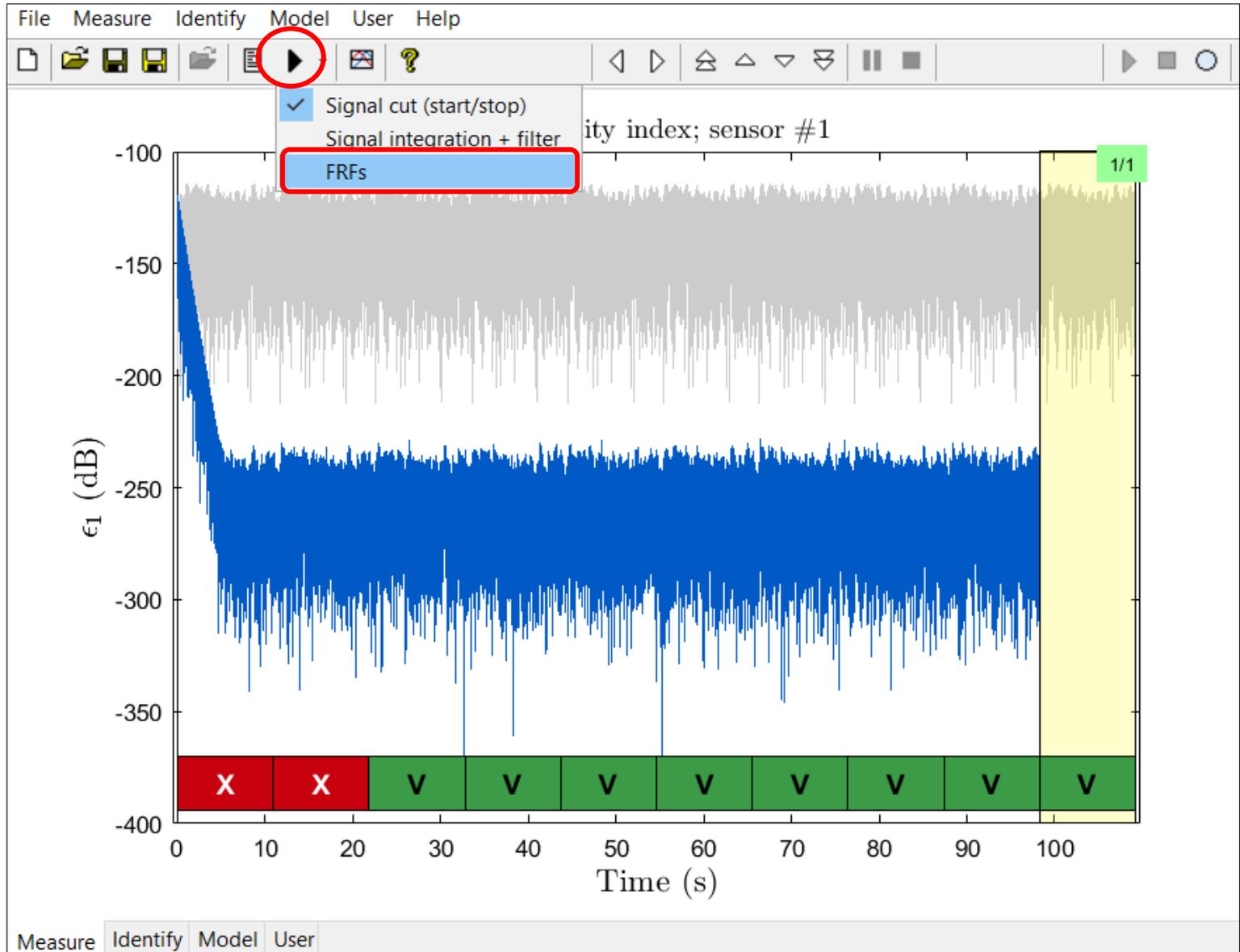
Transient Analysis to Avoid Leakage in FD Identification

1. Go to the 'Measure' tab and play 'Signal cut'



2. Display the Periodicity of the signal

Nonparametric FRF Analysis Before Estimating Parameters



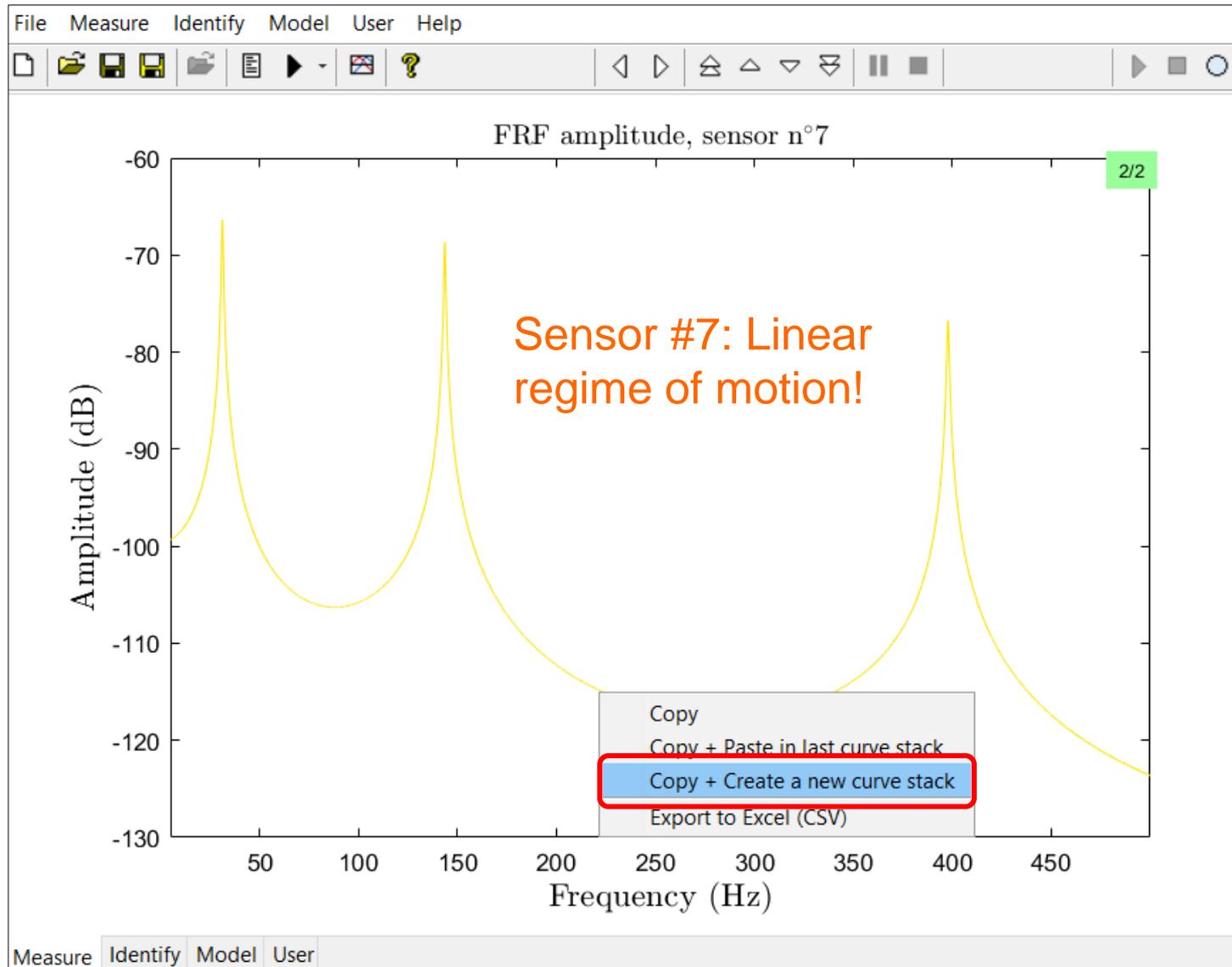
Calculation over the Input Band (Number of Points Is Fixed)

The image shows a software interface with a menu bar (File, Measure, Identify, Model, User, Help) and a toolbar. A red circle highlights a document icon in the toolbar, with an orange arrow pointing to the 'Number of points' field in the 'FRFs parameters' dialog box. The dialog box has a title bar 'FRFs parameters' and a 'Fixed!' label. It contains three input fields: 'Number of points' (set to 32768), 'Frequency min' (set to 5 Hz), and 'Frequency max' (set to 500 Hz). The 'Frequency min' and 'Frequency max' fields are highlighted with a green rounded rectangle. At the bottom are 'Apply' and 'Cancel' buttons.

Parameter	Value	Unit
Number of points	32768	
Frequency min	5	Hz
Frequency max	500	Hz

Choose the frequency range of interest and compute the FRFs.

The Input Band Encompasses the First Three Beam Modes



FNSI Can Be Used for Linear System Identification!

File Measure Identify Model User Help

1. FNSI stabilisation diagram
FNSI identification
FNSI postprocessing

2. FNSI stabilisation diagram parameters

Frequency min: 5 Hz

Frequency max: 500 Hz

Max order: 20

noise weighting

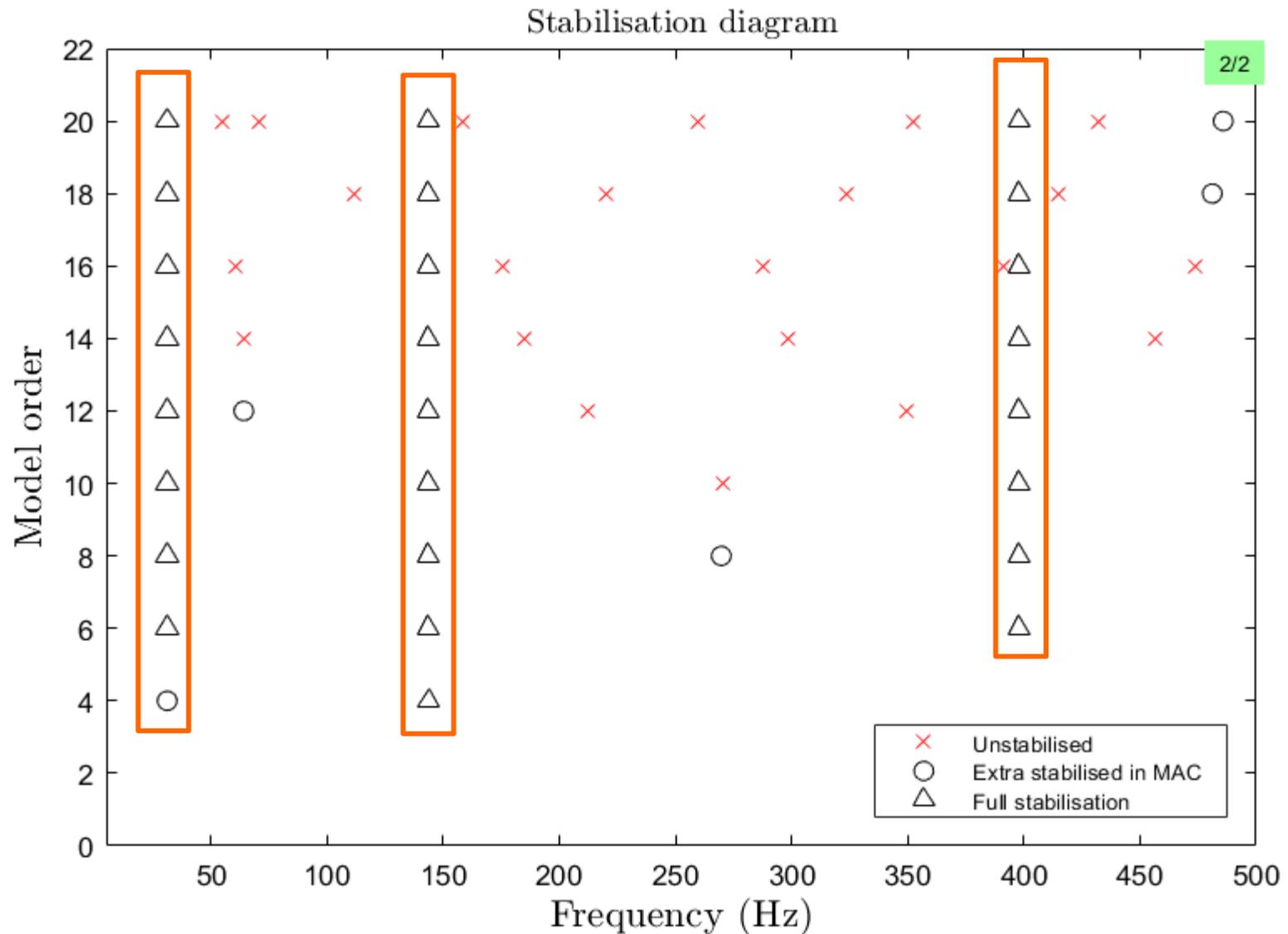
Matrix block rows: 22 auto

Apply Start (F5) Cancel

Measure Identify Model User

Internal FNSI parameter:
should be at least = $n + 1$.

The Three Beam Modes Are Clearly Distinguished



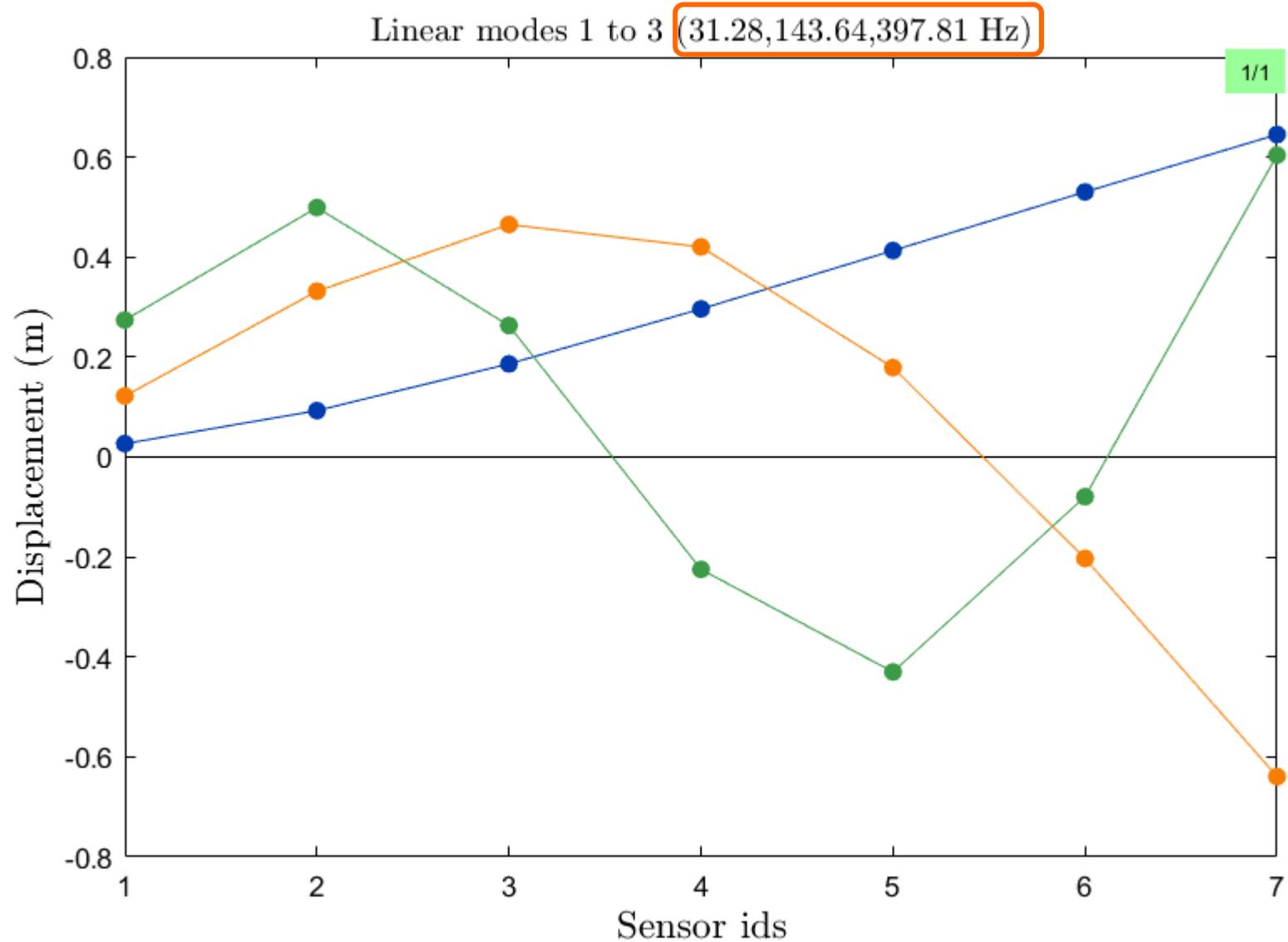
Identification: Select Model Order 6 and Parameter Estimation

The screenshot displays the 'Identify' window of a software application. The main plot shows 'Model order' on the y-axis (0 to 22) and 'Frequency (Hz)' on the x-axis (0 to 500). A red circle highlights the 'Run' button in the toolbar, with an arrow pointing to a dropdown menu where 'FNSI identification' is selected. A dialog box titled 'FNSI identification parameters' is open, showing the following settings:

- Frequency min: 5 Hz
- Frequency max: 500 Hz
- Order: 6
- noise weighting
- Matrix block rows: 22 auto
- NR optimisation NLS optimisation no optimisation

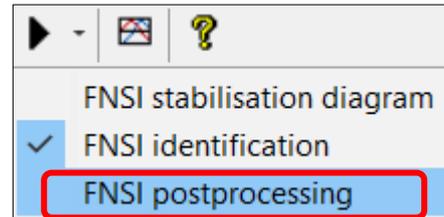
The 'Start (F5)' button in the dialog is highlighted with a red circle. The 'Apply' button is disabled, and 'Cancel' is visible. The status bar at the bottom shows 'Measure Identify Model User'.

Modal Properties are Accurately Estimated

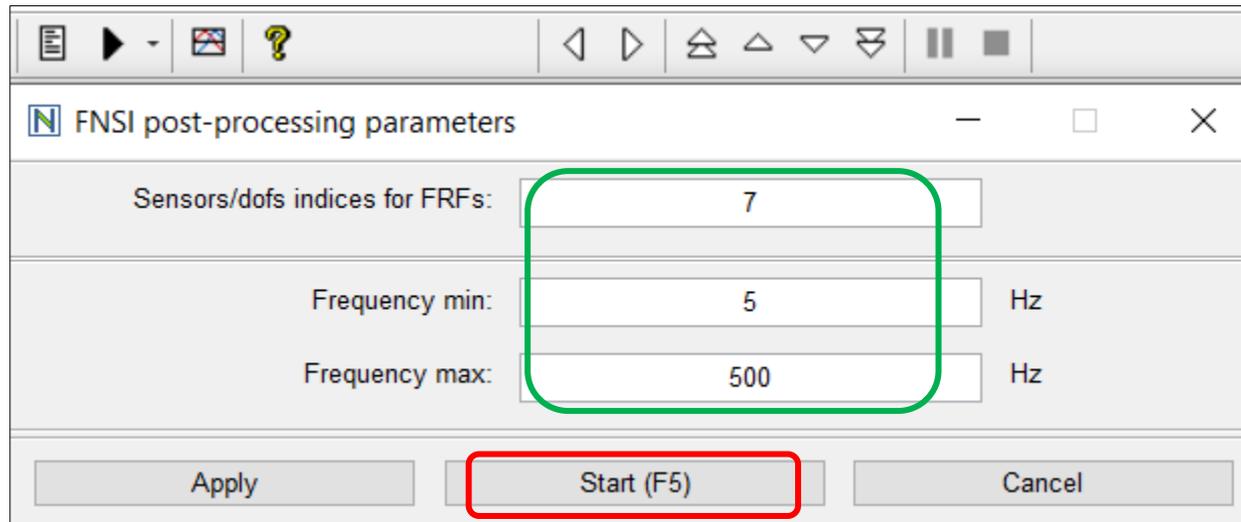


FRF Calculation based on the Identified State-space Model

1.

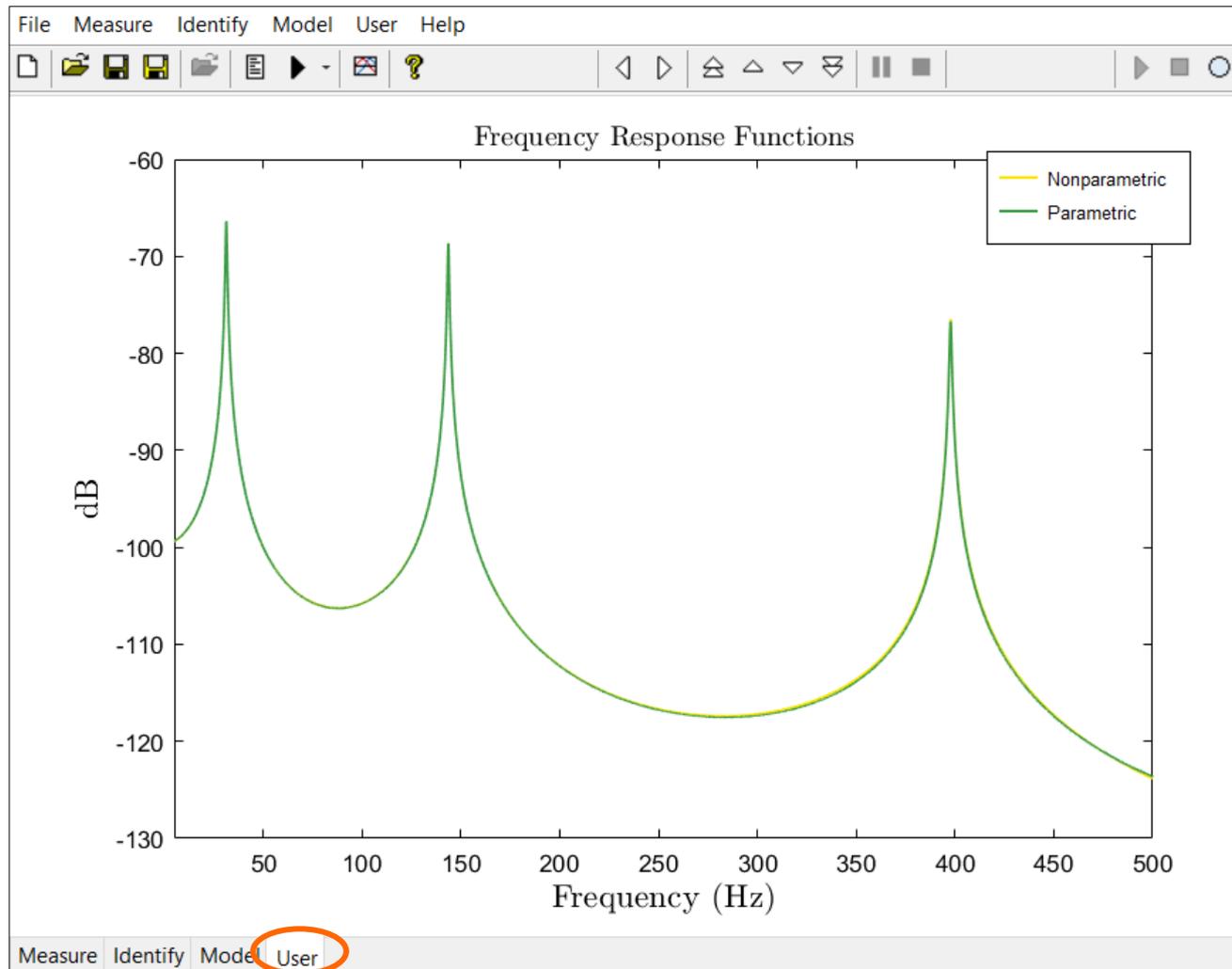


2.



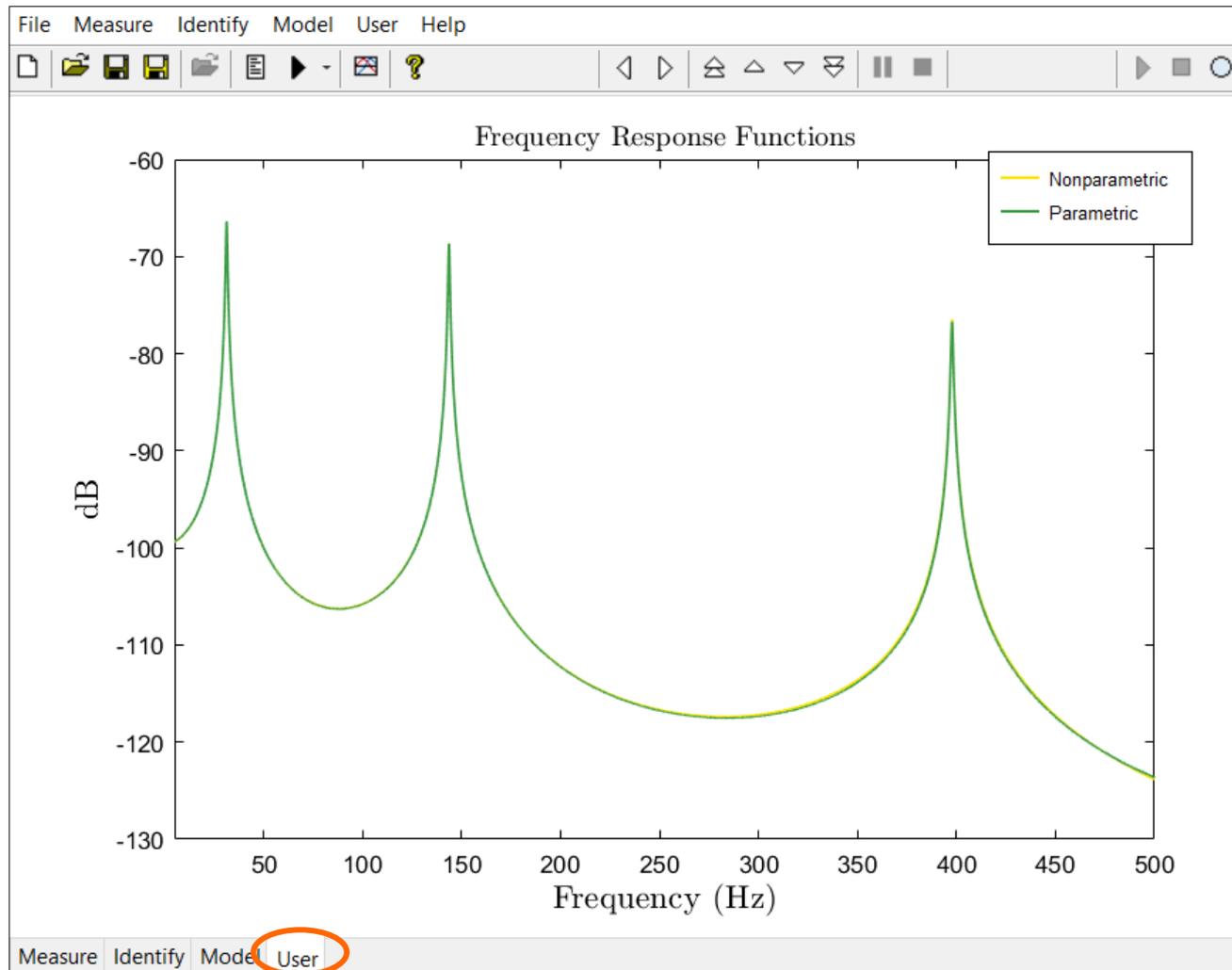
Compare the computed FRFS in a curve stack

Nonparametric and parametric FRFs match very well!



Compare the computed FRFS in a curve stack

Nonparametric and parametric FRFs match very well!



Nonlinear Identification at High Level (15 N)

Create a new model with the displacement series obtained using a higher forcing amplitude.

NI2D: New model

User models | Spring/mass system | MCK matrices | Finite element model | DAQ model | Measured signals

Sensor signals: [7x327680] Num.

Accelerations Displacements

Shaker(s) signal: [1x327680]

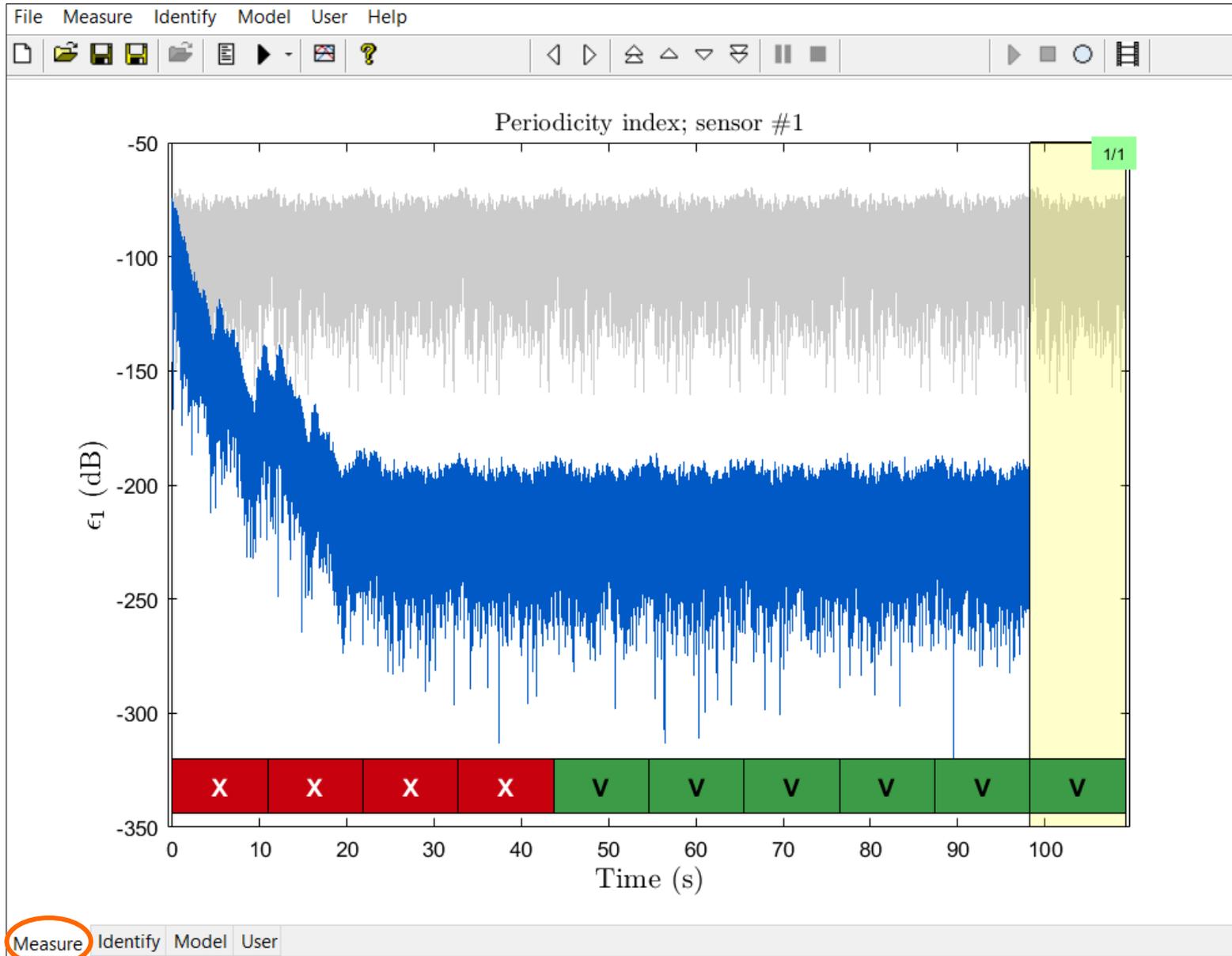
Shaker/sensor connections: 2

Sampling frequency: 3000 Hz

Number of points per period: 32768

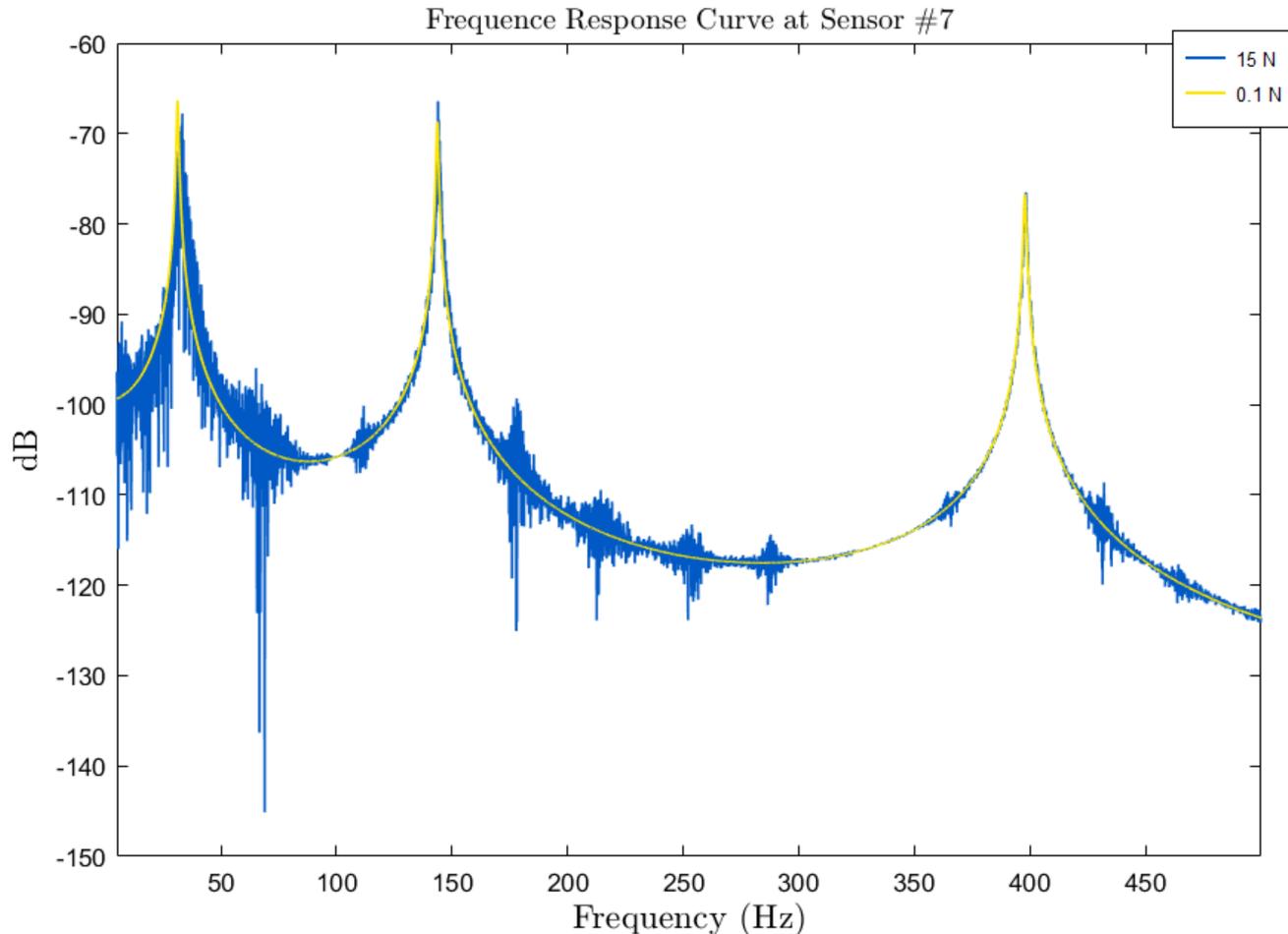
Continue > Abort

Get Rid of Transients



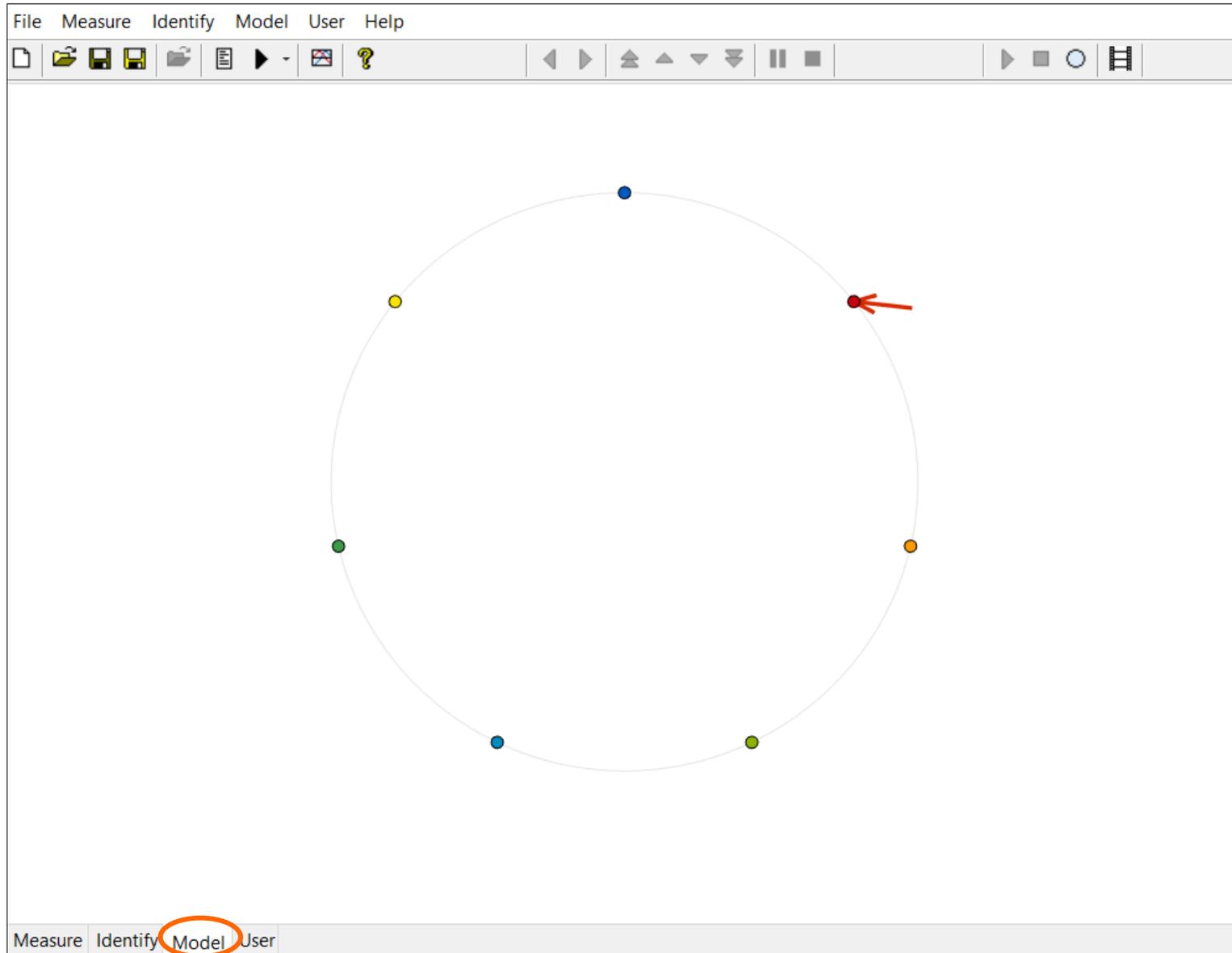
And Compute the FRF

Compare the FRF to the FRF for a forcing amplitude of 0.1 N by saving them in the same curve stack. You can copy data from one curve stack to another by 'right click' and 'copy'.



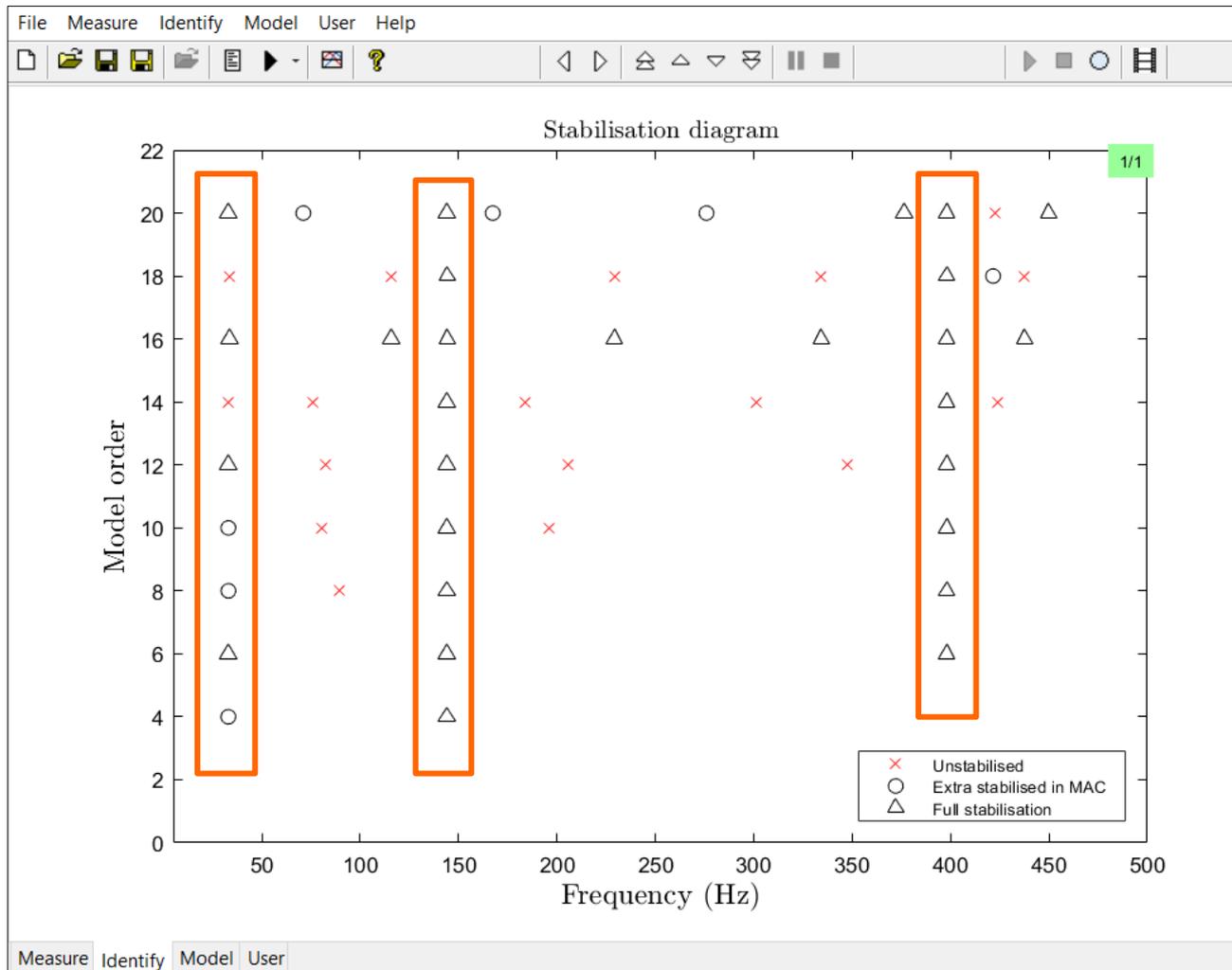
Substantial nonlinear distortions are detected in FRF Plots.

Fitting a Linear Model to Nonlinear Data

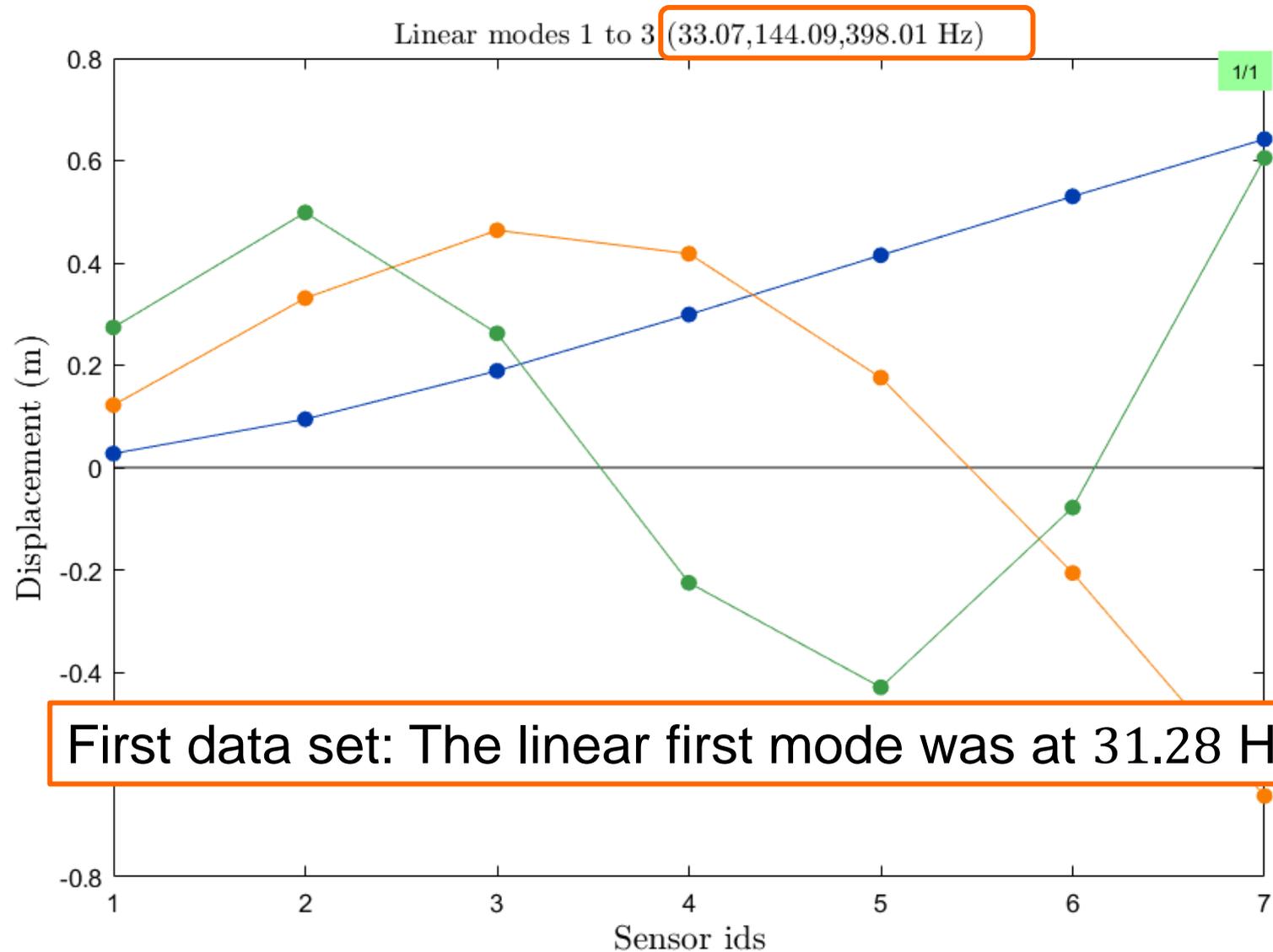


Accurate Stabilisation of Linearised Modal Properties

Go to the 'Identify' tab and compute the stabilisation diagram, using the same parameters as before.



The First Mode Exhibits an Important Hardening



Physical Reasoning Suggests a Cubic Nonlinearity

The screenshot displays a software application window with a menu bar (File, Measure, Identify, Model, User, Help) and a toolbar. A red text overlay reads "Ctrl + left click + drag". A yellow cursor is positioned over a blue dot on a curved line. A red arrow points to another blue dot on the same line. A dialog box titled "Polynomial NL spring n..." is open, with a green border around its input fields. The dialog shows "Coefficient: 1" and "Exponent: 3" in N/m^x units. Below these are radio buttons for "odd" (selected), "even", and "unilateral". "Apply" and "Cancel" buttons are at the bottom. A photograph on the right shows a mechanical assembly with a cable and a metal block.

File Measure Identify Model User Help

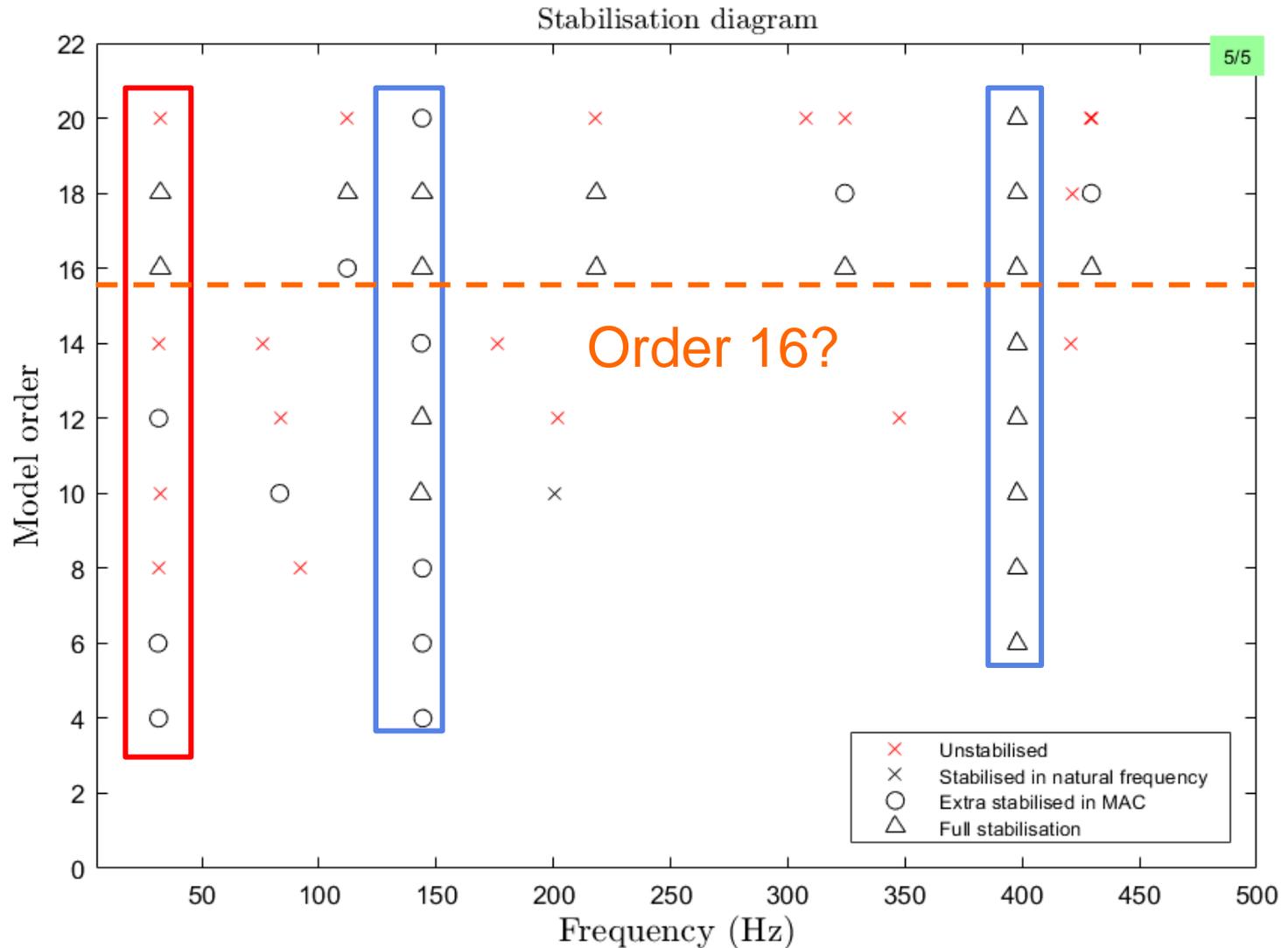
Ctrl + left click + drag

Polynomial NL spring n...
Coefficient: 1 N/m^x
Exponent: 3
 odd even unilateral
Apply Cancel

Measure Identify Model User

Compute the Stabilisation Diagram Again.

Inaccurate Stabilisation of Mode 1.



Set the FNSI Identification Parameters

N FNSI identification parameters

Frequency min: 5 Hz

Frequency max: 500 Hz

Order: 16

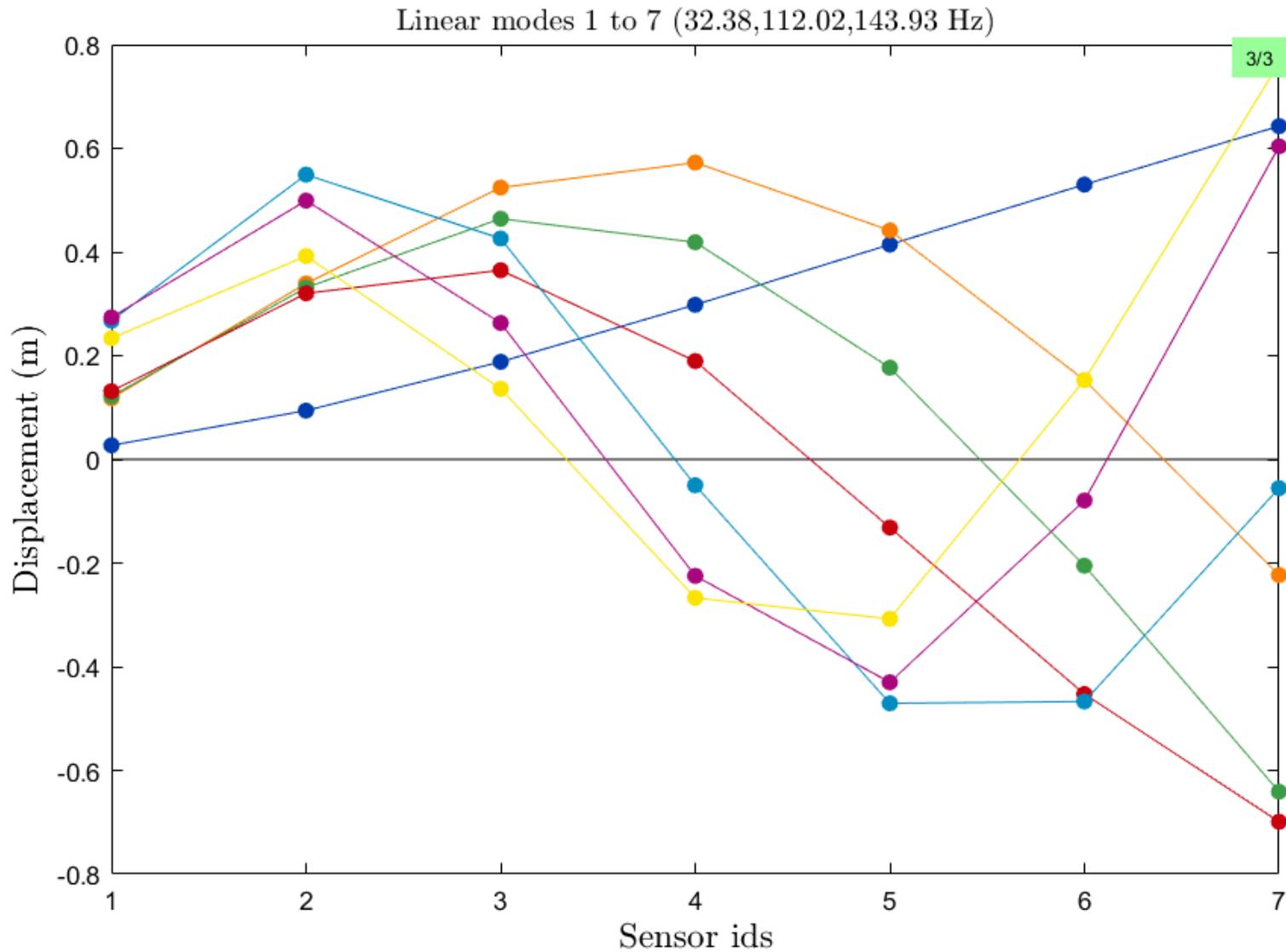
noise weighting

Matrix block rows: 22 auto

NR optimisation NLS optimisation no optimisation

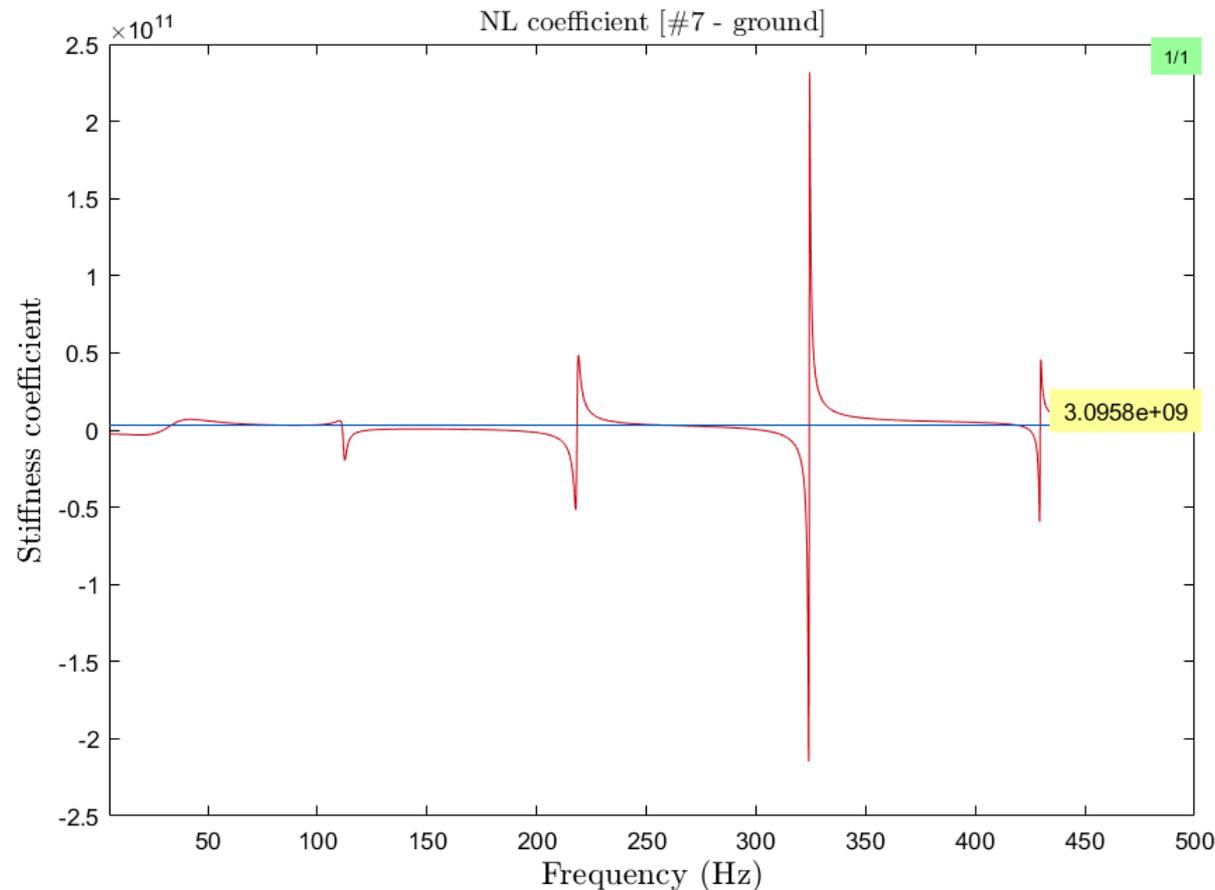
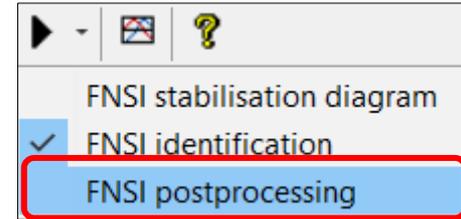
Apply Start (F5) Cancel

More than Three Modes Are Identified



The Nonlinear Coefficient

1. Go to the FNSI postprocessing



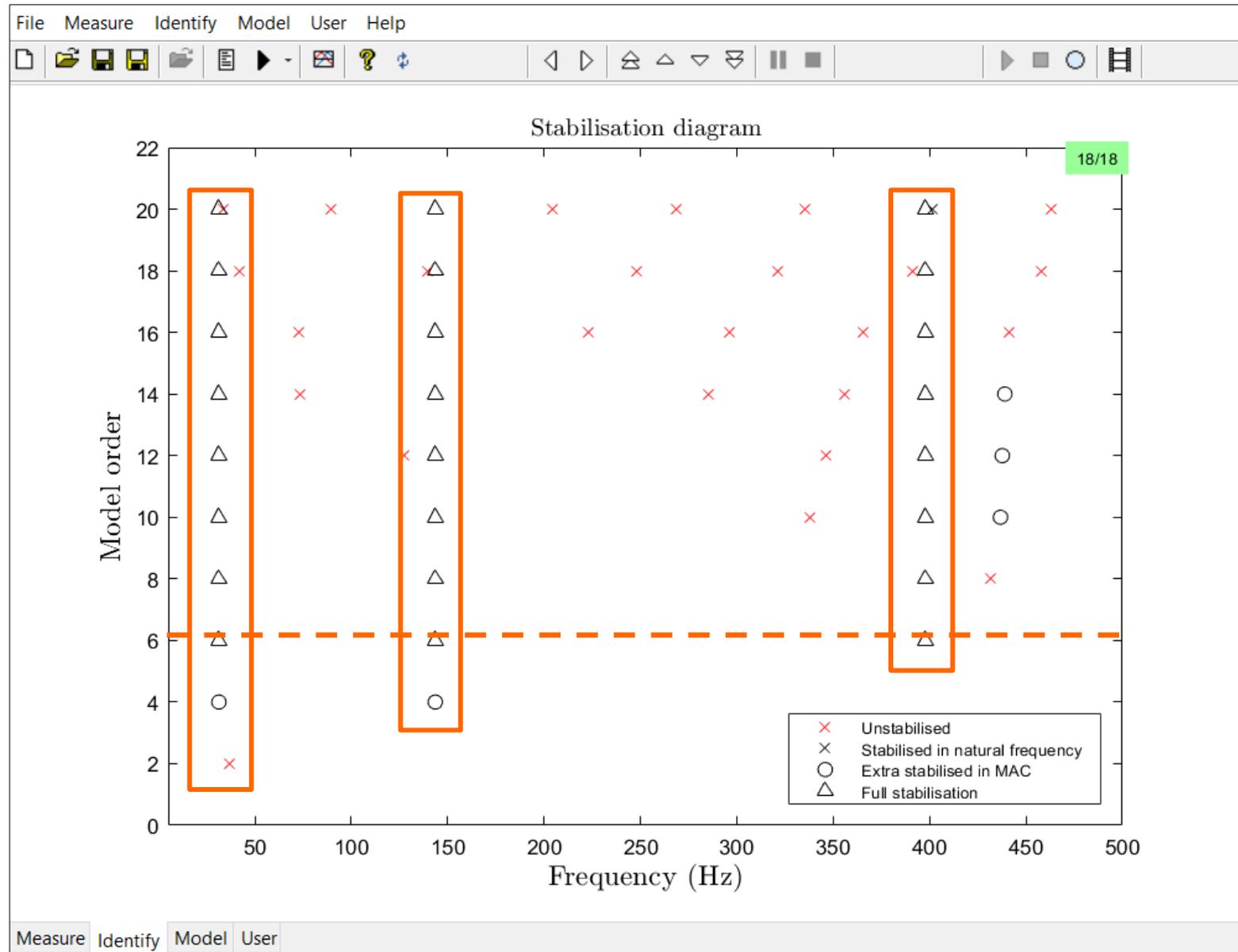
2. Multiple spurious poles appear in the nonlinear coefficient

Can You Guess the Exact Nonlinearity at Beam Tip?

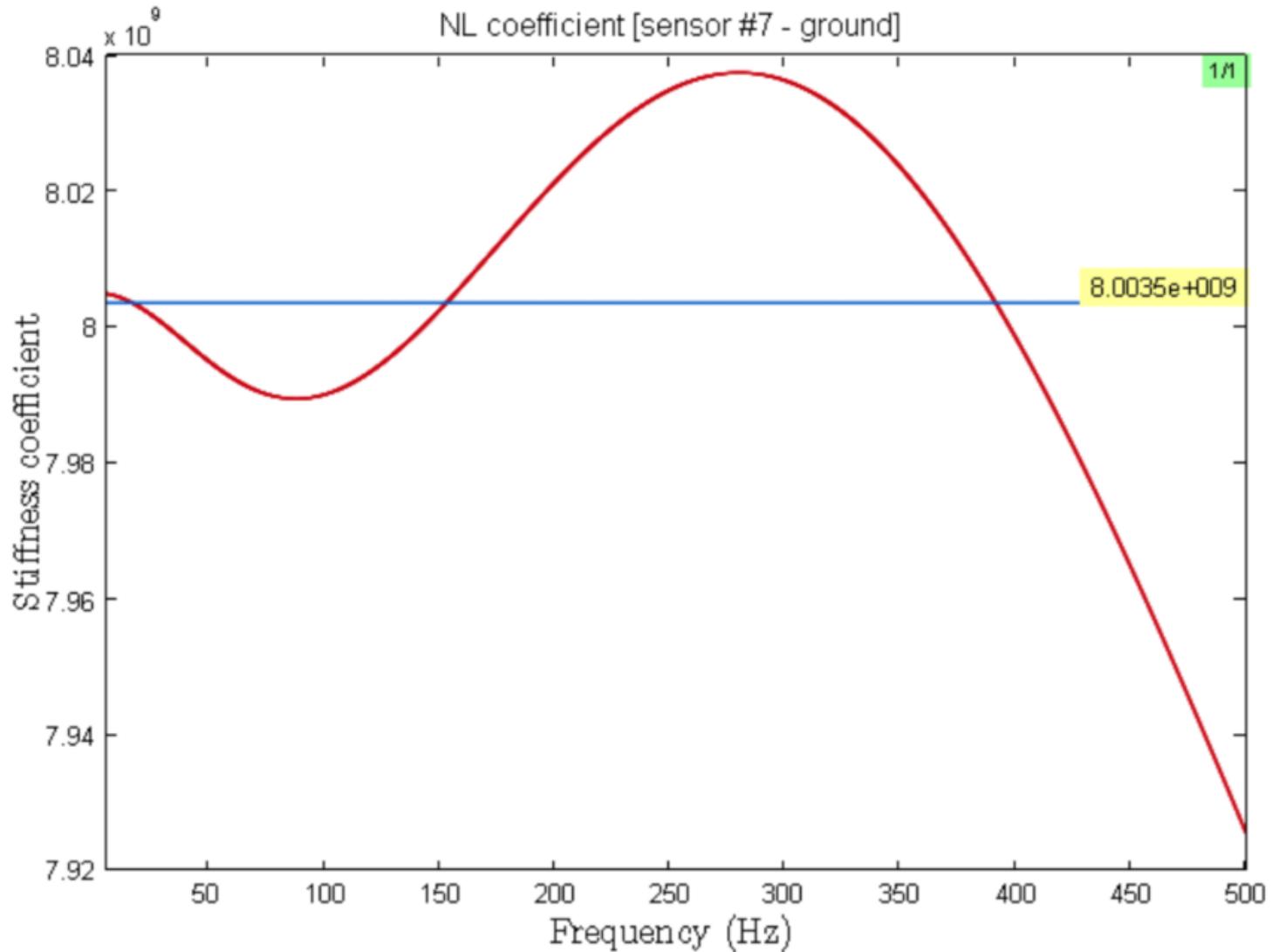
A few hints:

- ▶ Check the stabilisation of the first mode.
- ▶ Check the modal parameters compared to linear identification.
- ▶ Check the stability of the nonlinear coefficients versus frequency.
- ▶ Check the magnitude of the imaginary parts of the coefficients.

Accurate Nonlinear Stabilisation

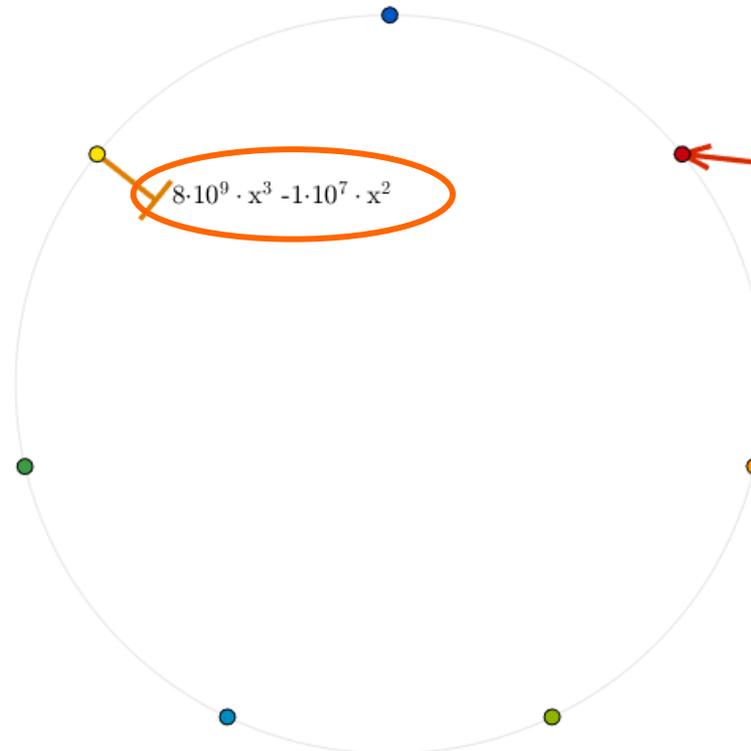


Nonlinear Coefficient with Virtually no Frequency Dependence



Successful Identification of the Nonlinear Coefficients

File Measure Identify Model User Help



Measure Identify Model User

Concluding Remarks and Learning Outcomes

- ▶ NI2D software makes the use of FNSI intuitive and effective (selection of nonlinear basis functions, stabilisation diagram, ...).
- ▶ Similar steps are followed to apply FNSI to linear and NL data.
- ▶ A successful characterisation remains of utmost importance towards accurately estimating model parameters.