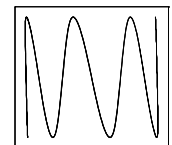
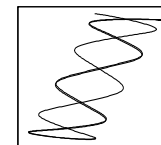
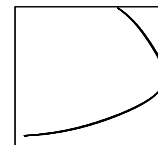
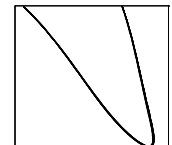
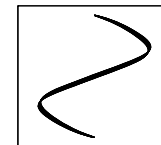
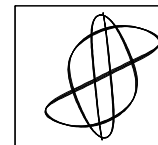
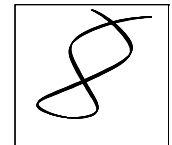
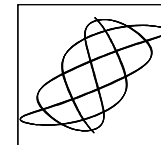
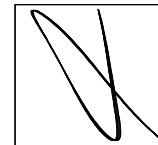


Nonlinear Vibrations of Aerospace Structures

T03

Nonlinear modal analysis

Nonlinear normal modes
Frequency-energy plot



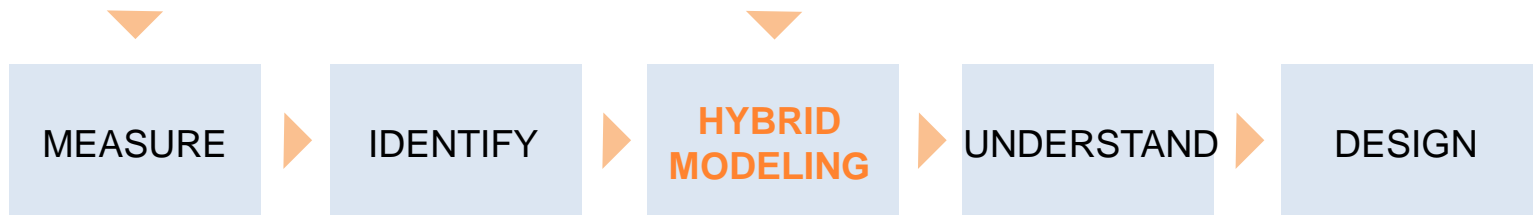
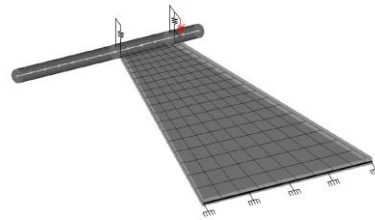
NI2D Philosophy

From measurements to design

VIBRATION
MEASUREMENTS



LINEAR FINITE
ELEMENT MODEL

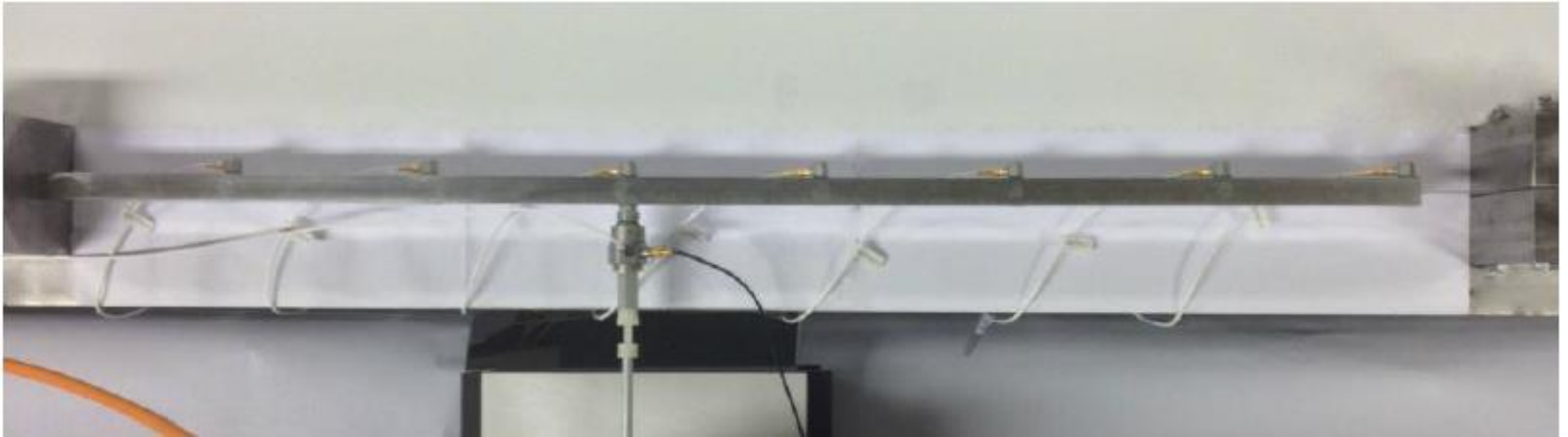


A priori knowledge about the nonlinearities is available:

Load the linear FEM into NI2D and implement the nonlinearities using NI2D elements library.

Tutorial 1: The First Mode of the Nonlinear Beam

The Nonlinear Beam



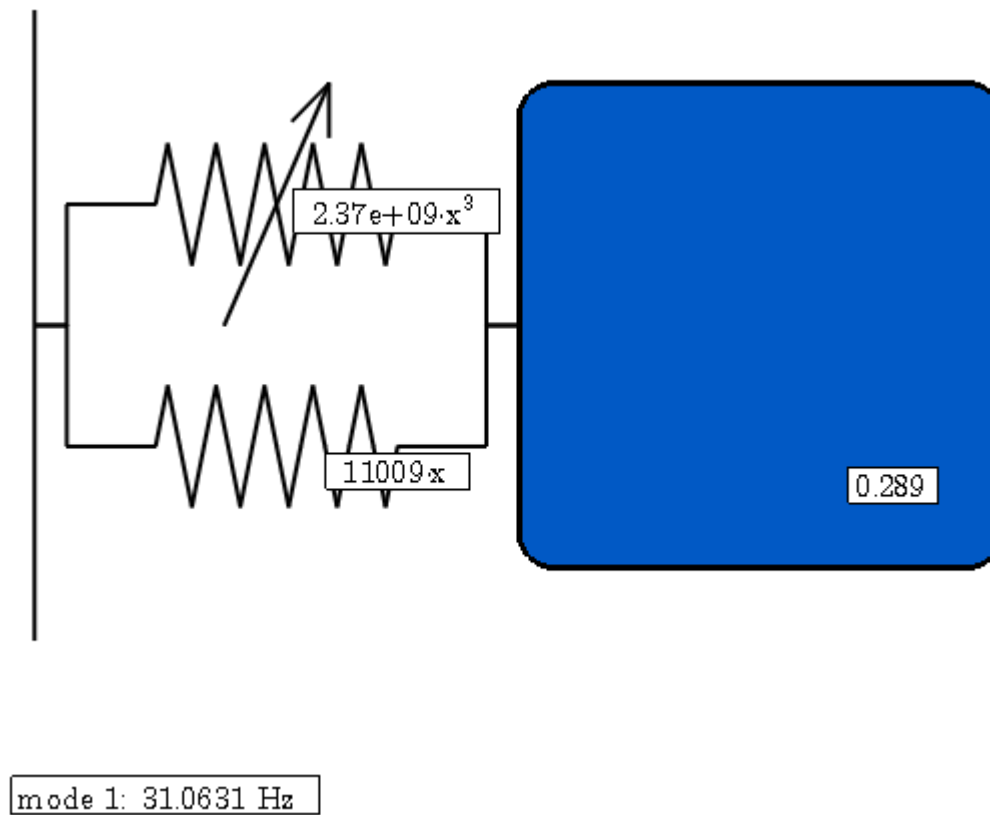
Linear model identified at low level (31 Hz, 0.12%):

$$0.289\ddot{x} + 0.1357\dot{x} + 11009x = F\sin\omega t$$

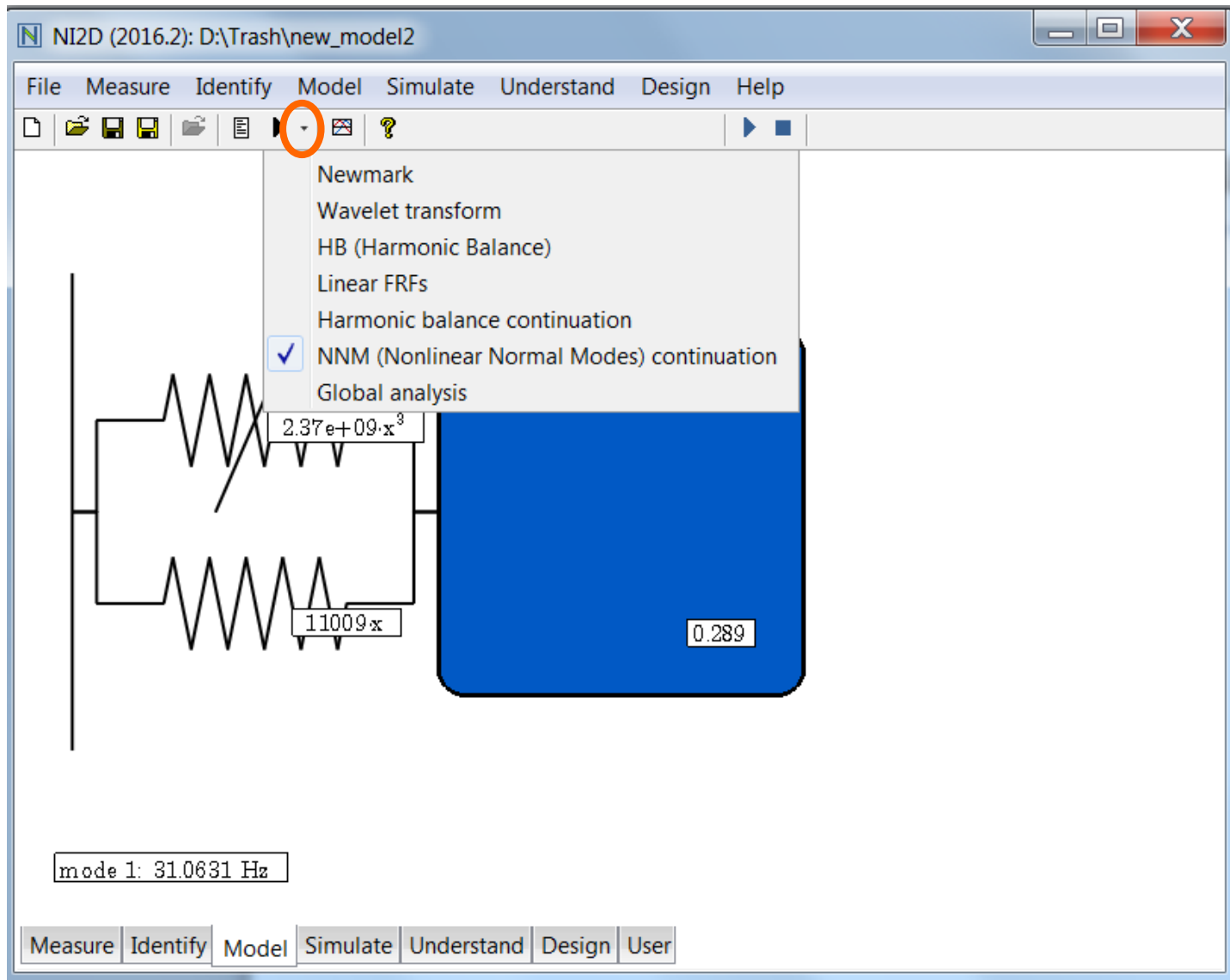
Nonlinearity identified at high level: $2.37 \cdot 10^9 x^3$

The Nonlinear Beam

No forcing, no damping



The NNM Solver



Set Appropriate Parameters

NI2D (2016.2): D:\Trash\new_model2

File Measure Identify Model Simulate Understand Design Help

2.37e+09.x³

11009x

mode 1: 31.0631 Hz

NNM continuation parameters

Starting point: 31.0631 Hz

☒ Hz

Min: 0 Hz

Max: Inf Hz

Direction: ☐ - ☒ +

☒ Stability ☐ Half-period ☒ Sensitivity analysis

☒ Adaptive

Stepsize: 1e-005

Min: 1e-006

Max: 10

Optimal number of iterations: 3

Max. number of iterations: 10

Precision: 1e-006

Maximum number of points: 20

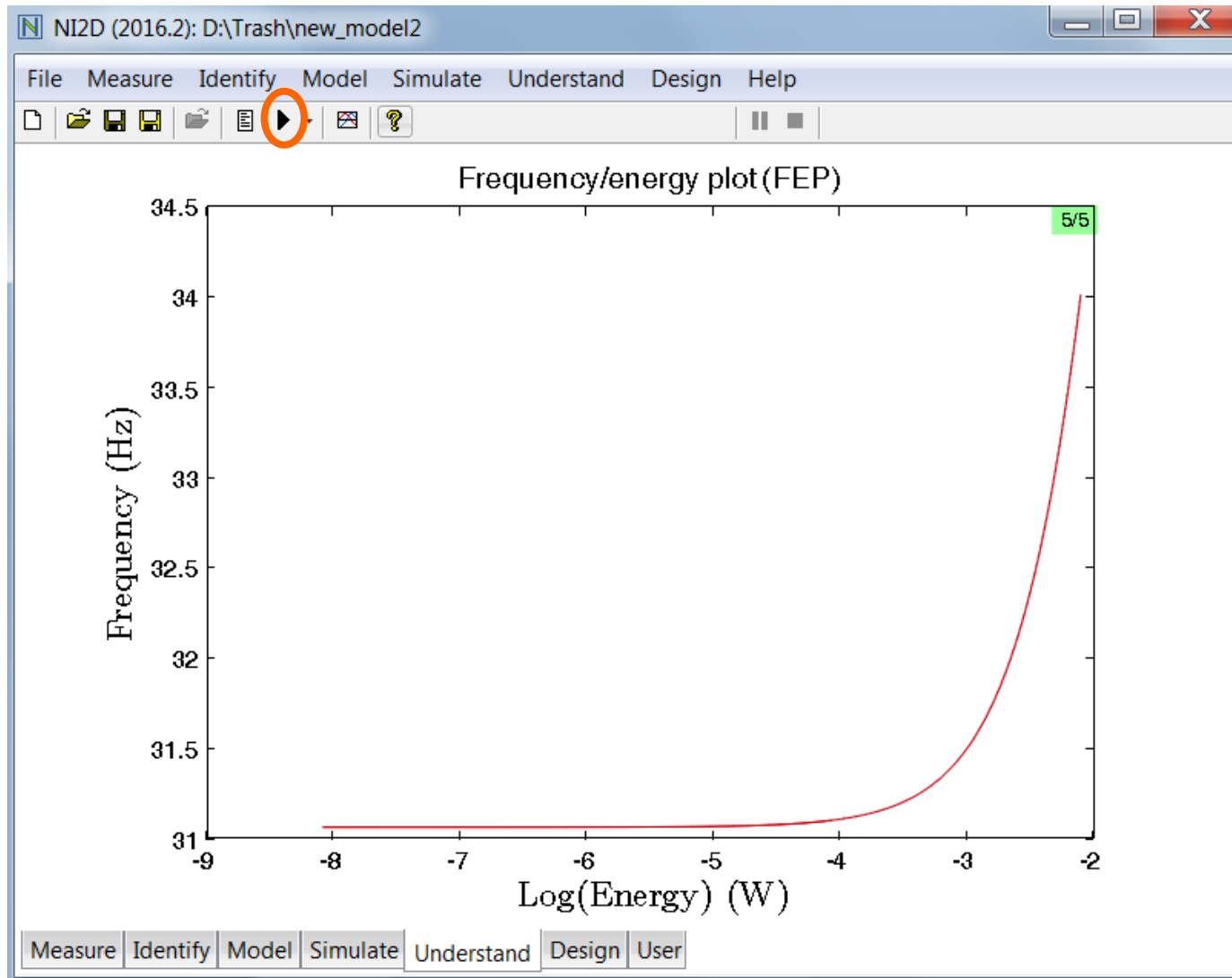
Beta max. angle: 90 °

Scaling factor: 0.0001

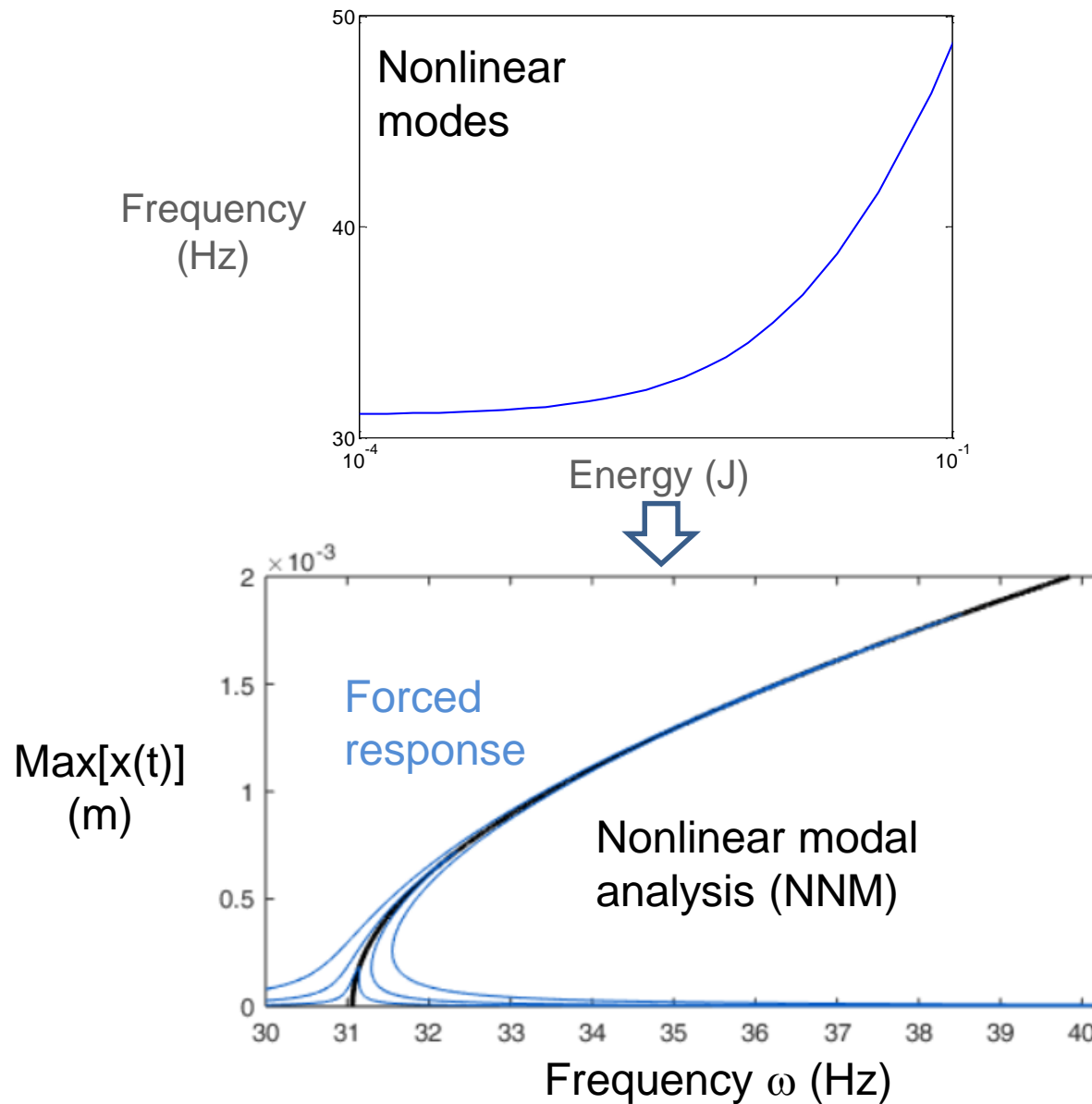
Number of points: 360

Newmark param... Apply Start Cancel

Compute The First Nonlinear Mode



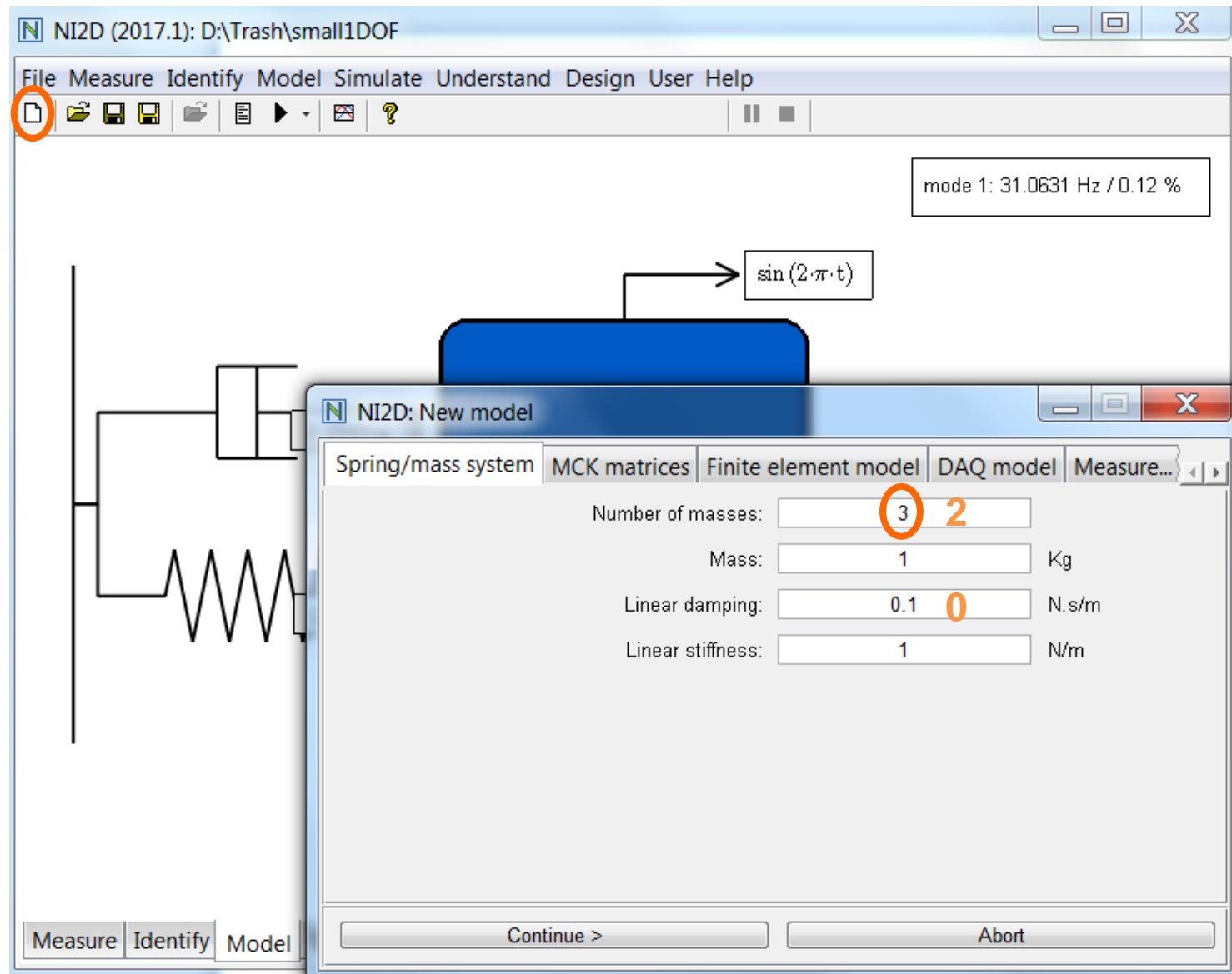
The Link Between Nonlinear Modes and FRFs



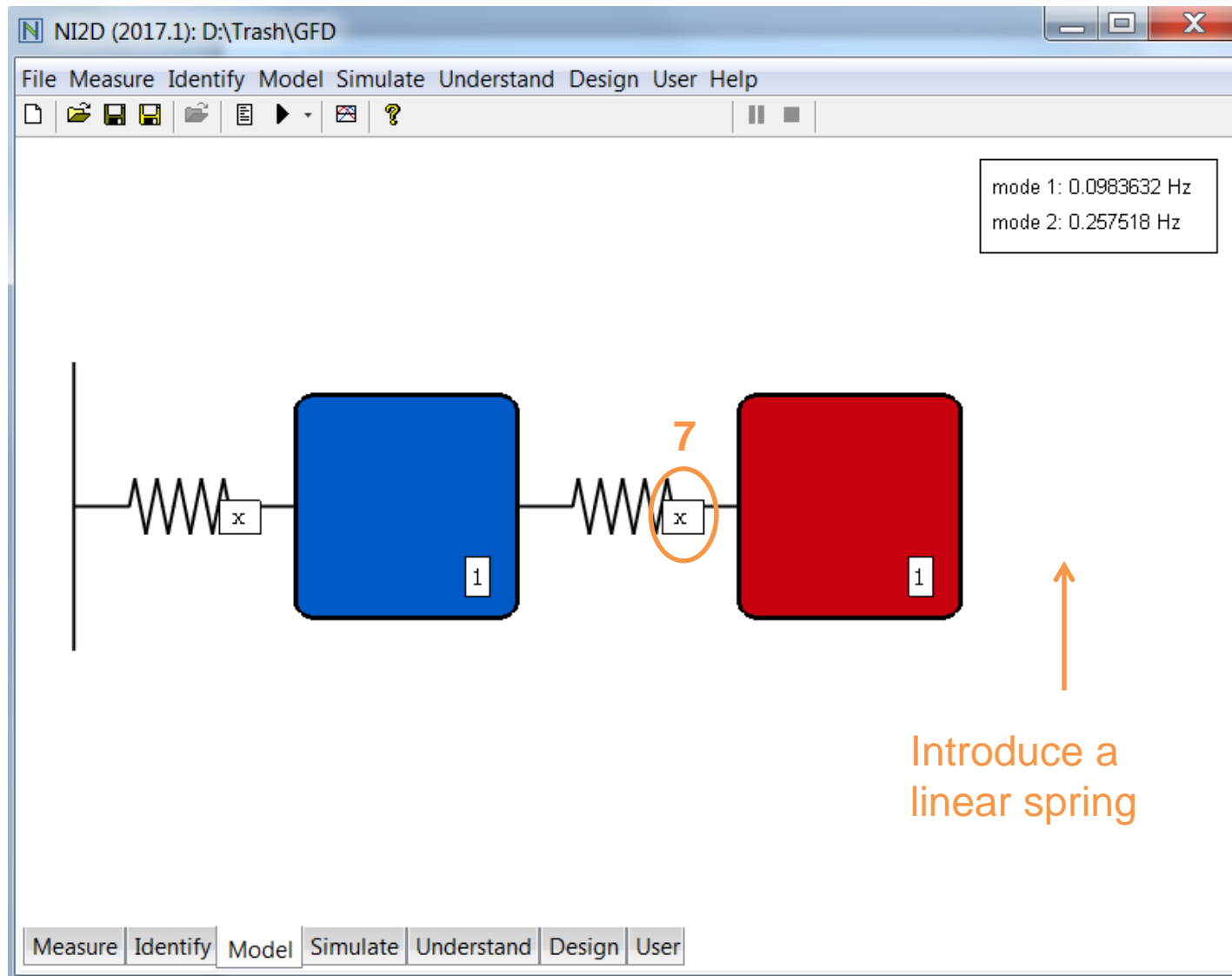
Concept of backbone curve !

Tutorial 2: The Modes of a Multi-DOF System

Create a 2-DOF Model

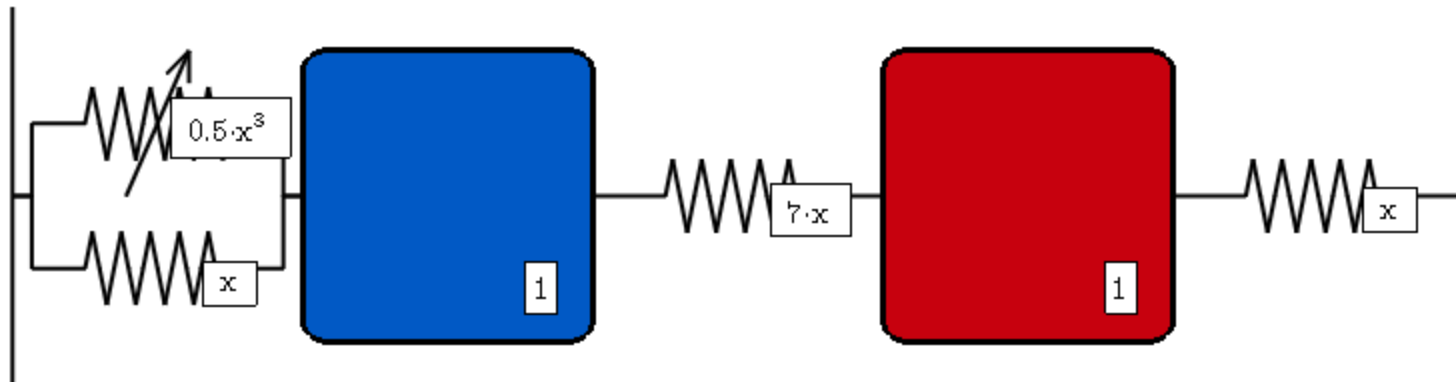


Modify the 2-DOF Model



The Final Model

mode 1: 0.159155 Hz
mode 2: 0.616404 Hz



In-Phase Mode: Set Appropriate Parameters

NNM continuation parameters

Starting point: 0.15915 Hz

☒ Hz

Min: 0 Hz

Max: Inf Hz

Direction: ☐ - ☒ +

☒ Stability ☐ Half-period ☒ Sensitivity analysis

Stepsize: 0.01

☒ Adaptive

Min: 1e-006

Max: 10

Optimal number of iterations: 3

Max. number of iterations: 10

Precision: 1e-006

Maximum number of points: 15

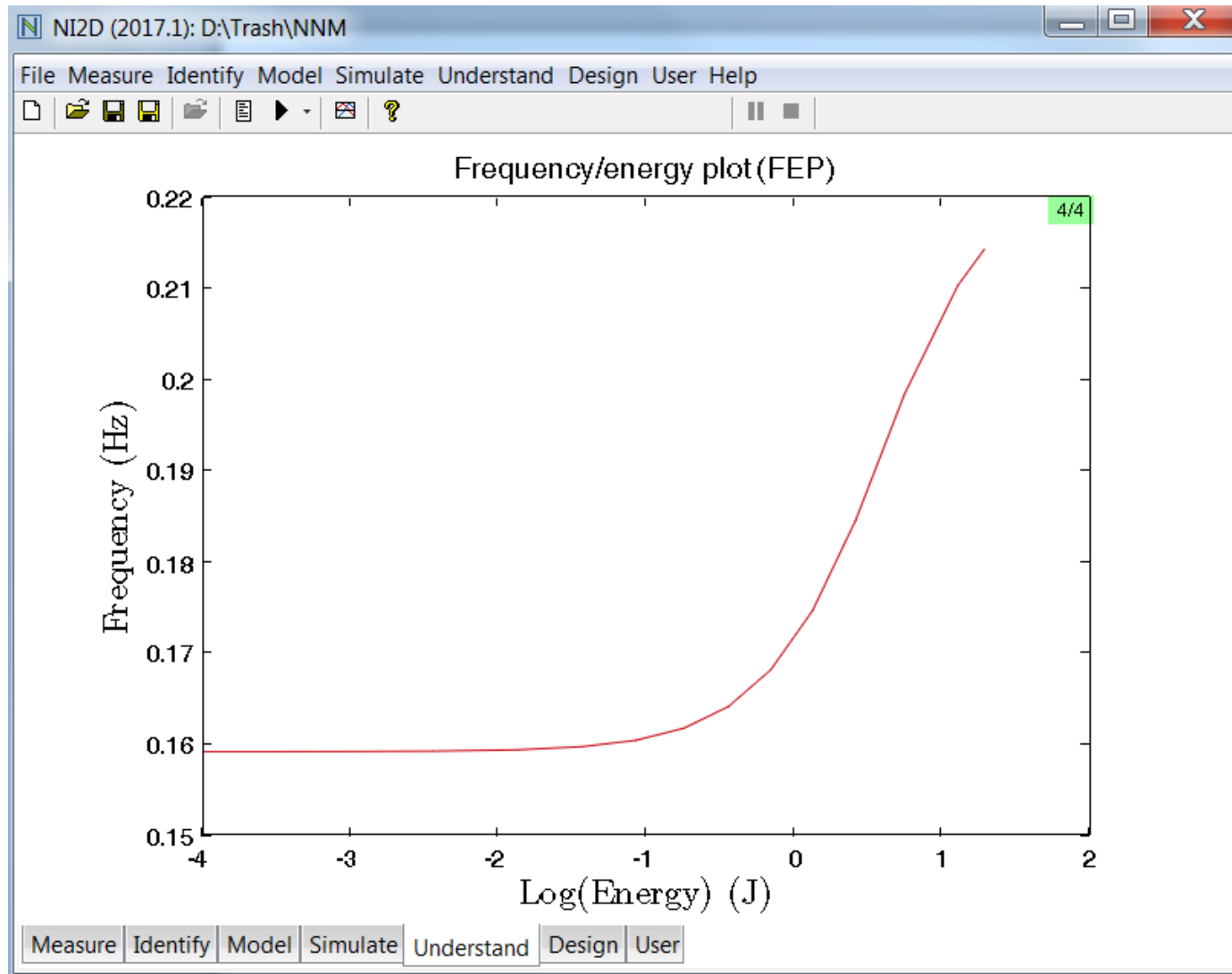
Beta max. angle: 90 °

Scaling factor: 0.0001

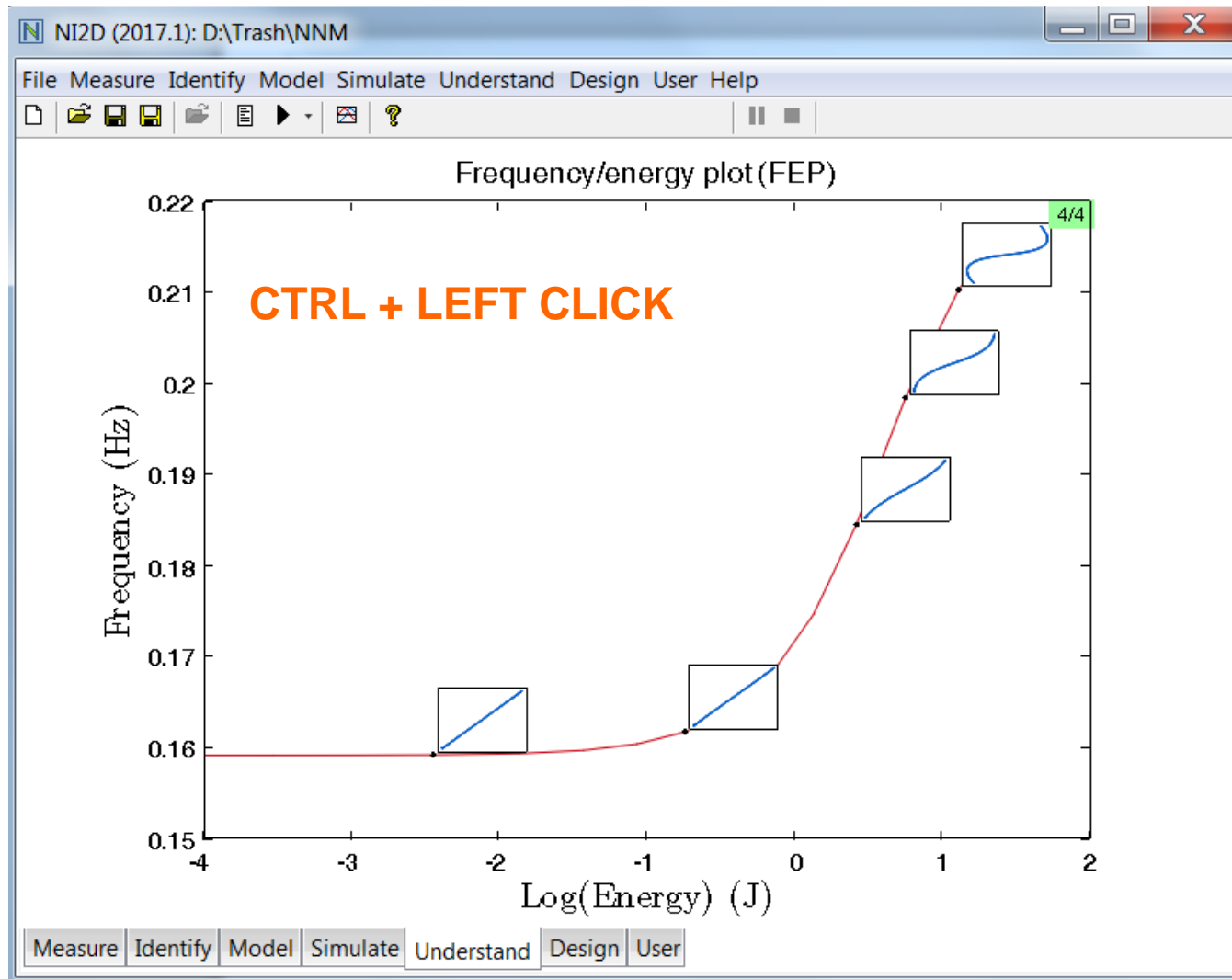
Number of points: 360

Newmark param... Apply Start Cancel

In-Phase Mode: The Resonance Frequencies

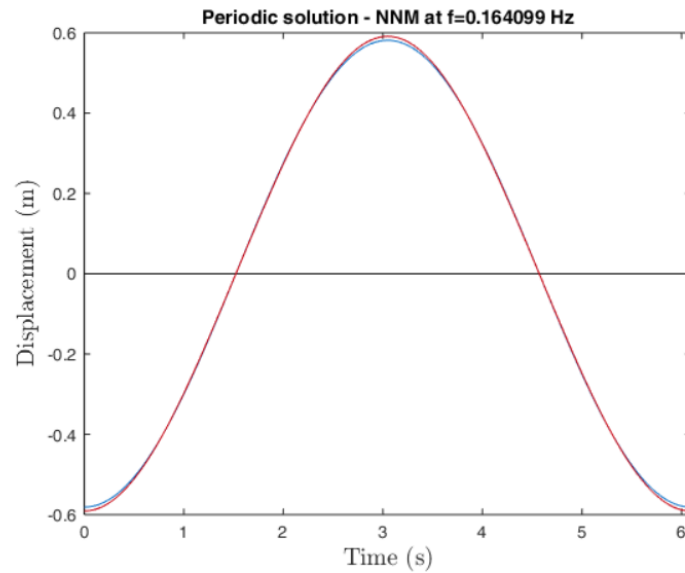


In-Phase Mode: The Modal Shapes

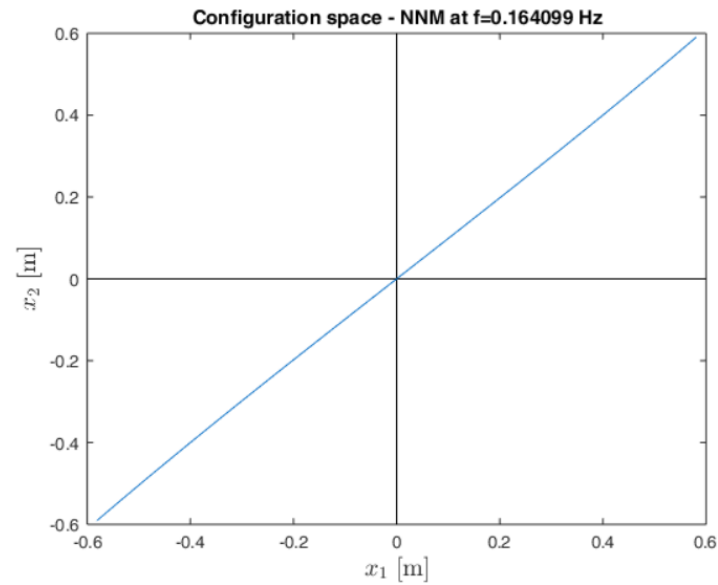


In-Phase Mode @ Low Energies

Nonlinear Normal Mode (type <?> for available keys)

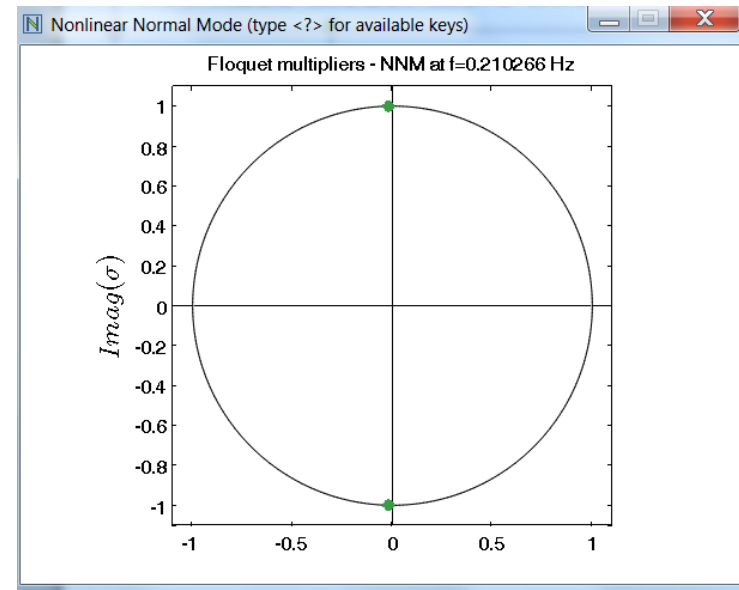
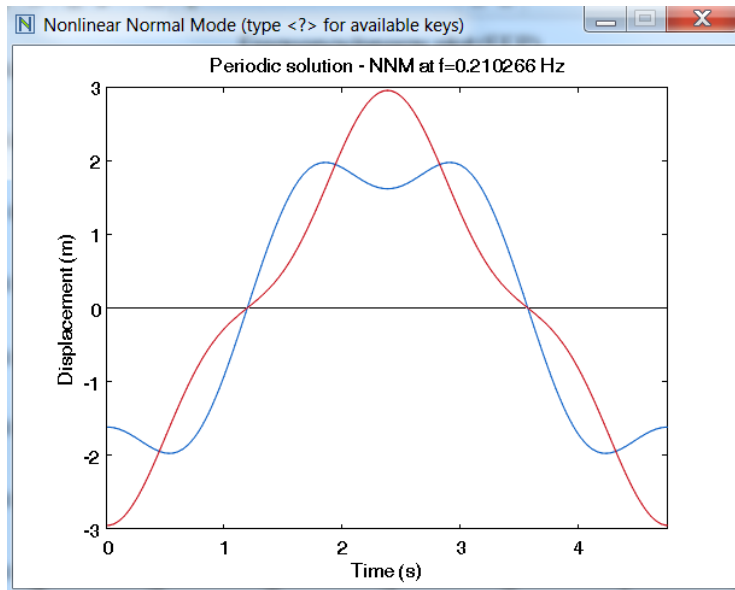


Nonlinear Normal Mode (type <?> for available keys)

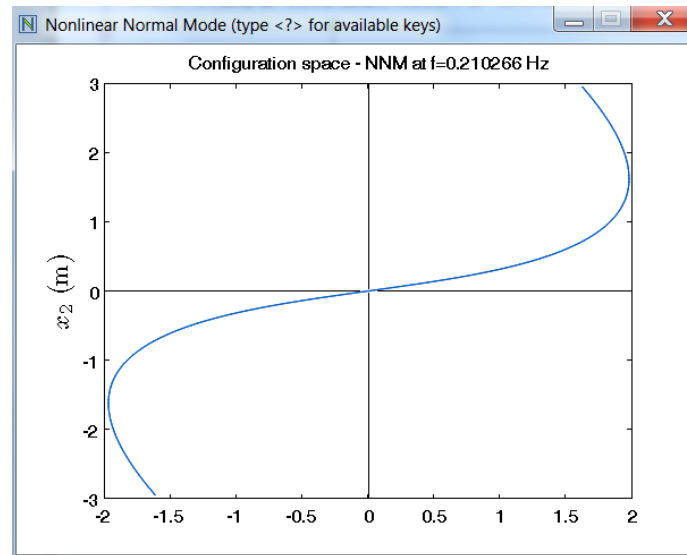


Double click + A

In-Phase Mode @ High Energies



Double click + A



THE MOTION IS NON SYNCHRONOUS !?

Out-of-Phase Mode: Set the Parameters

NNM continuation parameters

Starting point: 0.6164 Hz

☒ Hz

Min: 0 Hz

Max: Inf Hz

Direction: ☐ - ☒ +

☒ Stability ☐ Half-period ☒ Sensitivity analysis

Stepsize: 0.01

☒ Adaptative

Min: 1e-006

Max: 10

Optimal number of iterations: 3

Max. number of iterations: 10

Precision: 1e-006

Maximum number of points: 20

Beta max. angle: 90 °

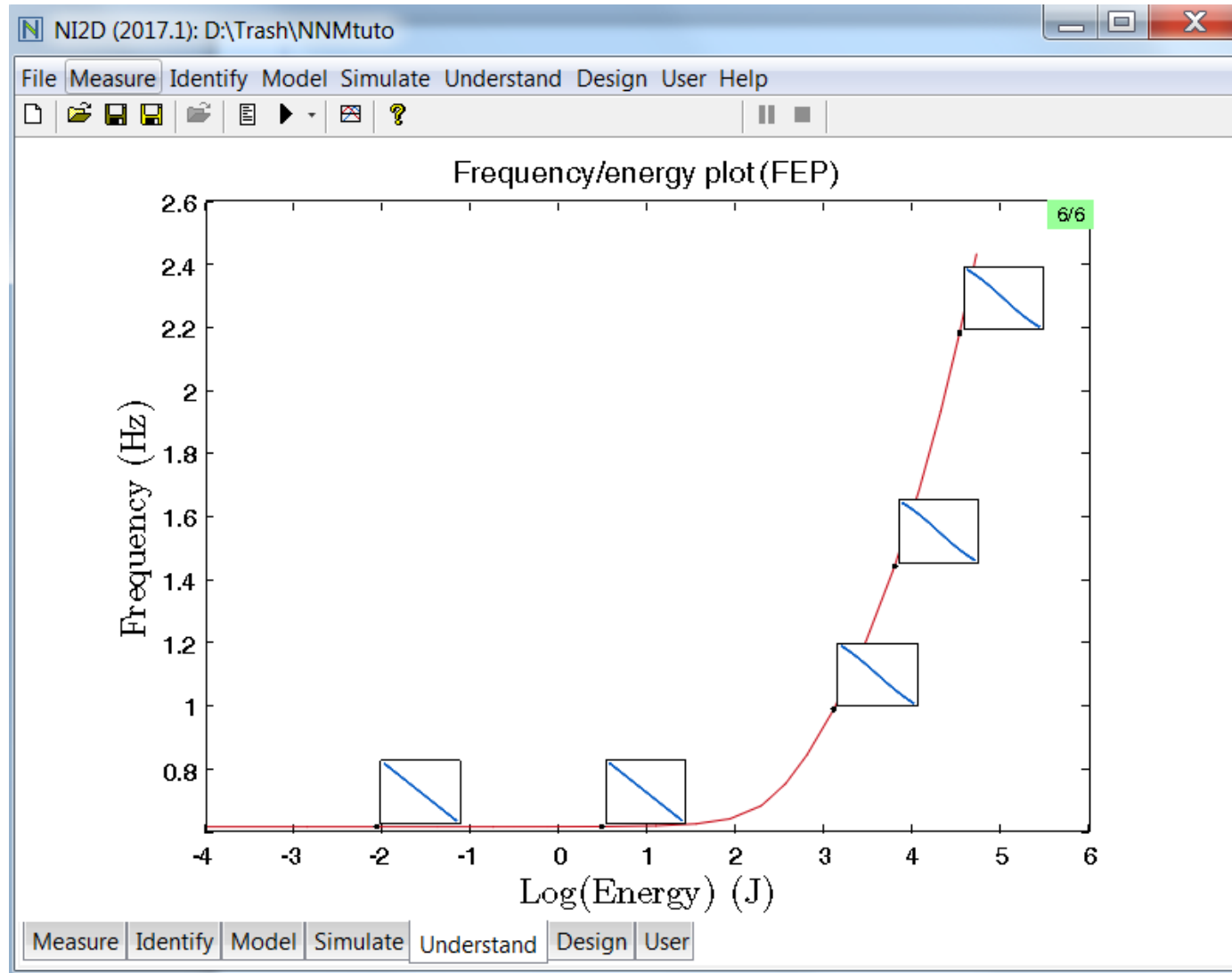
Scaling factor: 0.0001

Number of points: 360

Newmark param... Apply Start Cancel

Right click

Out-of-Phase Mode: Frequencies and Modal Shapes



Let's Go Back to the In-Phase Mode

NNM continuation parameters

Starting point: 0.15915 Hz

☒ Hz

Min: 0 Hz

Max: Inf Hz

Direction: ☐ - ☒ +

☐ Stability ☐ Half-period ☒ Sensitivity analysis

Stepsize: 0.01

☒ Adaptive

Min: 1e-06

Max: 10

Optimal number of iterations: 3

Max. number of iterations: 10

Precision: 1e-06

Maximum number of points: 50

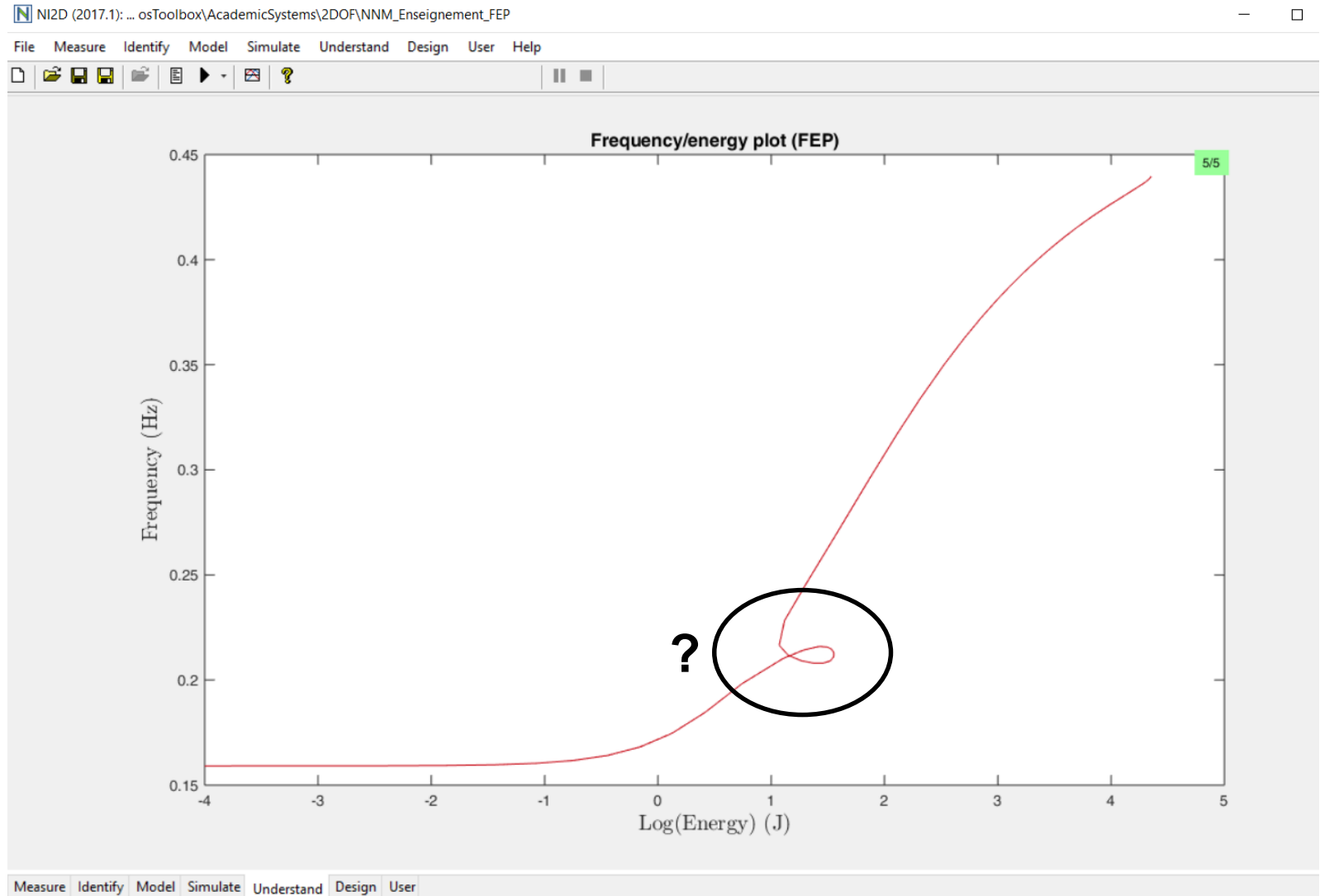
Beta max. angle: 90 °

Scaling factor: 0.0001

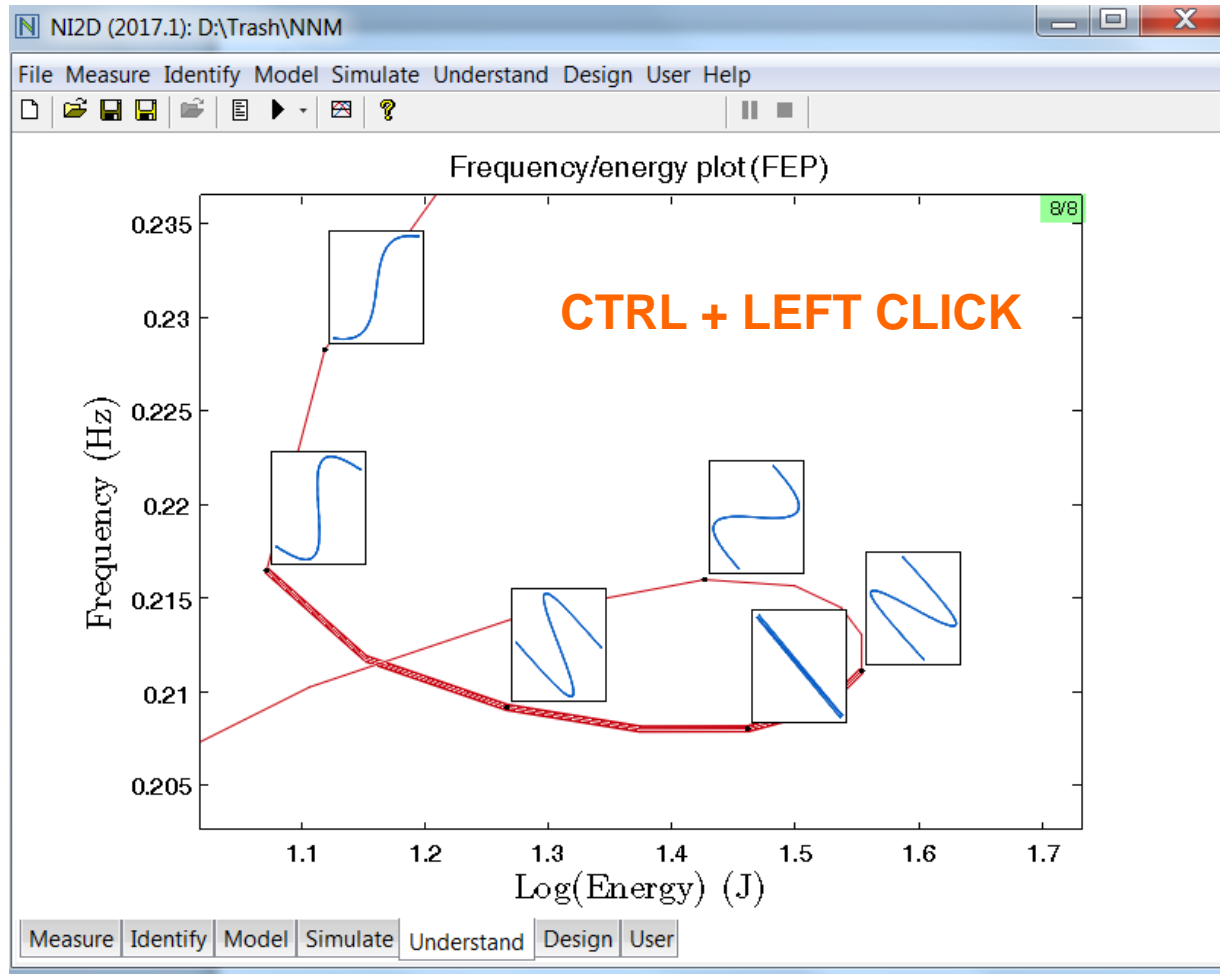
Number of points: 360

Right click
for mode 2

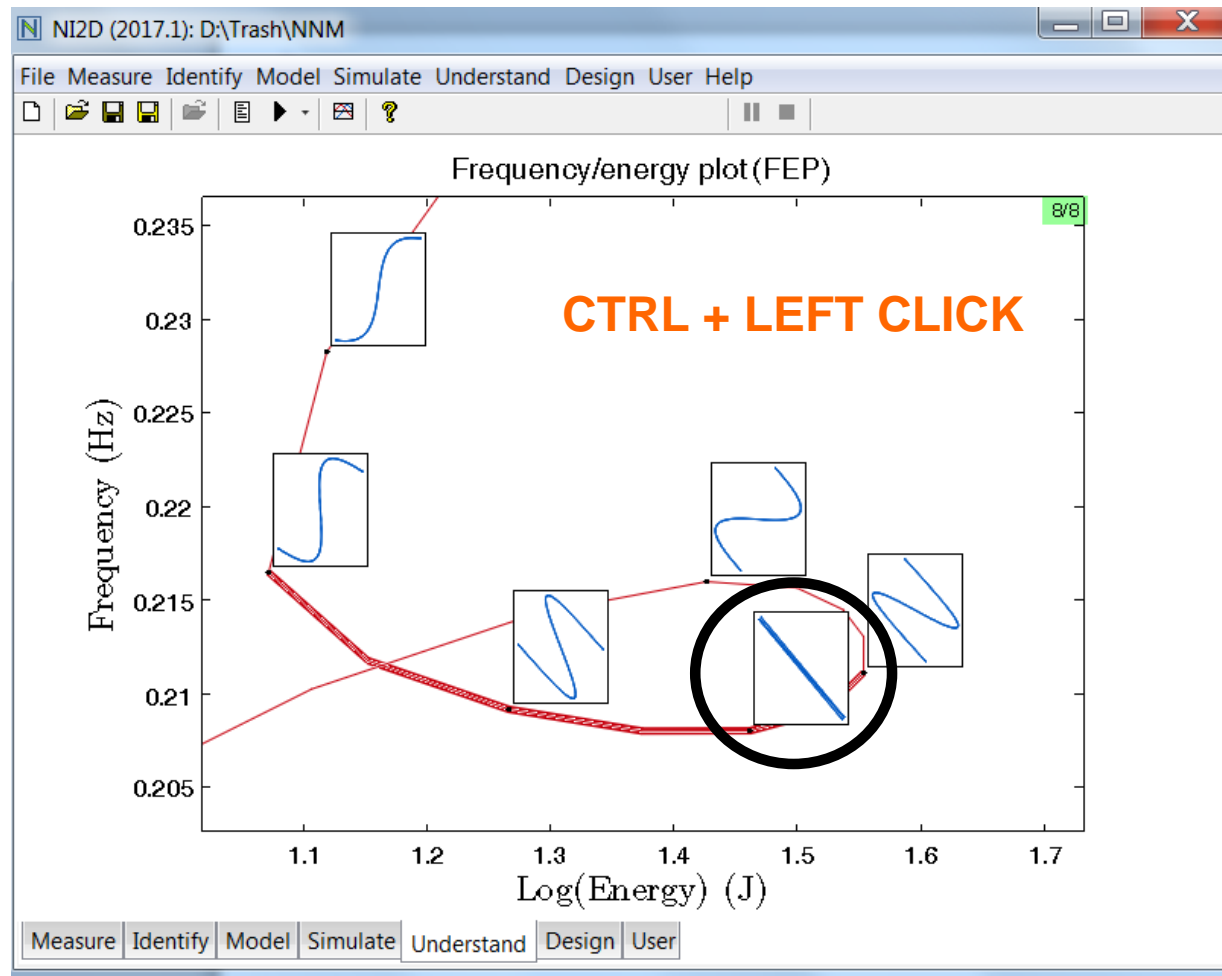
One New Feature !



Zoom Around the Loop



In-Phase and Out-of-Phase NNMs “Connected” !



Let's Go Even Further

NNM continuation parameters

Starting point: 0.15915 Hz

☒ Hz

Min: 0 Hz

Max: Inf Hz

Direction: ☐ - ☒ +

☐ Stability ☐ Half-period ☒ Sensitivity analysis

Stepsize: 0.01

☒ Adaptive

Min: 1e-06

Max: 10

Optimal number of iterations: 3

Max. number of iterations: 10

Precision: 1e-06

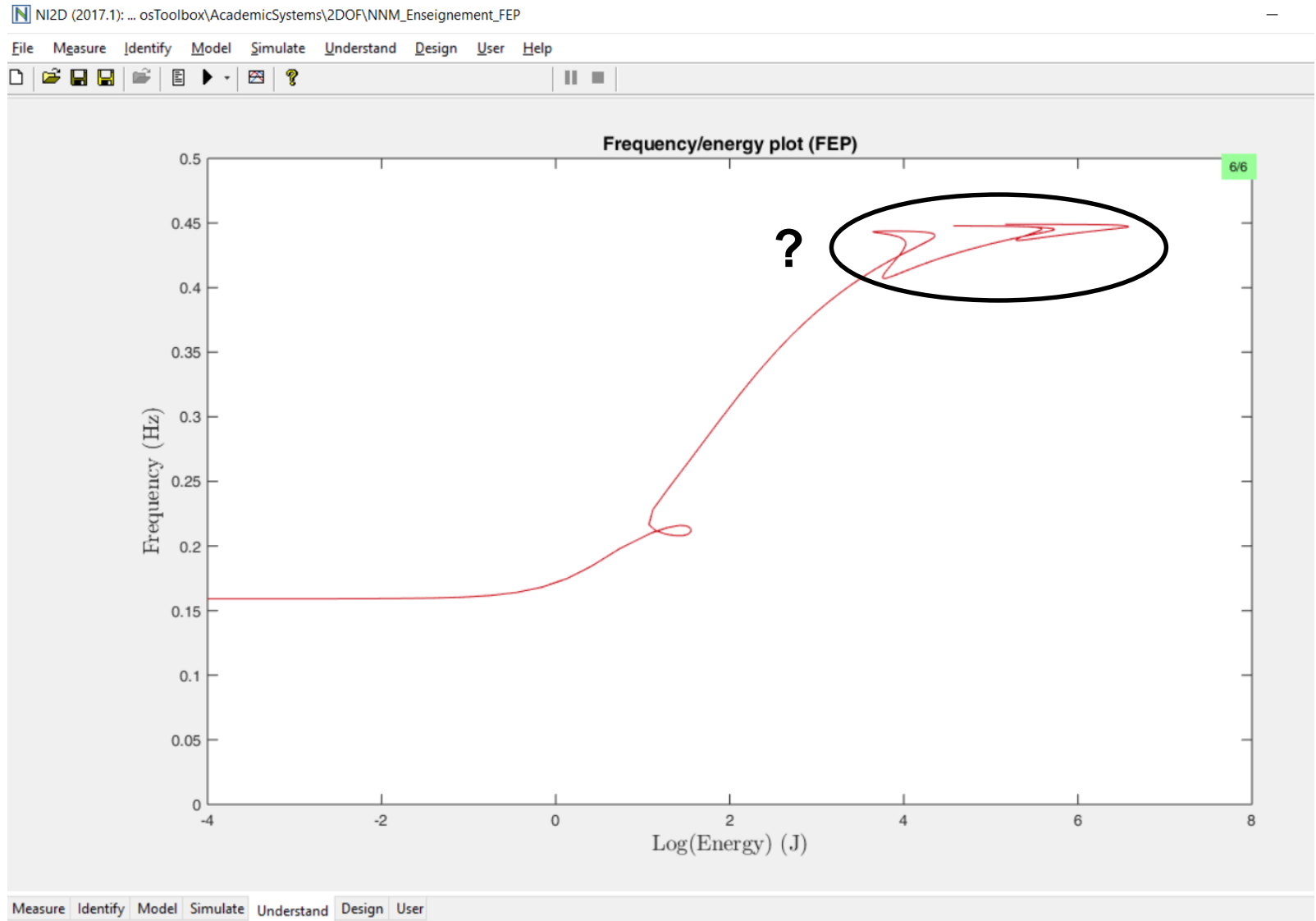
Maximum number of points: 500

Beta max. angle: 90 °

Scaling factor: 0.0001

Number of points: 360

Additional Loops



Zoom Around the Loops

