
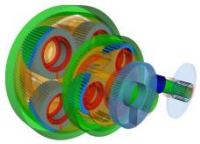


SIMULIA 3DEXPERIENCE Conference
Design, Modeling and Simulation

OTraPArTe: Order Analysis and Identification of Critical Transfer Paths in Drive Trains

Darmstadt, Germany, 20.11.2019

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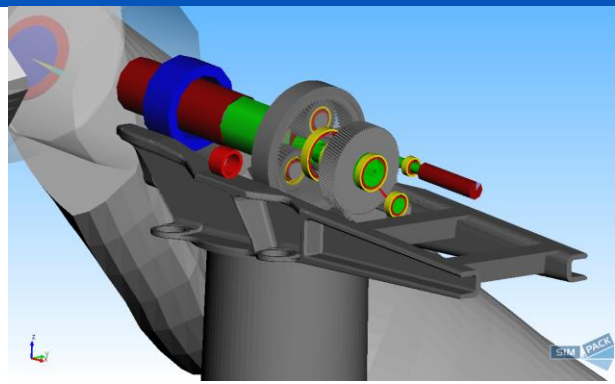
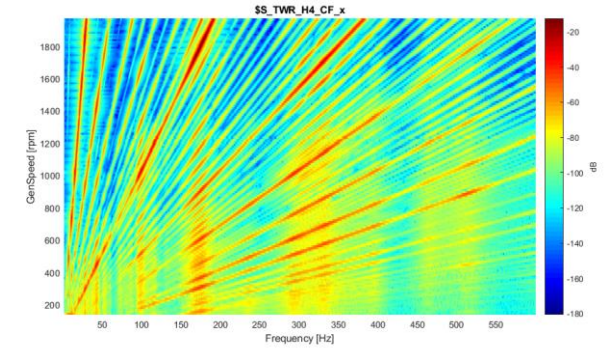
MəsH ENGINEERING TEAM

Overview

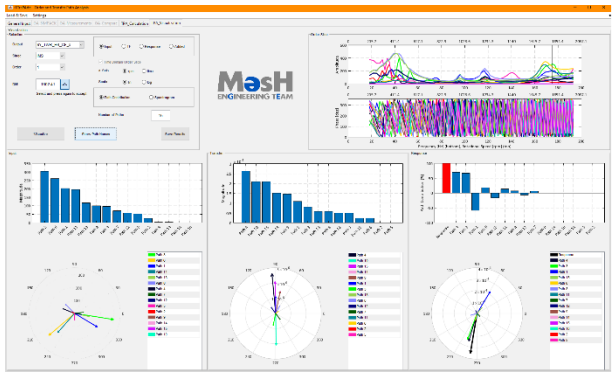
1. **Introduction - Vibration in rotating machinery**
   - What are the problems?
   - Where do they come from?



2. **Identification of vibrations and their sources**
   - Order Analysis with OTraParTe



3. **Understanding the transfer path of a vibration**
   - Transfer Path Analysis with OTraParTe



4. **Conclusion**

1 Introduction – Vibrations in rotating machinery

Speed-dependant excitations

- Gears
- Motors
- Generators

Transmission via all connected components

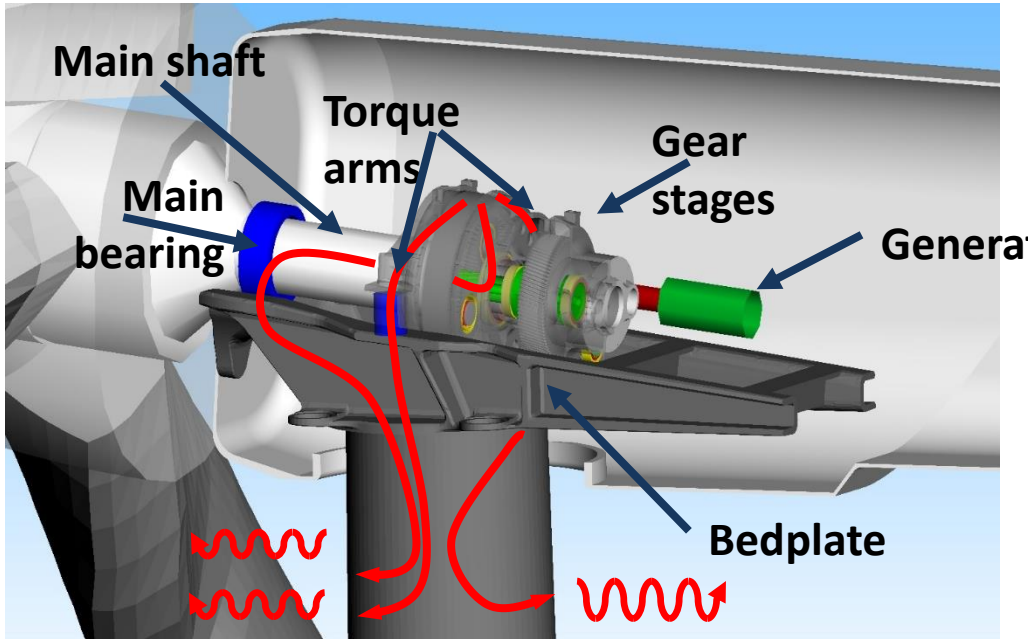
- Shafts
- Bearings
- Support structure

Dynamic loads

- Fatigue

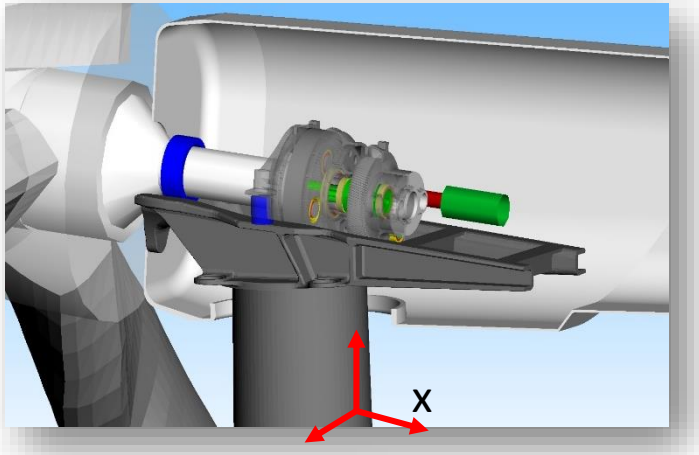
Vibration of radiating surfaces

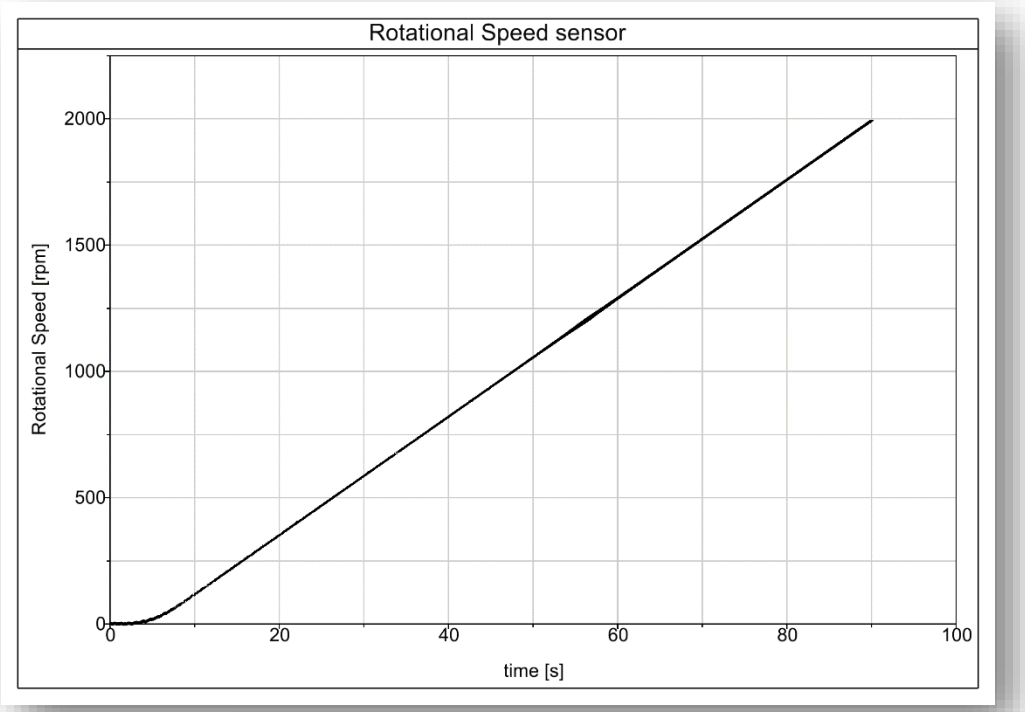
- Audible noise

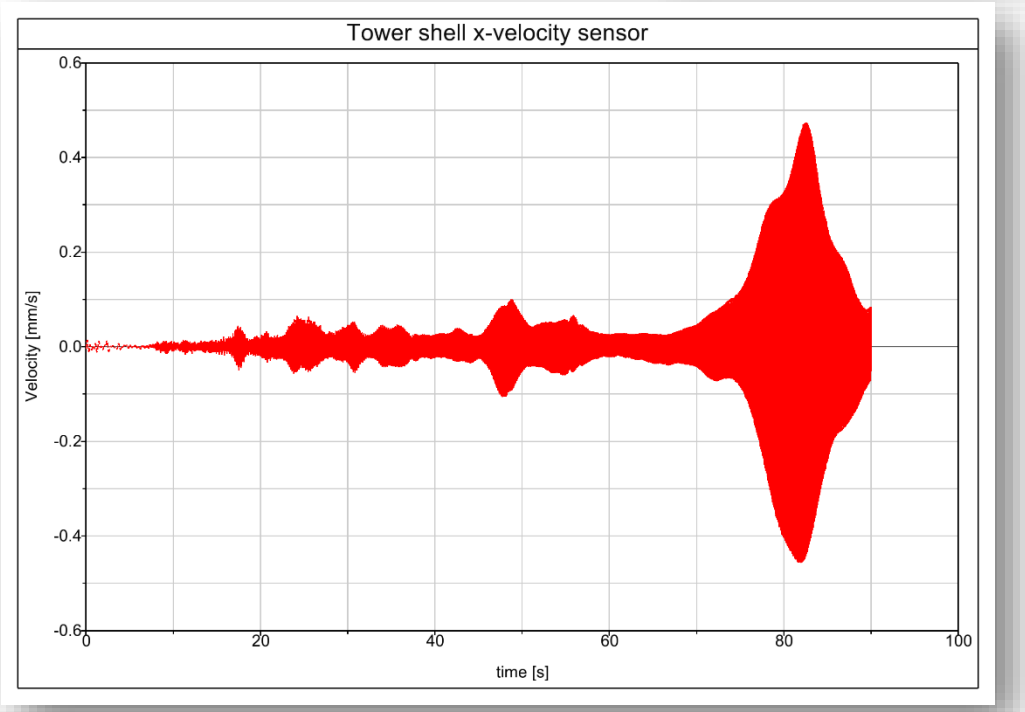


2 Identification of vibrations and their sources

- **Simpack model of complete wind turbine**
  - Time-Domain Simulation
    → Run-Up in complete operating range
  - Gearbox consisting of three gear stages
  - Measurement of vibration with velocity sensors at tower surface



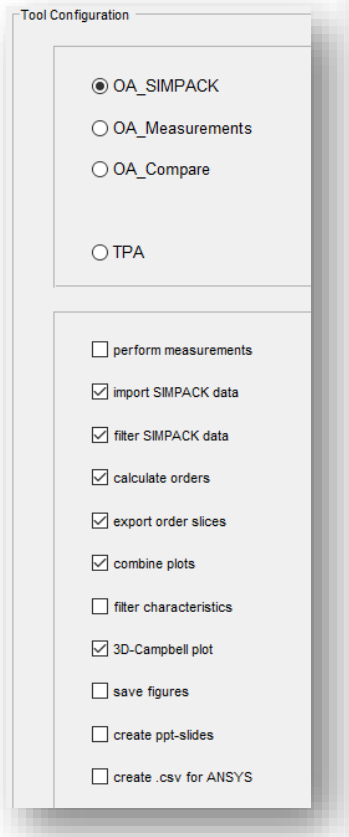


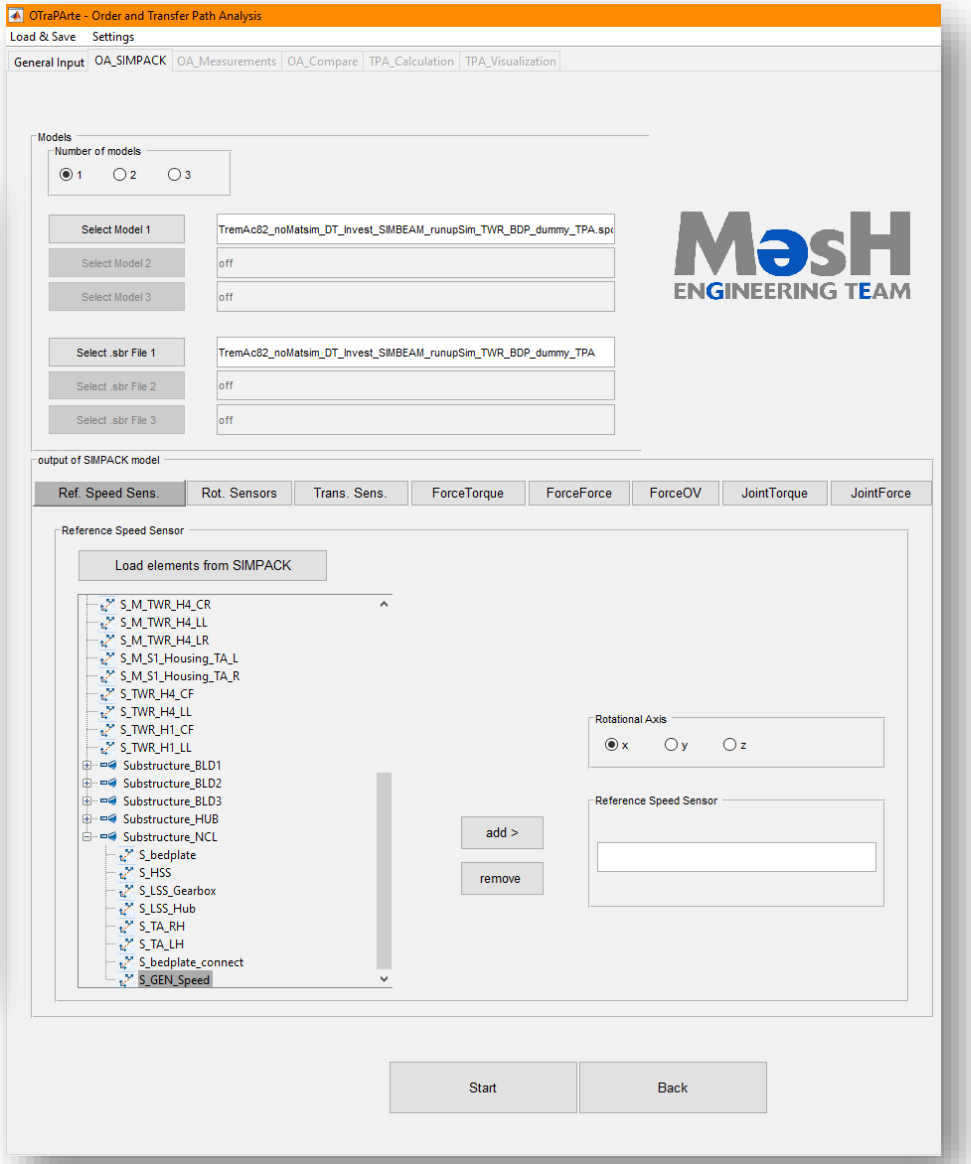


2 Identification of vibrations and their sources - OTraParTe

OTraParTe: Order Analysis features

- Simpack Time Domain Results
  or physical measurement data
  - Comparison of up to 3 models
  - Selection of elements from Simpack model
  - Calling Simpack measurement
  - Filtering of data
  - FFT of data
  - Visualization & Export of 2D order diagrams and 3D-Campbell plots
  - Automatic creation of Power Point slides
  - Automatic creation of ANSYS-readable .csv files with interface loads

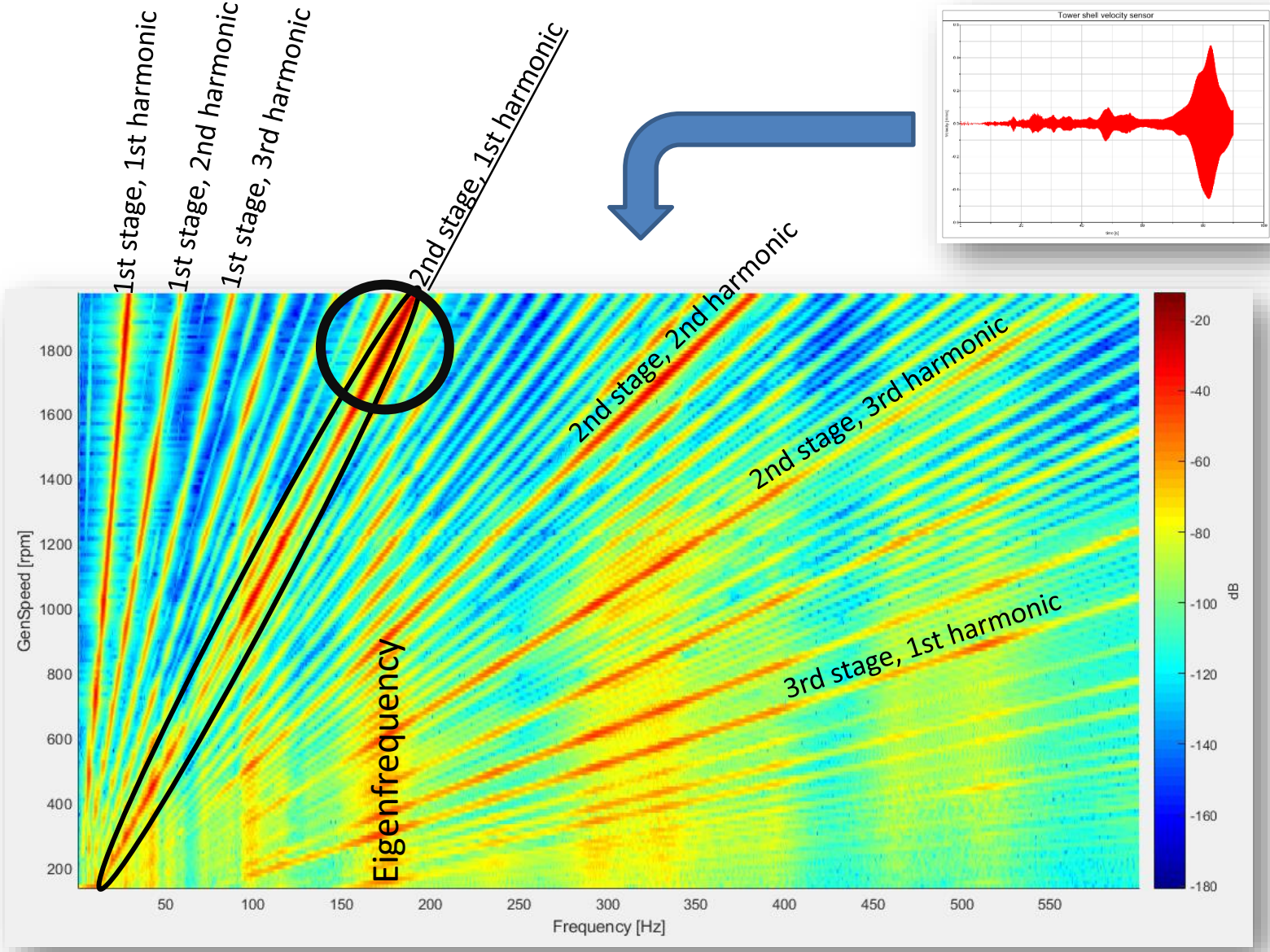




2 Identification of vibrations and their sources - OTraParTe

3D – Campbell Plot

- Frequency of response peaks is proportional to frequency of rotation
  - E.g. 2nd stage order: **5.8333**
- Skewed lines are the „order slices“
- For every gear stage there are multiple order slices → Harmonics
- Vertical distributions of amplitudes are eigenfrequencies
- Hot Spots are usually resonances → Avoid!

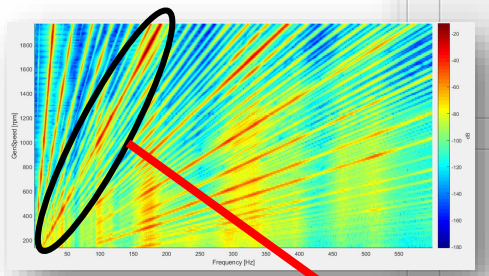


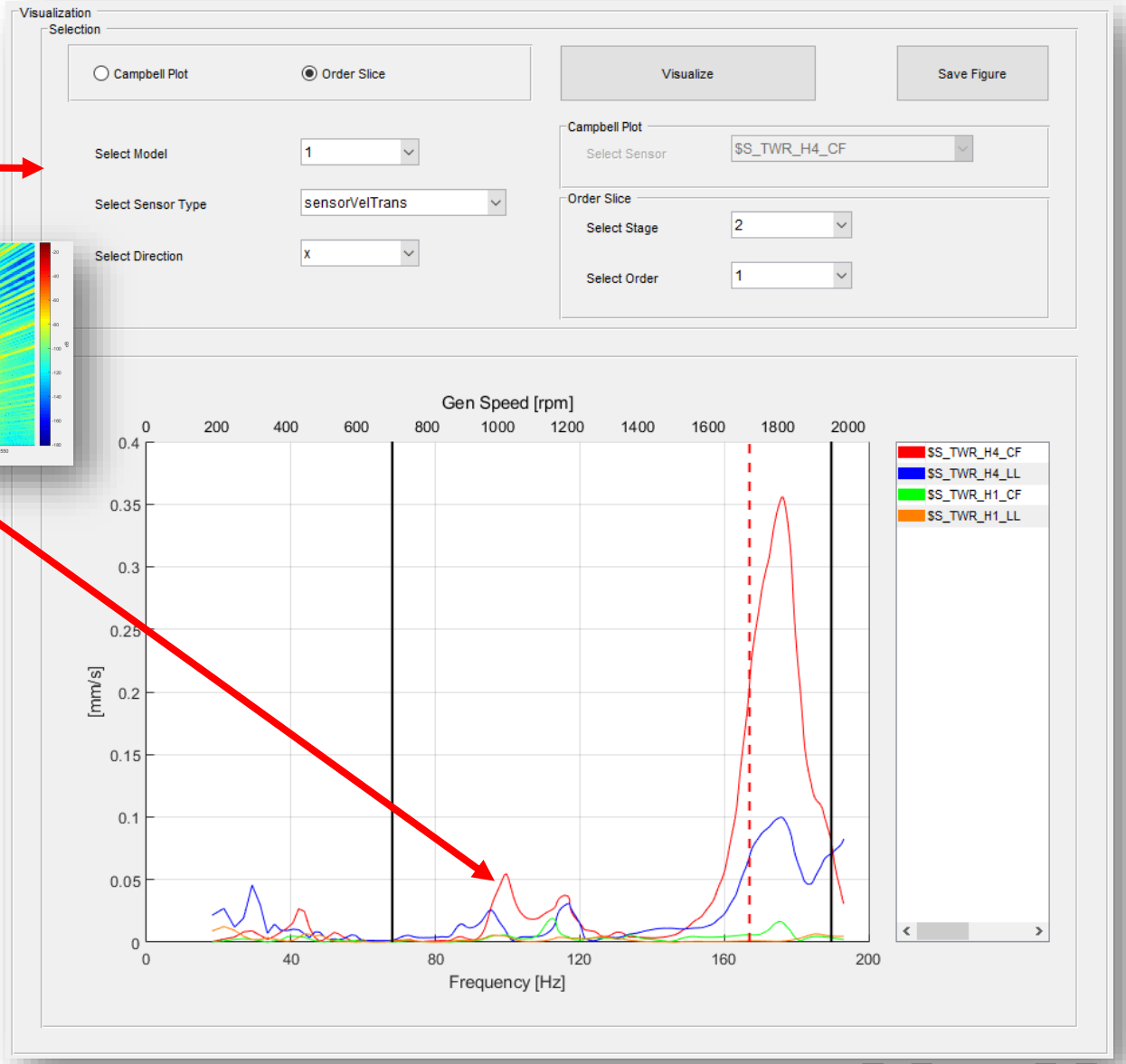
Resonant vibration identified on tower surface at 175Hz, excited by 2nd stage gear

2. Identification of vibrations and their sources - OTraParTe

2D – Order slice

- Selection of gearbox stage and order, sensor type and direction
- Extraction of sloped line from 3D -Campbell plot
- Comparison of multiple sensors
- Operating range and nominal speed also shown

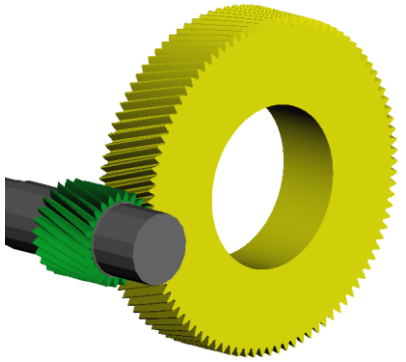




At a speed of 1800rpm we find the resonance with an amplitude of 0.35mm/s

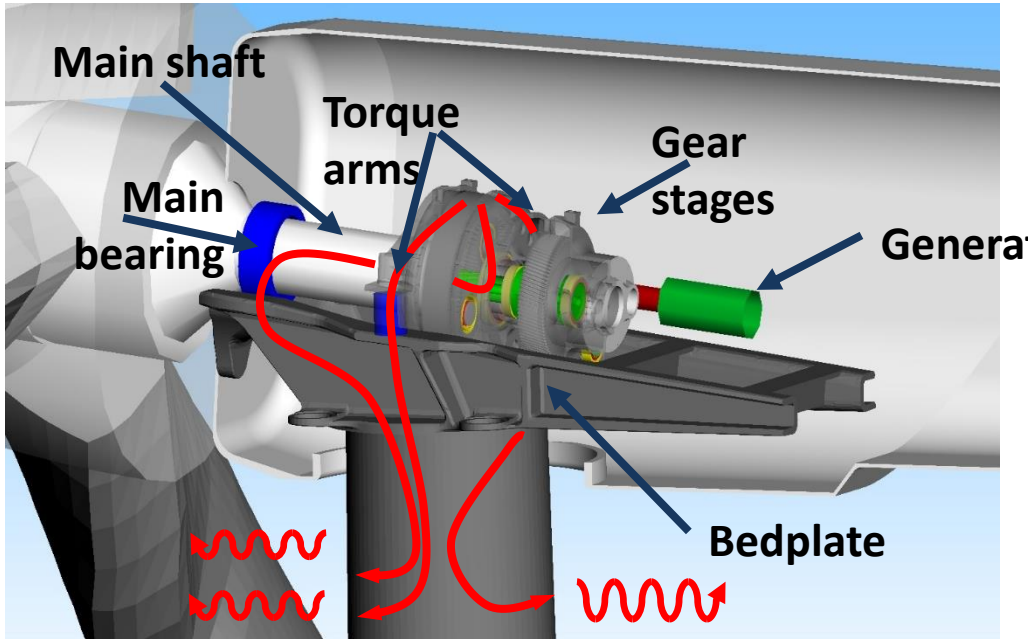
2 Identification of vibrations and their sources

Source - Path - Receiver



- **We found which „source“ is responsible for the resonant vibration**
  - But what now?
- **Minimizing or shifting the excitation…**
  - Changing macrogeometry of gears
  - Changing microgeometry of gears

  … is always preferable

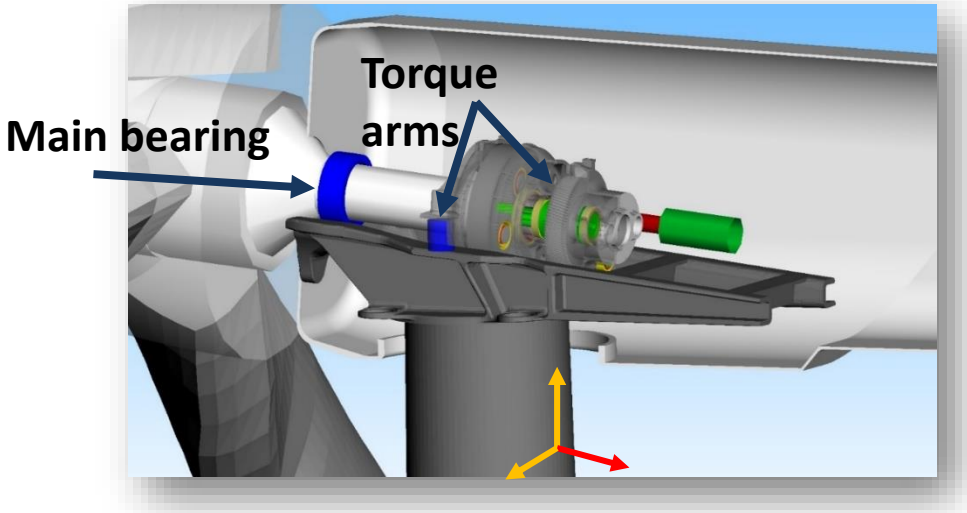


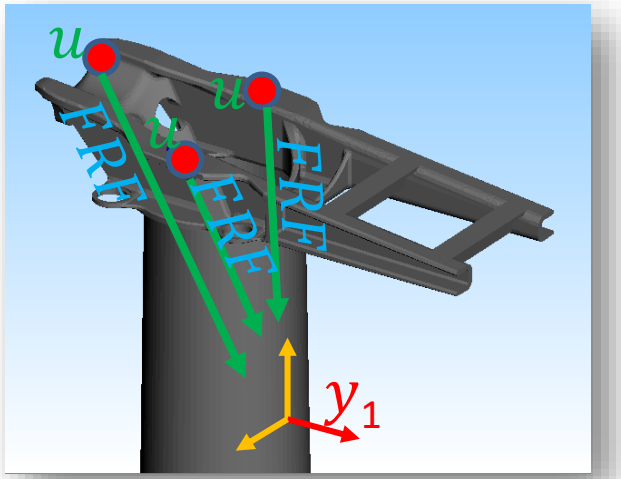
- **But if you want to analyze the path a vibration takes to a receiver?**

→ **Transfer Path Analysis**

3 Understanding the transfer path of a vibration

- **What is a transfer path?**
  - Transfer path: Every possible connection
    Source → Interface → Receiver
  - Definition of interfaces between the active parts (sources) and the passive parts
- **What do we need to do a Transfer Path Analysis?**
  - u: **Forces & Torques** transmitted at the interfaces
    Here: 3 interfaces with 3 forces, 2 torques each
    → u has 15 components
  - The FRF (Frequency Response Functions) are obtained from Simpack Linear System Analysis





$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} = \begin{bmatrix} y_{11} + y_{12} + \cdots + y_{1k} \\ y_{21} + y_{22} + \cdots + y_{2k} \\ \vdots \\ y_{n1} + y_{n2} + \cdots + y_{nk} \end{bmatrix} = \begin{bmatrix} FRF_{11} & FRF_{12} \dots & FRF_{1k} \\ FRF_{21} & FRF_{22} \dots & \vdots \\ \vdots & \vdots & \vdots \\ FRF_{n1} & \dots & FRF_{nk} \end{bmatrix} * \begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_k \end{bmatrix}$$

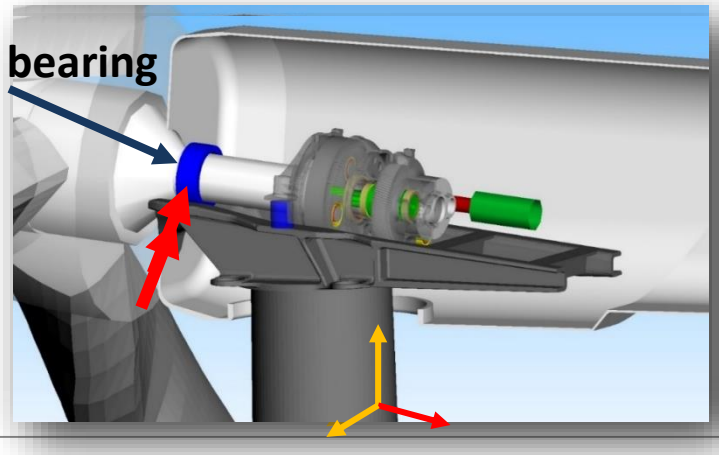
- Components of the total response

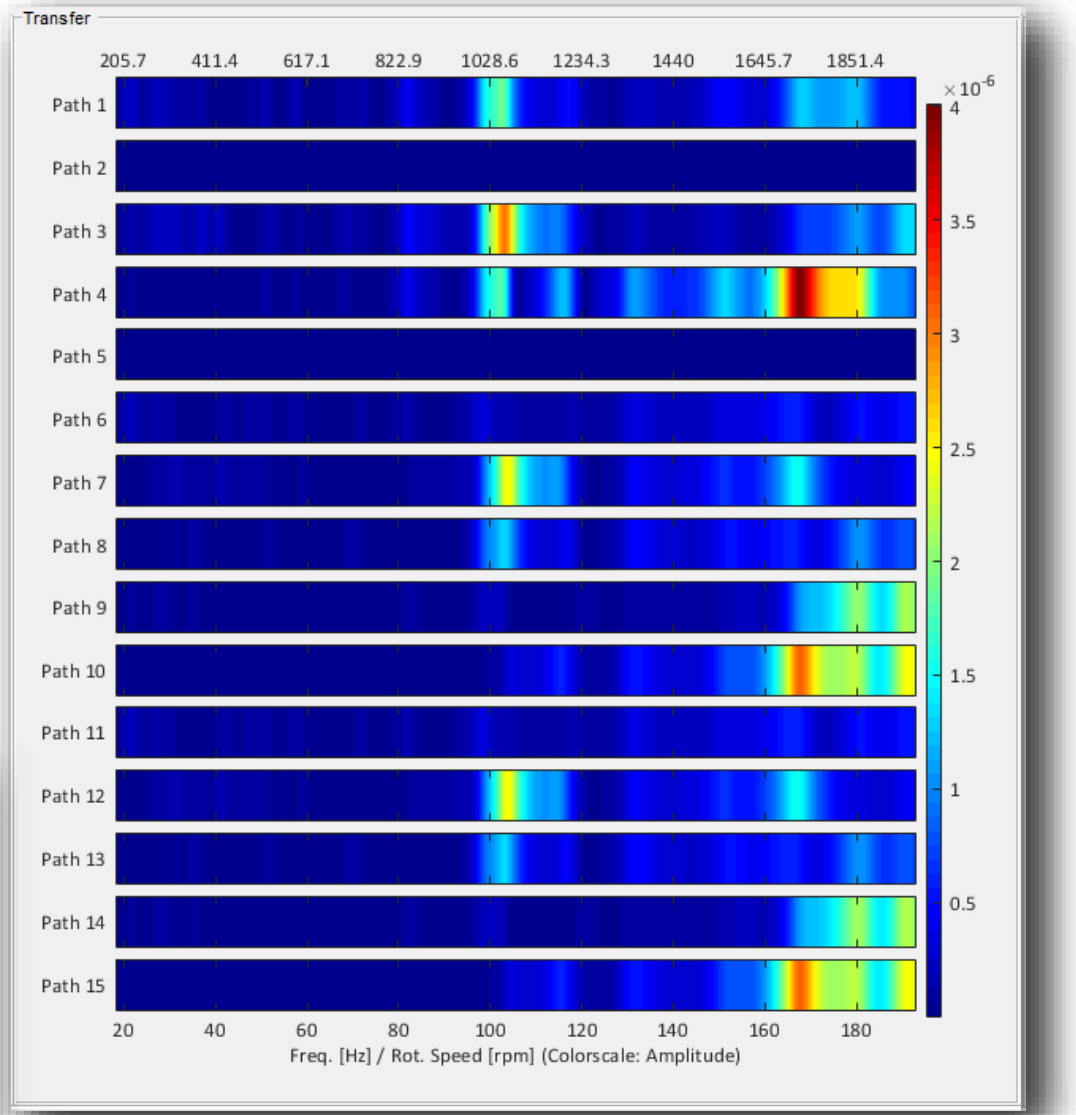
3 Understanding the transfer path of a vibration

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} = \begin{bmatrix} y_{11} + y_{12} + \cdots + y_{1k} \\ y_{21} + y_{22} + \cdots + y_{2k} \\ \vdots \\ y_{n1} + y_{n2} + \cdots + y_{nk} \end{bmatrix} = \begin{bmatrix} FRF_{11} & FRF_{12} \dots & FRF_{1k} \\ FRF_{21} & FRF_{22} \dots & \vdots \\ \vdots & \vdots & \vdots \\ FRF_{n1} & \dots & FRF_{nk} \end{bmatrix} * \begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_k \end{bmatrix}$$

- **Spectogram:** Overview over amplitudes of one order slice
- Path 4 is a dominant component! It is a torque at the main bearing,For each path, the FRF and interface load can be analyzed separately

→ At 175Hz, the structure is „sensitive“ to excitations,



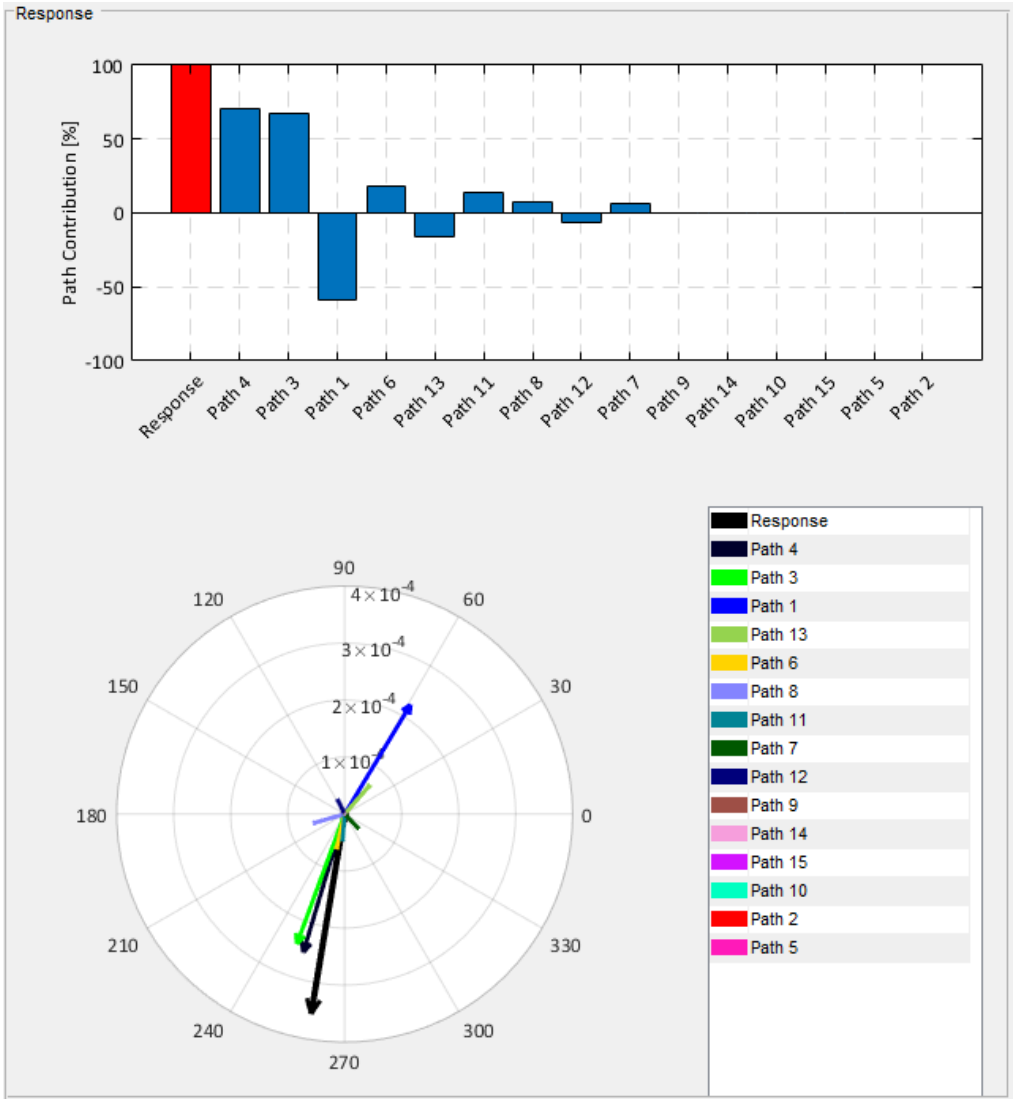


3 Understanding the transfer path of a vibration

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} = \begin{bmatrix} y_{11} + y_{12} + \cdots + y_{1k} \\ y_{21} + y_{22} + \cdots + y_{2k} \\ \vdots \\ y_{n1} + y_{n2} + \cdots + y_{nk} \end{bmatrix} = \begin{bmatrix} FRF_{11} & FRF_{12} \dots & FRF_{1k} \\ FRF_{21} & FRF_{22} \dots & \vdots \\ \vdots & \vdots & \vdots \\ FRF_{n1} & \dots & FRF_{nk} \end{bmatrix} * \begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_k \end{bmatrix}$$

- Information of phase is important!
  - Response terms can cancel each other out
- Impact of phasing visible with Vector plots
- Vector plot of **response** for each path
- Vector plot of **interface load** for each path
- Vector plot of **FRF** for each path

→ The response component of Path 1, is having an opposing phase to the main contributors Path 3 and Path 4

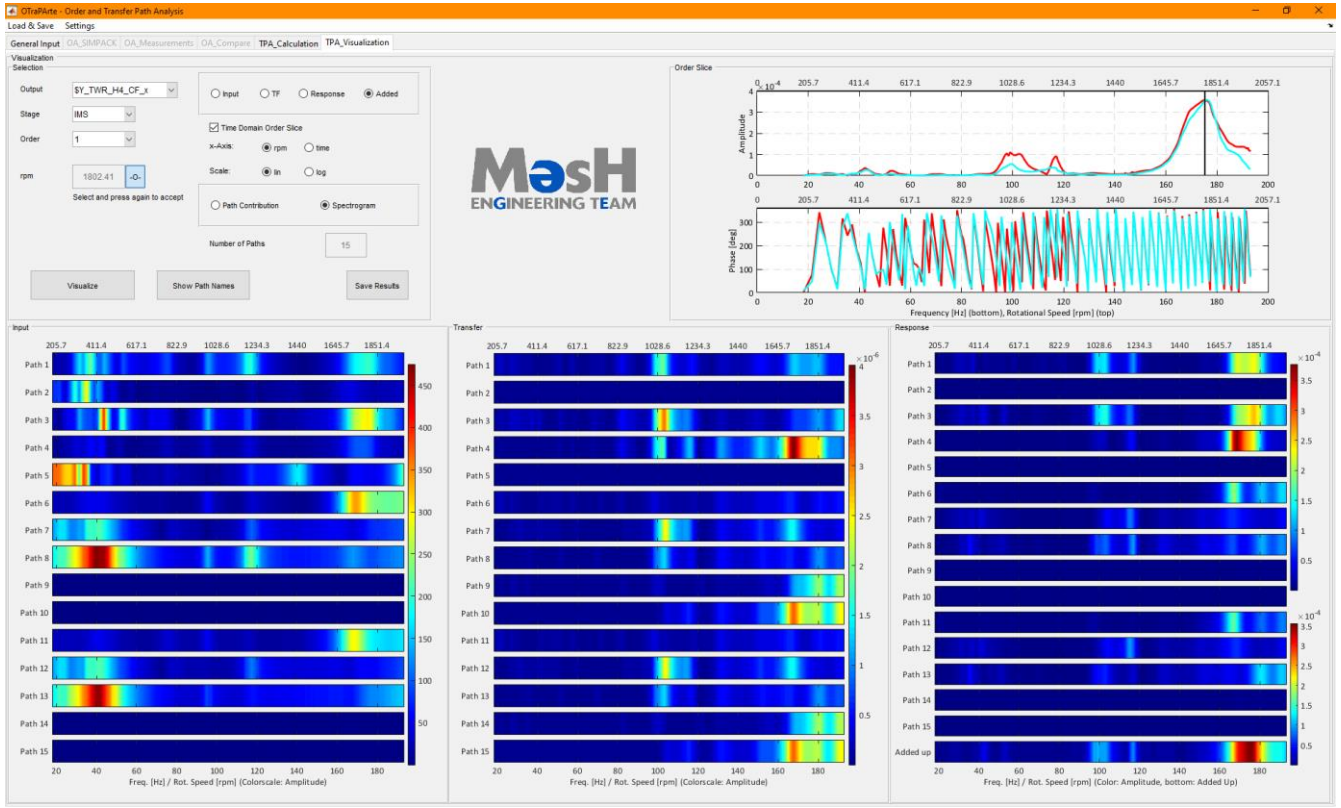


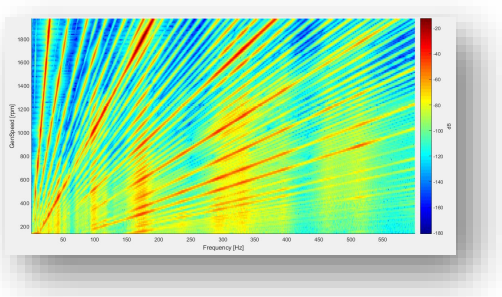
Conclusion

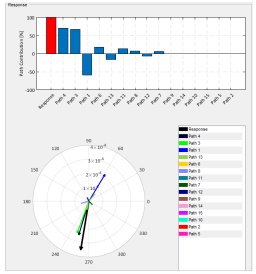
OTraPArTe – A GUI for:

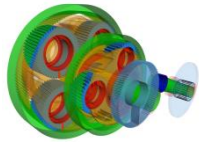
- **Order Analysis:**
  Identification of vibrations and their sources
- **Transfer Path Analysis:**
  Understanding the transfer path of a vibration

- **Usage possible in different engineering fields**
- **Combination of physical measurement data and Simpack results possible**









Thank you for your kind attention!

Questions?

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