



Balancing with MADYN 2000

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1. General Explanations

MADYN 2000 allows balancing a flexible rotor by means of a model. The technic used in the program corresponds to high speed balancing. A vibration measurement can be copied to the model in form of amplitudes and phase angles as a function of speed (resonance curve, bode plot). The user can then define balancing planes in the model and run balancing. The result of a balancing run is identified unbalances in the balancing planes, which best represent the measured vibration. Balancing weights must be applied in opposite direction of the identified unbalances.

Apart from unbalances, the program can also identify bent shafts or coupling offsets. This would be rather for monitoring purposes and is not explained here.

The different steps for balancing are described in the following by means of the example of a steam turbine shown in figure 1. All loads and analyses are under Harmonic Analyses.

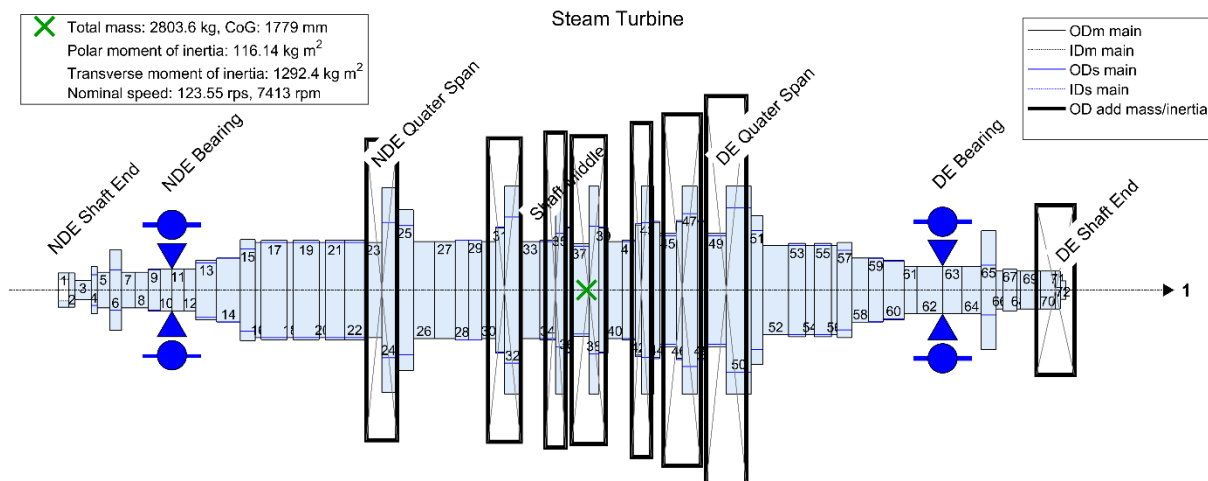


Fig.1.1: Example



2. Measured Data

Real measured data are not available for this turbine. A measurement was therefore simulated with an analysis. The load case for this simulation is Harmonic Load Case 1 “Arbitrary unbalance distributions at masses”. The load with unbalances at all disks and the coupling with different magnitude in arbitrary directions is shown in figure 2.1. The sum of all unbalances corresponds to a level of about G15, which is realistic for such rotor before high speed balancing.

The unbalance response is calculated in “Analysis 1” in the example system. The response of the support vibrations has been exported to the text files

“SBS_Vibrations_DE_Steam_Turbine_unbalance_at_masses” and
“SBS_Vibrations_DE_Steam_Turbine_unbalance_at_masses”.

Typical measured data are support vibrations as in our example or relative shaft vibrations.

Steam Turbine

Harmonic Loads

Load case: Arbitratry unbalance distritution at masses

Unbalance Reference Speed: 7413.00 rpm

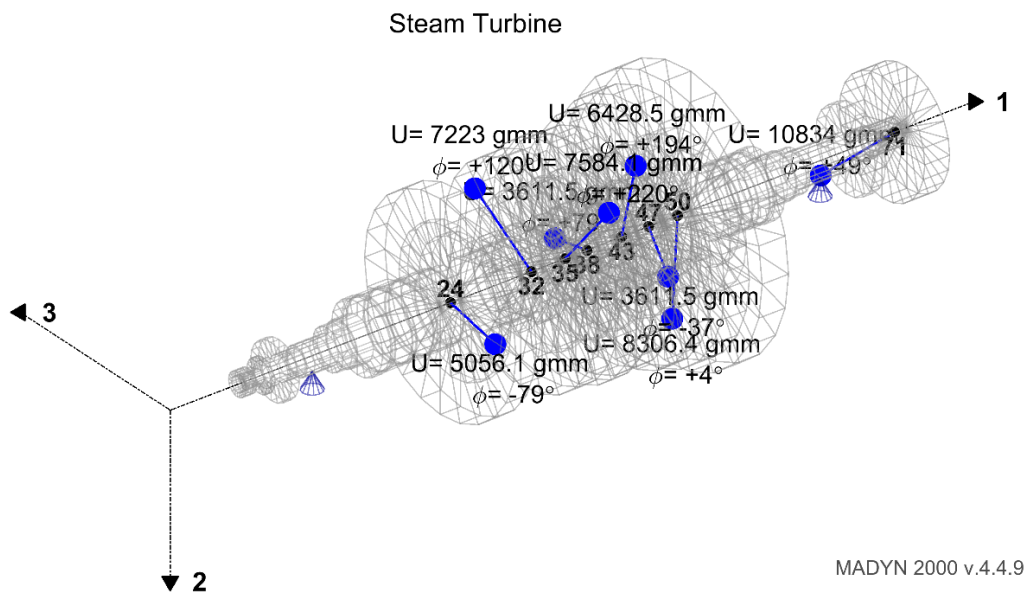


Fig. 2.1: Unbalance load case for the simulation of a measurement

3. Definition of Balancing Planes

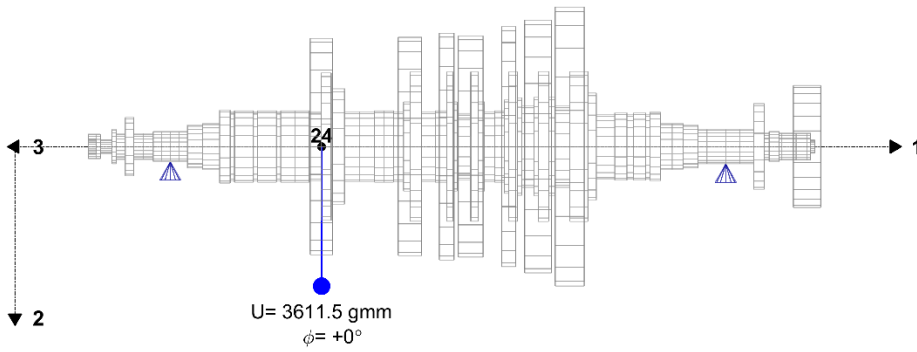
Balancing planes are defined by creating unbalance load cases with unit unbalances in balancing planes. In our example we have defined 4 planes. The load cases with a unit unbalance level G1 are shown in figure 3.1. They correspond to the load cases 2,3,4 and 5 in the system.

Harmonic Loads

Load case: Unit Unbalance NDE Plane G1

Unbalance Reference Speed: 7413.00 rpm

Steam Turbine

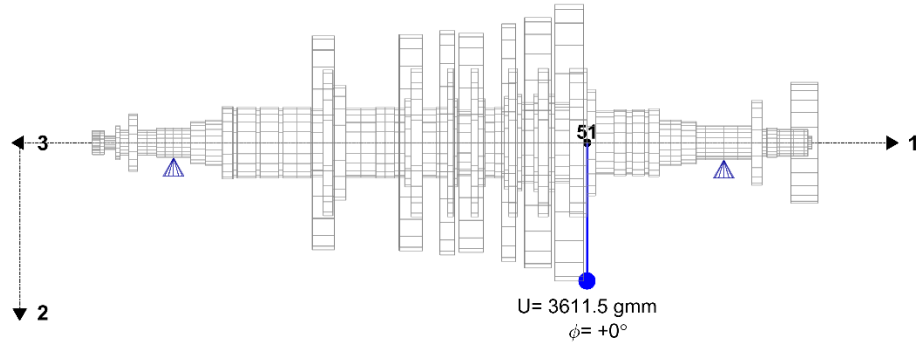


Harmonic Loads

Load case: Unit Unbalance DE Plane G1

Unbalance Reference Speed: 7413.00 rpm

Steam Turbine

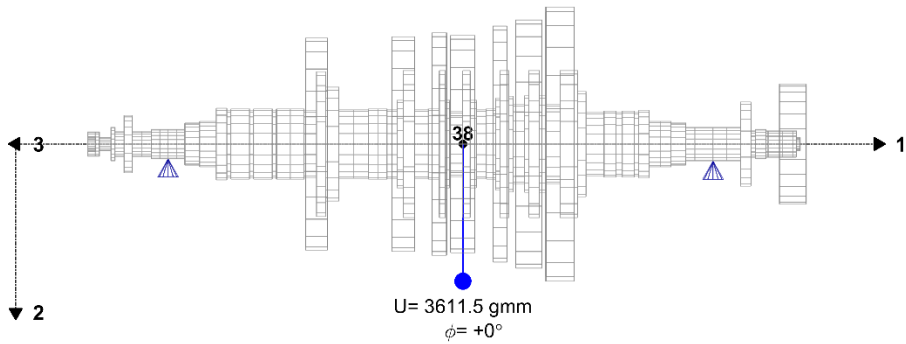


Harmonic Loads

Load case: Unit Unbalance Middle G1

Unbalance Reference Speed: 7413.00 rpm

Steam Turbine



Harmonic Loads

Load case: Unit Unbalance Coupling G1

Unbalance Reference Speed: 7413.00 rpm

Steam Turbine

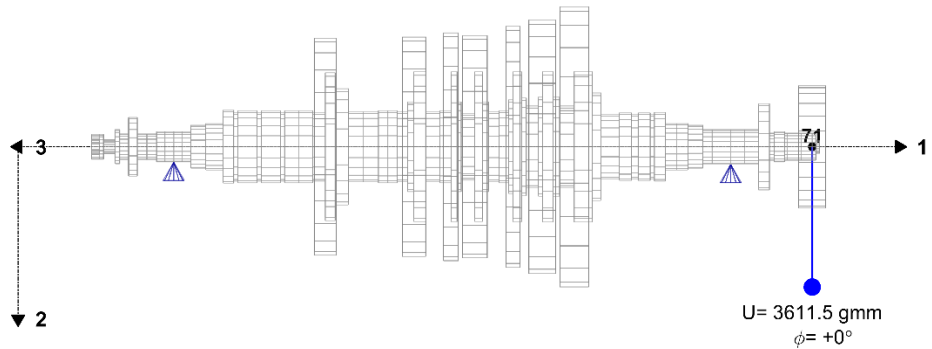


Fig. 3.1.: Load cases 2,3,4,5 with unit unbalances to define balancing planes



4. Definition of a Balancing Run

The analysis GUI for the definition of the balancing run of our example is shown in figure 4.1. Its details are explained in the following.

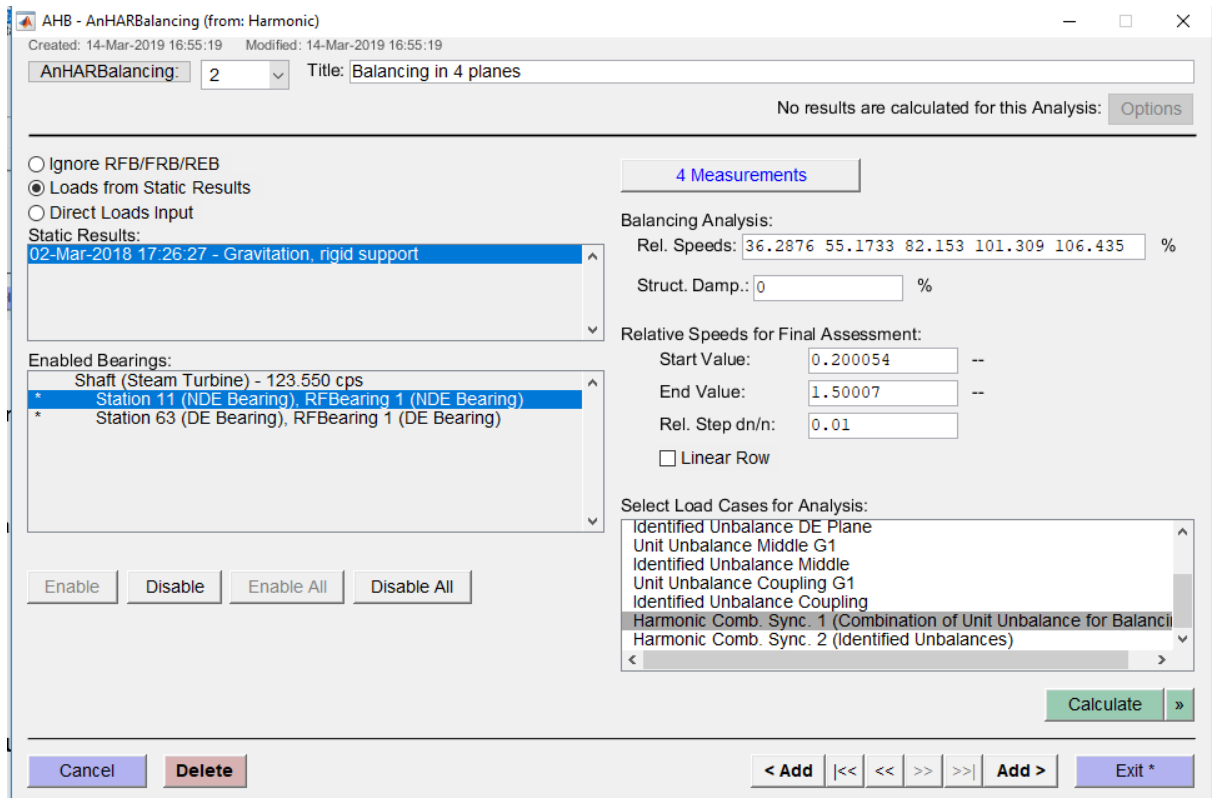


Fig. 4.1: Analysis GUI to define a balancing run

4.1 Definition of the Measurement

Clicking on the “Measurement” button in the analysis GUI in figure 4.1 opens the window to define measurements (see figure 4.2).

The GUI allows defining the measurement location and direction. In our case it is the support vibrations in 2- and 3-directions. Relative measurements could also be defined. A weight factor can be defined for different vibrations. It can be set to values lower than 100% in case the level of a vibration at a certain location is less important.

The speed, amplitudes and phase angles can be pasted into the edit fields from the text files mentioned in chapter 2.¹ The imported measurement can be plotted. The plot for the measurement in figure 4.2 is shown in figure 4.3. In the example system 4 such measurements were imported for both supports in vertical (2) and horizontal (3) direction.

¹ Additional interfaces for the import will be introduced after gaining some experience with real measurements.

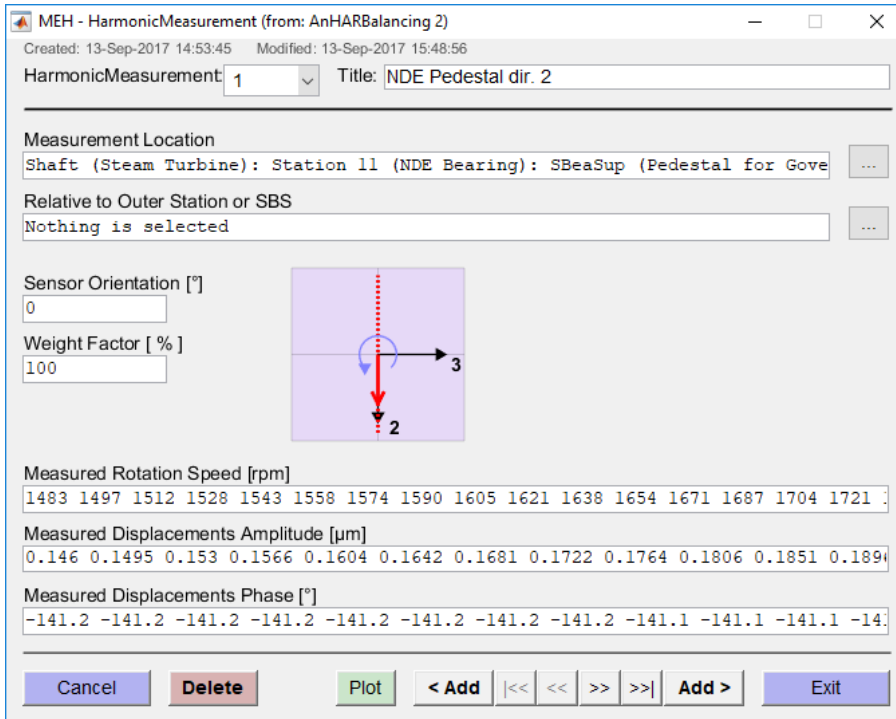


Fig. 4.2: Measurement GUI

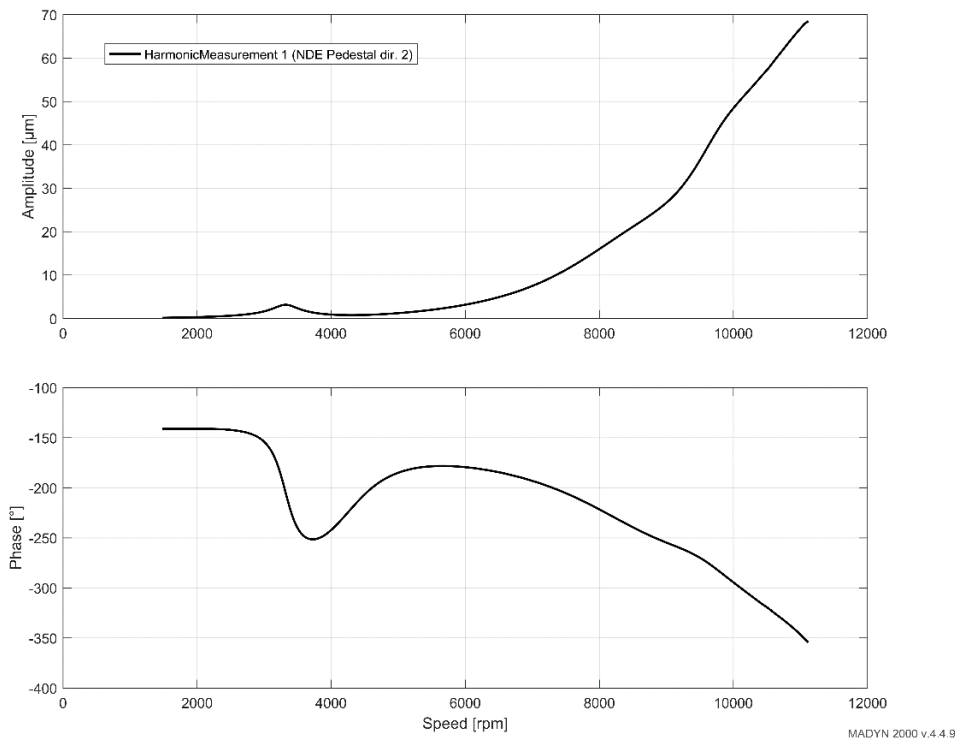


Fig. 4.3: Resonance curve of imported measurement (NDE support in vertical direction)



4.2 Parameters

Further parameters for the balancing run can be defined in the GUI shown in figure 4.1.

Apart from the usual definitions of bearing loads for Fluid Film or Rolling Element Bearings and a structural damping ratio as for all harmonic response analyses the following can be defined:

- Relative speeds for the balancing,
- a speed range for the final assessment and
- a load case with the unit unbalances.

The selection of speeds is important. Preferable they should be in the vicinity of resonances and in the speed range. The first two speeds are close to the first resonance and the next three speeds in the speed range. The maximum speed is close to a well damped resonance. Speeds should be close but not directly in low damped resonances, because the system is sensitive at such speeds.

The speed range for the final assessment is defined in the same manner as the speed range for normal harmonic response analyses. The response to the identified unbalances is calculated in this speed range.

The selected load case for balancing is a combination, which contains all the unit unbalances in the balancing planes. In the example system it is load case 6, containing a combination of the loads 2,3,4,5 shown in figure 3.1.

5. Result of the Balancing Run

Result of the balancing run are factors by which the unit unbalances must be multiplied to get a best match with the measured resonance curve at the balancing speeds. These factors can be printed. The result print for our example is shown in the following. It includes the usual system information, the loads corresponding to our unit loads and the factors. The factors are highlighted below. They are complex numbers converted to magnitude and phase angle.

```
Harmonic Responce Analysis:  
Balancing in 4 planes  
Created:      13-Sep-2017 15:44:42  
Modified:    02-Mar-2018 17:28:49
```

```
System:  
Steam Turbine  
TLA case: [1 0 0 1 0 0]
```

Loads:

```
HAR Combination: Combination of Unit Unbalance for Balancing  
Created: 11-May-2017 12:33:40
```

```
Unbalance Load Case: Unit Unbalance NDE Plane G1  
Created: 10-May-2017 16:14:55
```



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Unbalances

Location: G U [kgm] Phase [deg]
Steam Turbine: Station 24 (NDE Quater Span) 1.00 3.6115e-03 0.0

Unbalance Load Case: Unit Unbalance DE Plane G1
Created: 10-May-2017 16:16:00

Unbalances

Location: G U [kgm] Phase [deg]
Steam Turbine: Station 51 1.00 3.6115e-03 0.0

Unbalance Load Case: Unit Unbalance Middle G1
Created: 10-May-2017 16:16:58

Unbalances

Location: G U [kgm] Phase [deg]
Steam Turbine: Station 38 1.00 3.6115e-03 0.0

Unbalance Load Case: Unit Unbalance Coupling G1
Created: 10-May-2017 16:20:44

Unbalances

Location: G U [kgm] Phase [deg]
Steam Turbine: Station 71: Mass 1 1.00 3.6115e-03 0.0

Analysis Parameters:

Load Case:	Factor, %	Phase, deg
Unit Unbalance DE Plane G1	99.26	-94.5
Unit Unbalance NDE Plane G1	247.81	-13.3
Unit Unbalance Middle G1	314.55	+168.0
Unit Unbalance Coupling G1	298.90	+49.6

The response at the measurement locations to the identified unbalances is shown in figure 5.1. The measured data are copied into this plot (black, dashed lines). As can be seen there is perfect agreement.

It must be noted, that balancing weights must be applied in opposite direction of the identified unbalances in the balancing planes, i.e. 180 deg. must be added to the phase angles.

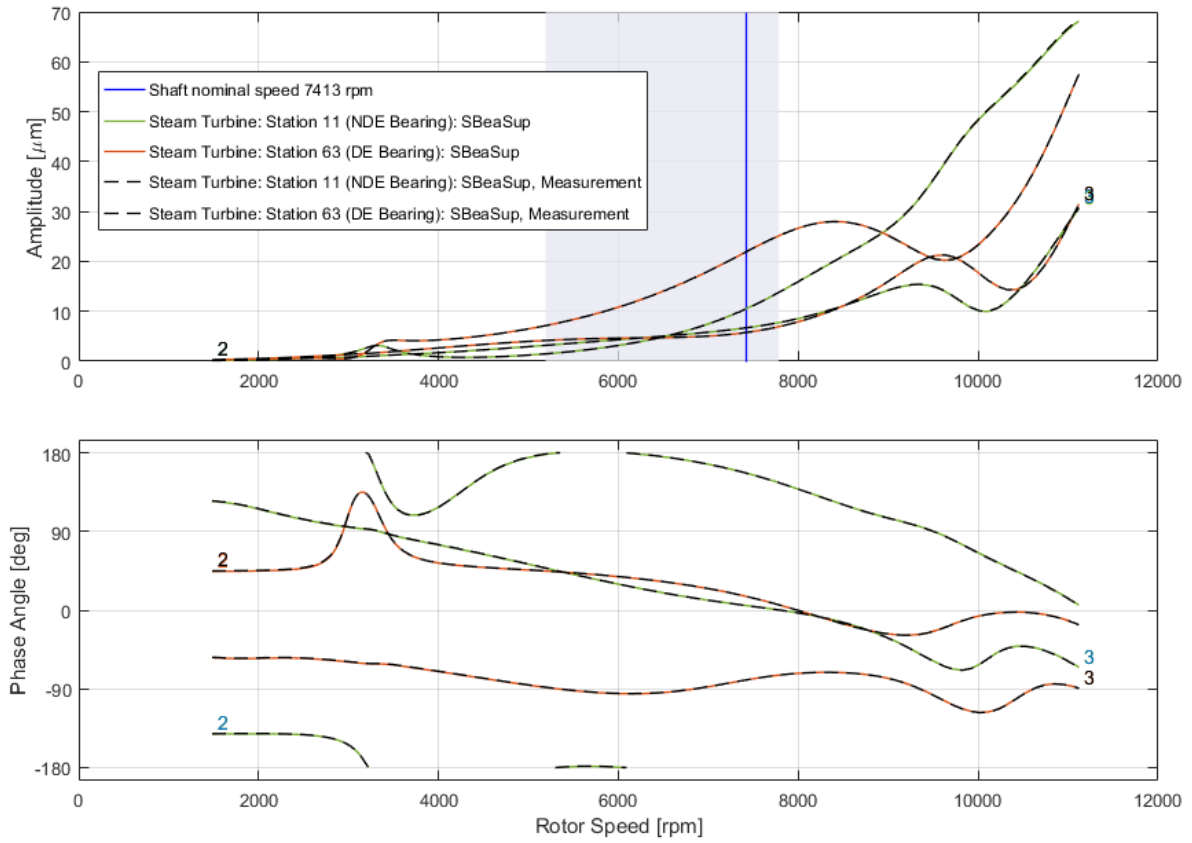


Fig. 5.1: Response to identified unbalances and measurement