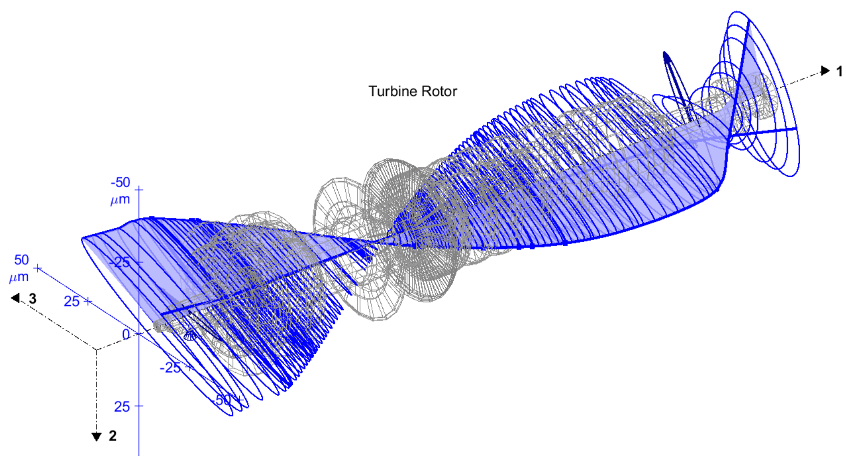
22nd Swiss CADFEM ANSYS Simulation Conference 2017

Coupled Rotor-Bearing-Casing Analysis

Gekoppelte Rotor-Gleitlager-Gehäuse Berechnung

Using State Space Matrices from ANSYS in MADYN 2000



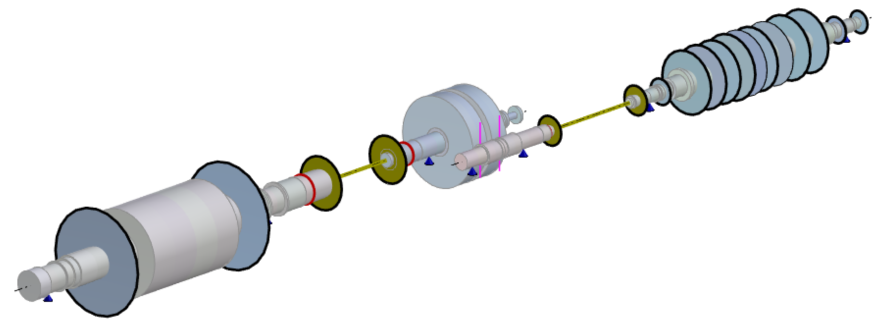
Joachim Schmied, Marco Perucchi
DELTA JS AG, Zurich, Switzerland
www.delta-js.ch

Contents

- What is rotordynamics?
- Support modelling with spring & mass
- Support modelling with transfer functions
- Support modelling with state space matrices from ANSYS

What is Rotordynamics?

- Rotordynamics is the analysis of rotating machines for their vibration behaviour.
- Systems can consist of rotors, bearings, supports & gears.



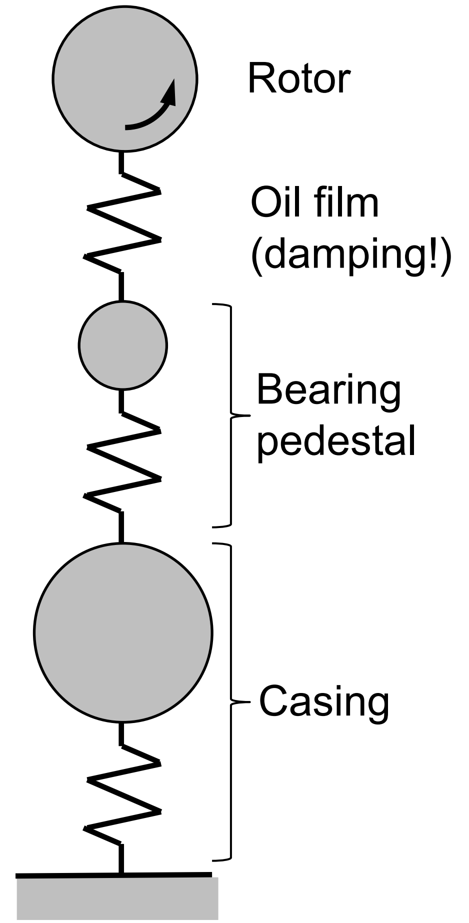
- Fluid film (or active magnetic) bearings are the main source of damping for the lateral vibrations. They can also destabilize.
- It is possible to carry out rotordynamic analyses with general FE or multibody dynamics programs. However, specialised <u>rotordynamics software</u> such as MADYN 2000 has proven to be <u>most efficient</u> for daily work.

What is Rotordynamics?
Analysis with MADYN 2000

- Concentration on modelling with Timoshenko beams, which are well suited for shafts.
- Speed and / or frequency dependent bearings (→ fluid film, active magnetic, rolling elements) are integrated.
- Consideration of gyroscopic forces.
- Efficient modelling, analysis and post-processing.
- The dynamic properties of complex support structures such as casings or foundations cannot be determined directly in MADYN 2000. But they can be imported into the system.

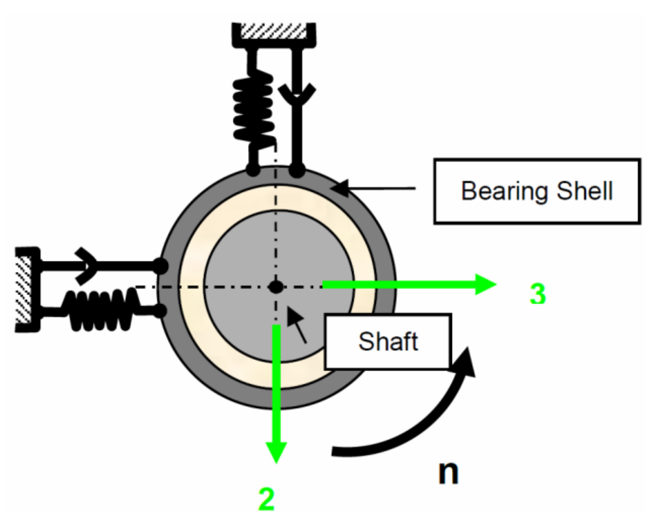
Bearings and Support Structure

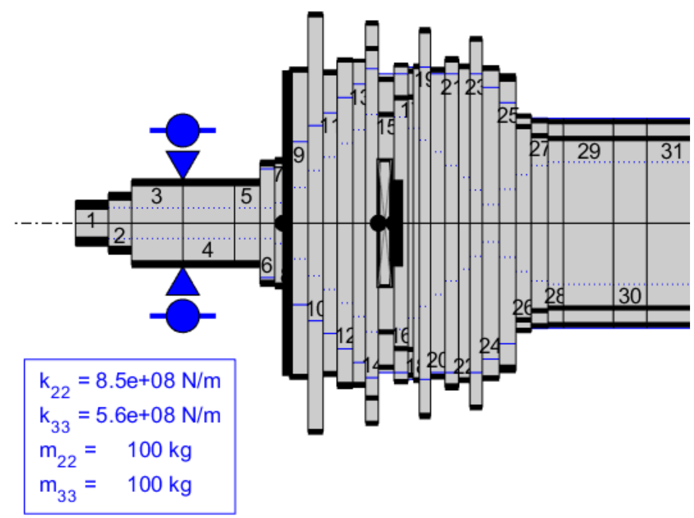
- The bearings enable the rotation of the shaft and can provide damping of the lateral vibrations (e.g. through movement of the shaft in the oil film).
- The support structure (→ pedestal, casing, base frame, foundation) also contributes to the flexibility of the system. The support structure must be considered in the model unless it is much stiffer than the bearing.



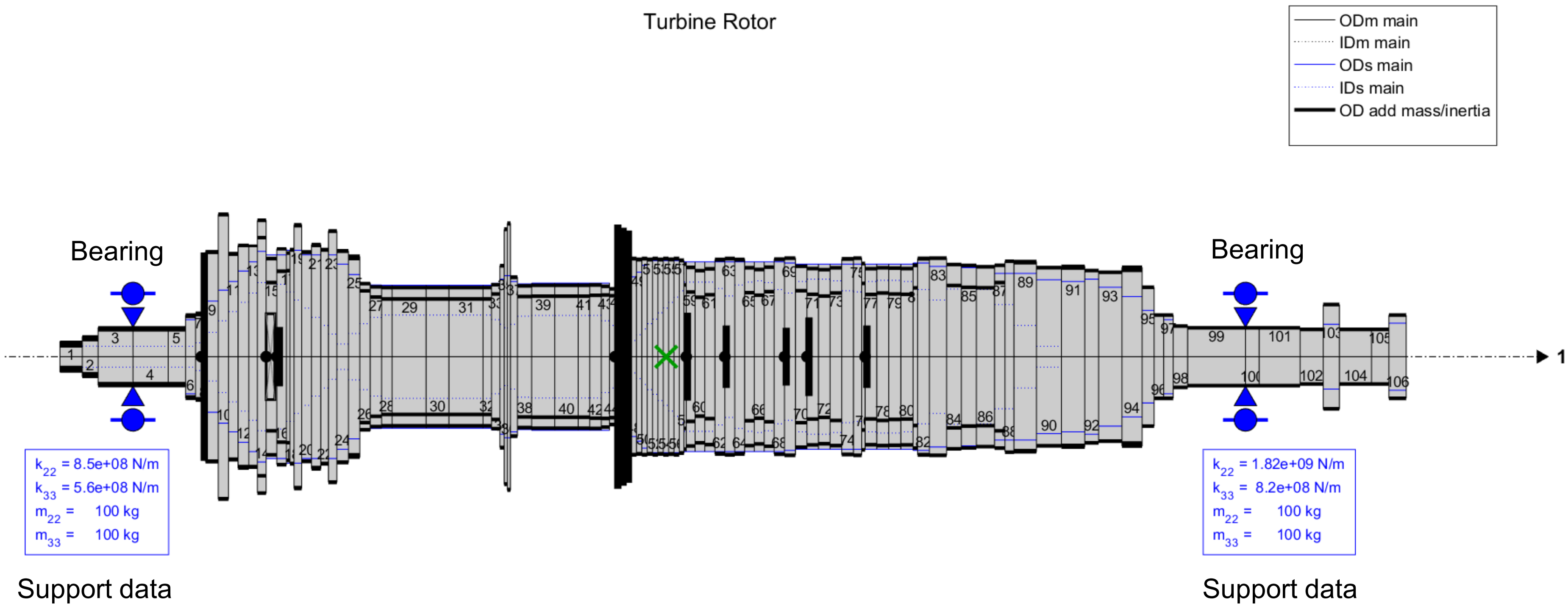
Support Modelling with Spring & Mass

- The spring & mass support is a traditional and still widely used approach to consider pedestal, casing etc.
- Only 1 degree of freedom per bearing / direction.
- No coupling effects between the bearings.

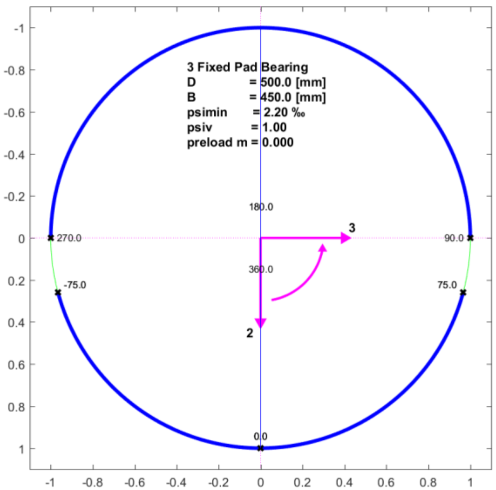


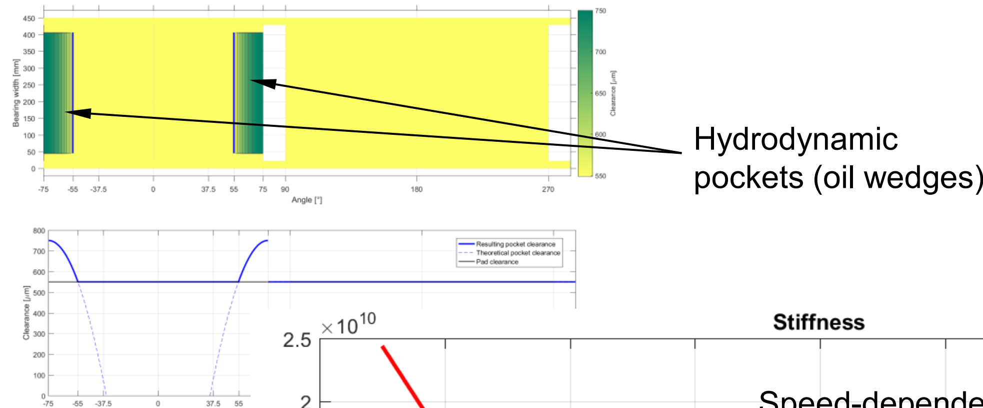


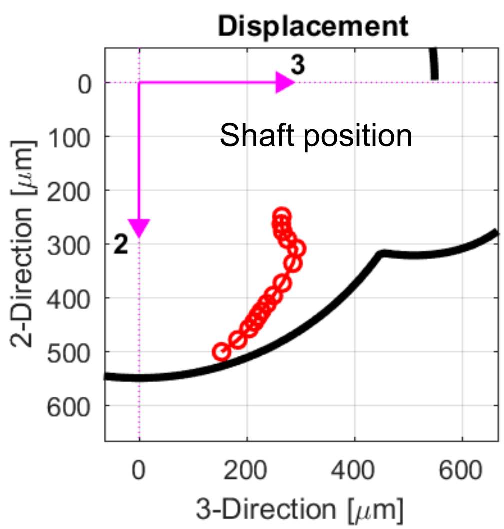
Rotordynamic Model – Turbine Shaft

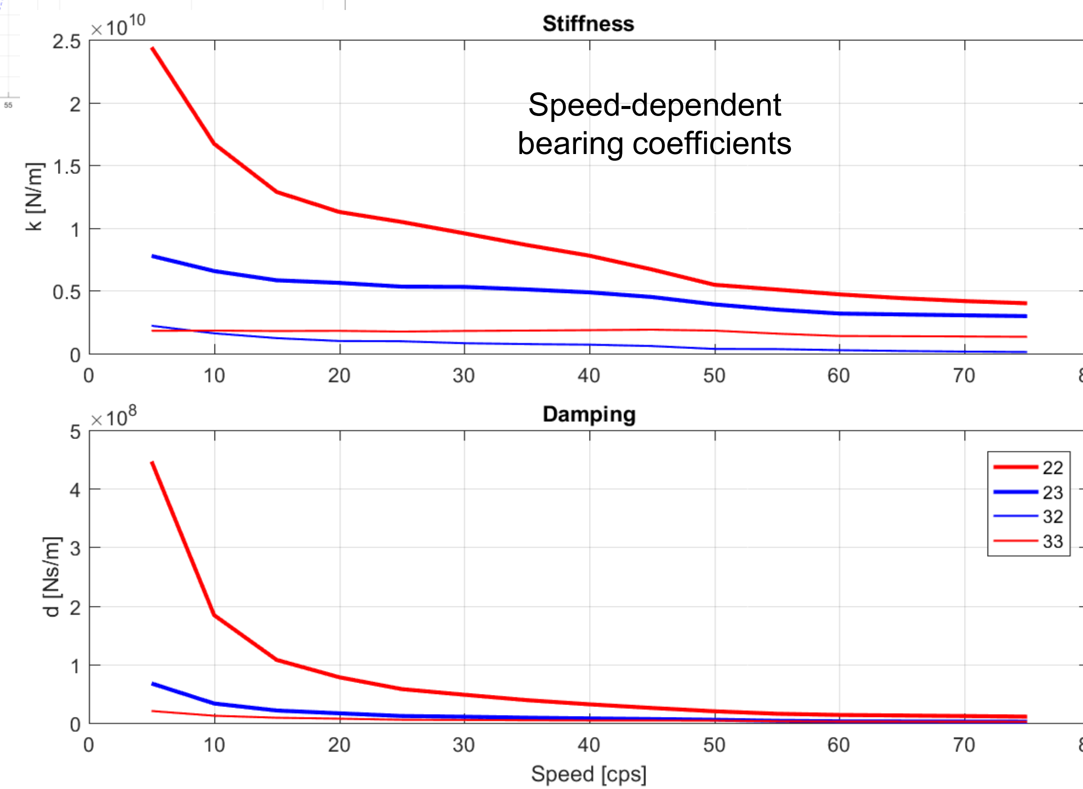


Support Modelling with Spring & Mass
Rotordynamic Model – Fluid Film Bearing



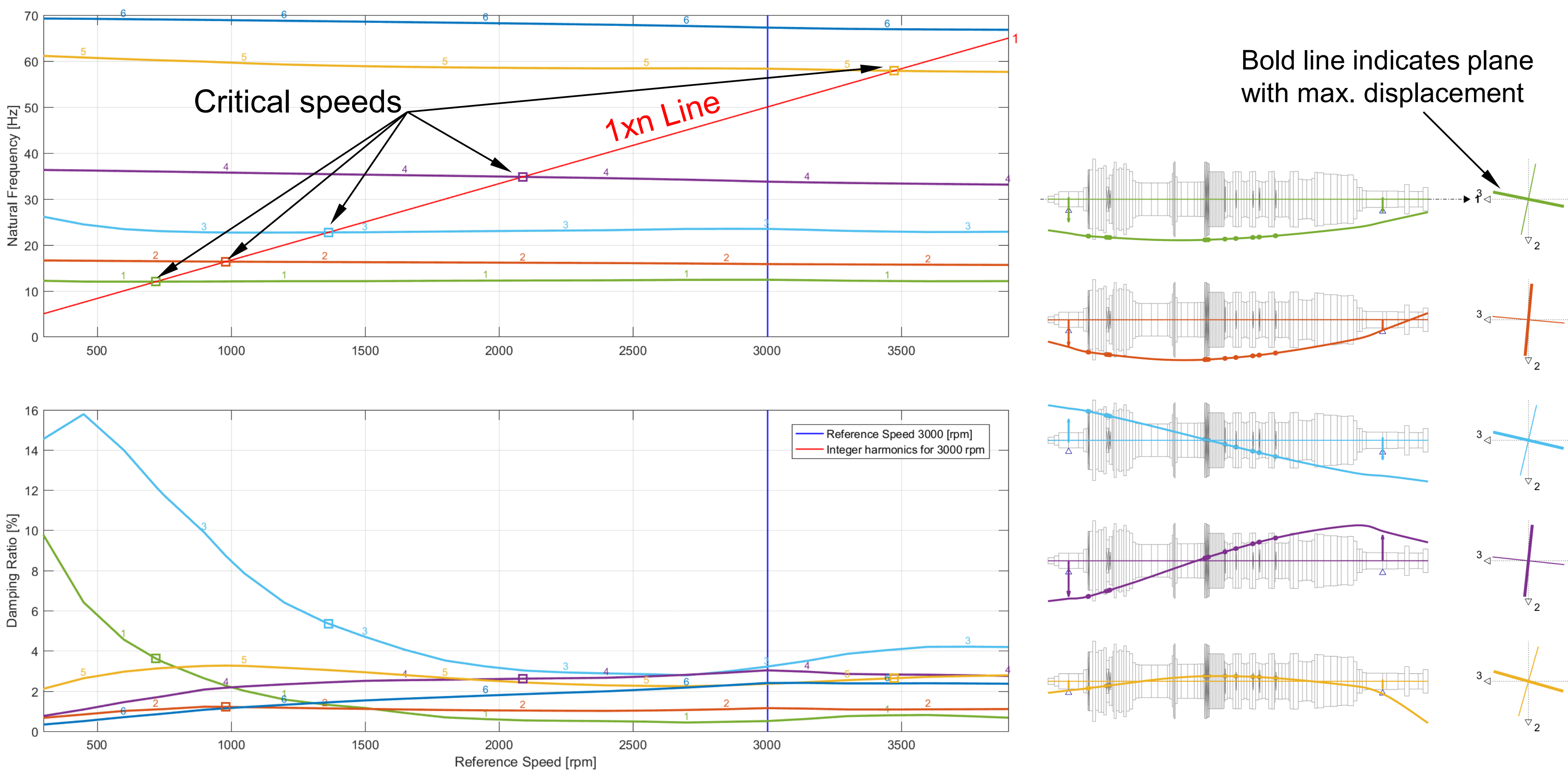






Support Modelling with Spring & Mass

Campbell Diagram and Critical Modes

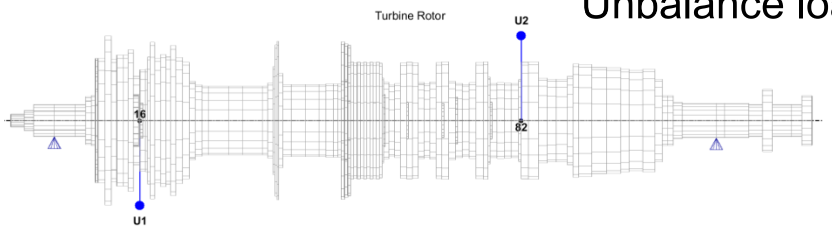


Support Modelling with Spring & Mass

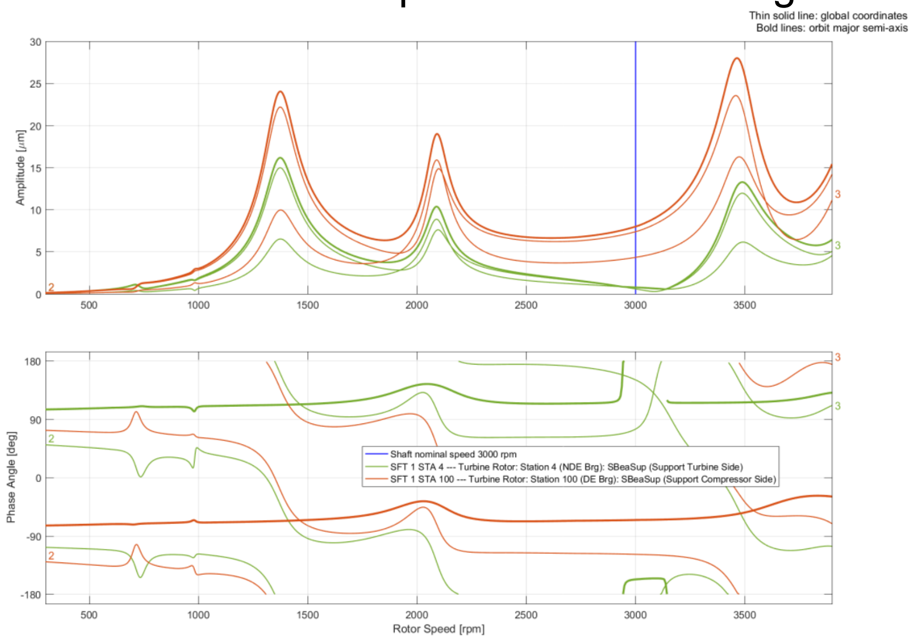
Unbalance Response

DELTA JS AG

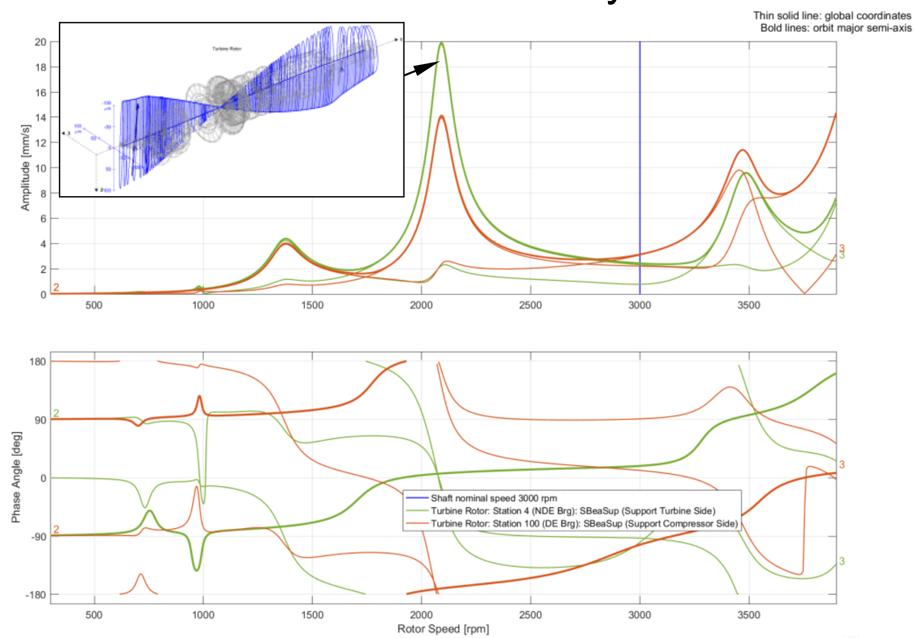
Unbalance load case



Relative shaft displacement at bearings



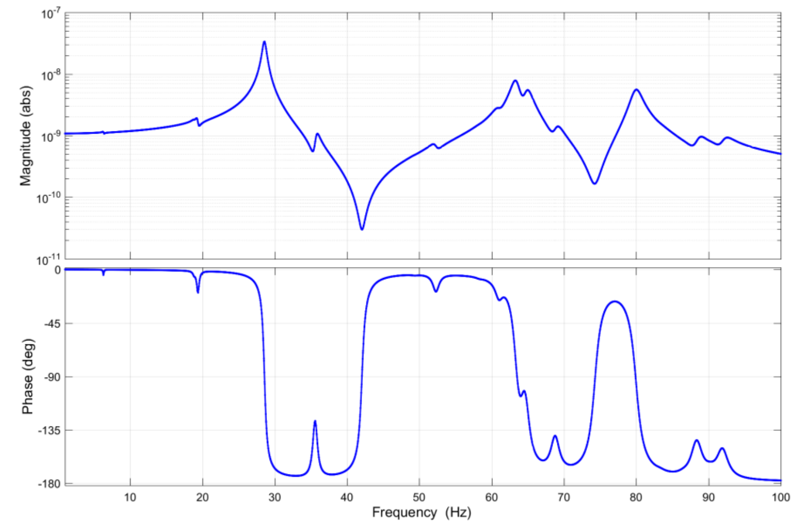
Pedestal velocity



Support Modelling with Transfer Functions

DELTA JS AG

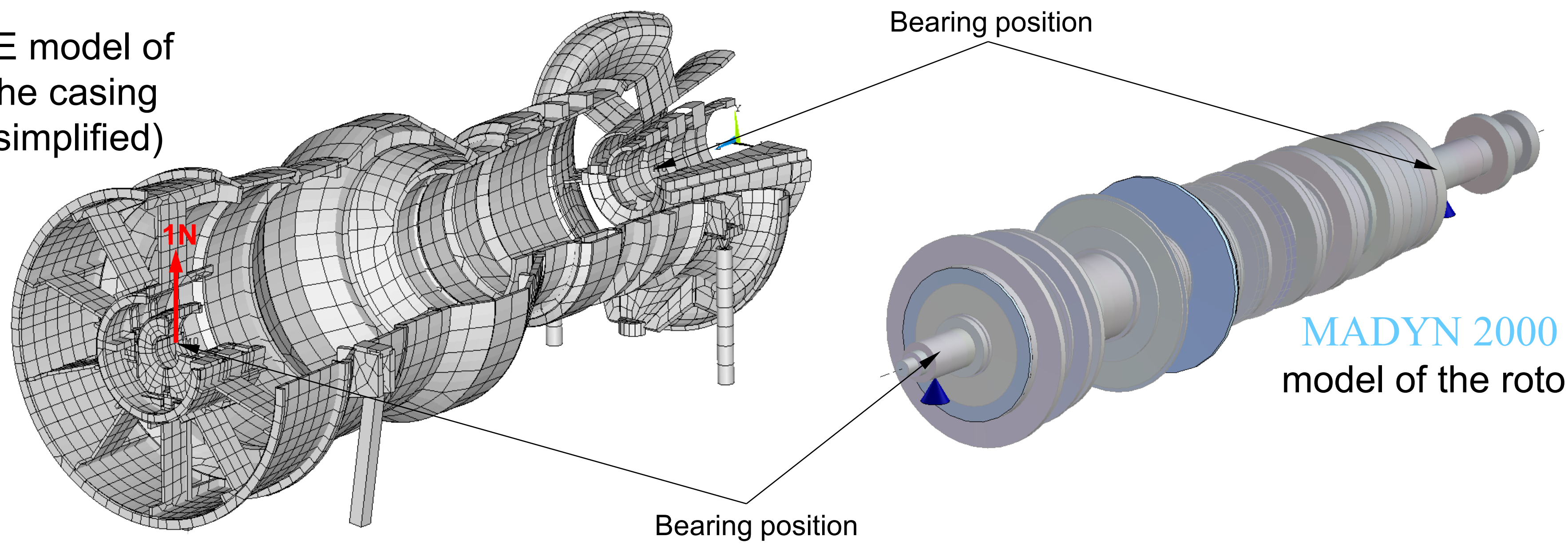
- Transfer functions describe the dynamic (i.e. frequency-dep.) flexibility of the support structure.



- They can be calculated with an FE program (→ harmonic response analysis) or measured.
- Creating and importing transfer functions can be time-consuming for systems with many bearings.
- Fitting polynomials to the imported transfer functions is required for eigenvalue analyses, but is sometimes difficult.

Calculating the TF in ANSYS

FE model of the casing (simplified)

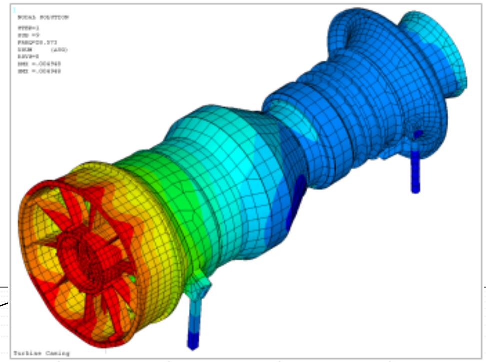


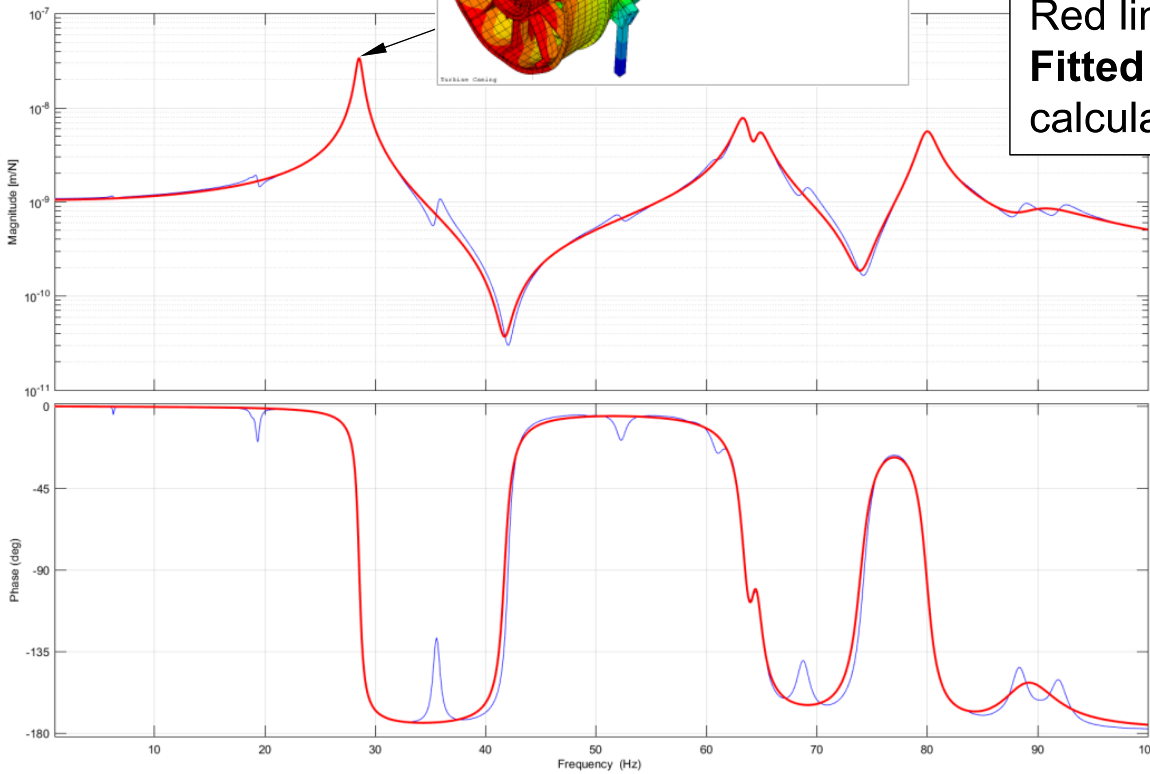
List of the response for 1N vertical harmonic excitation and 1% damping ratio.
(Transfer functions are imported into MADYN 2000 as text files.)

***** ANSYS POST26 VARIABLE LISTING *****

FREQ	NSOL UY Exhaust AMPLITUDE	PHASE
0.10000	0.107840E-08	-0.323132E-02
0.20000	0.107843E-08	-0.646297E-02
0.30000	0.107848E-08	-0.969526E-02
0.40000	0.107855E-08	-0.129285E-01
0.50000	0.107864E-08	-0.161631E-01
0.60000	0.107875E-08	-0.193993E-01
0.70000	0.107888E-08	-0.226375E-01

Importing the Transfer Functions





Blue line:
Imported source data → used for harmonic analysis (e.g. unbalance response)

Red line:
Fitted polynomial → required for the calculation of the damped eigenvalues

DELTA JS AG

Support Modelling with State Space Matrices from ANSYS

- In MADYN 2000 the support structure can be considered in the form of state space matrices. This allows damped eigen-value analyses of the rotor without fitting polynomials.
- The state space matrices can be created in ANSYS from the results of the modal analysis in post-processing via the command SPMWRITE.
- The interface nodes (i.e. the nodes at the centres of the bearings) and the directions have to be defined. The state space matrices are written to Jobname.spm.
- Modal damping for the modes considered in the state space matrices has to be introduced during import to MADYN 2000.

Basics of State Space Matrices

- Any linear dynamic system can be represented in State Space form:
  $\dot{z} = A\, z + B\, u$
  $y = C\, z + D\, z$

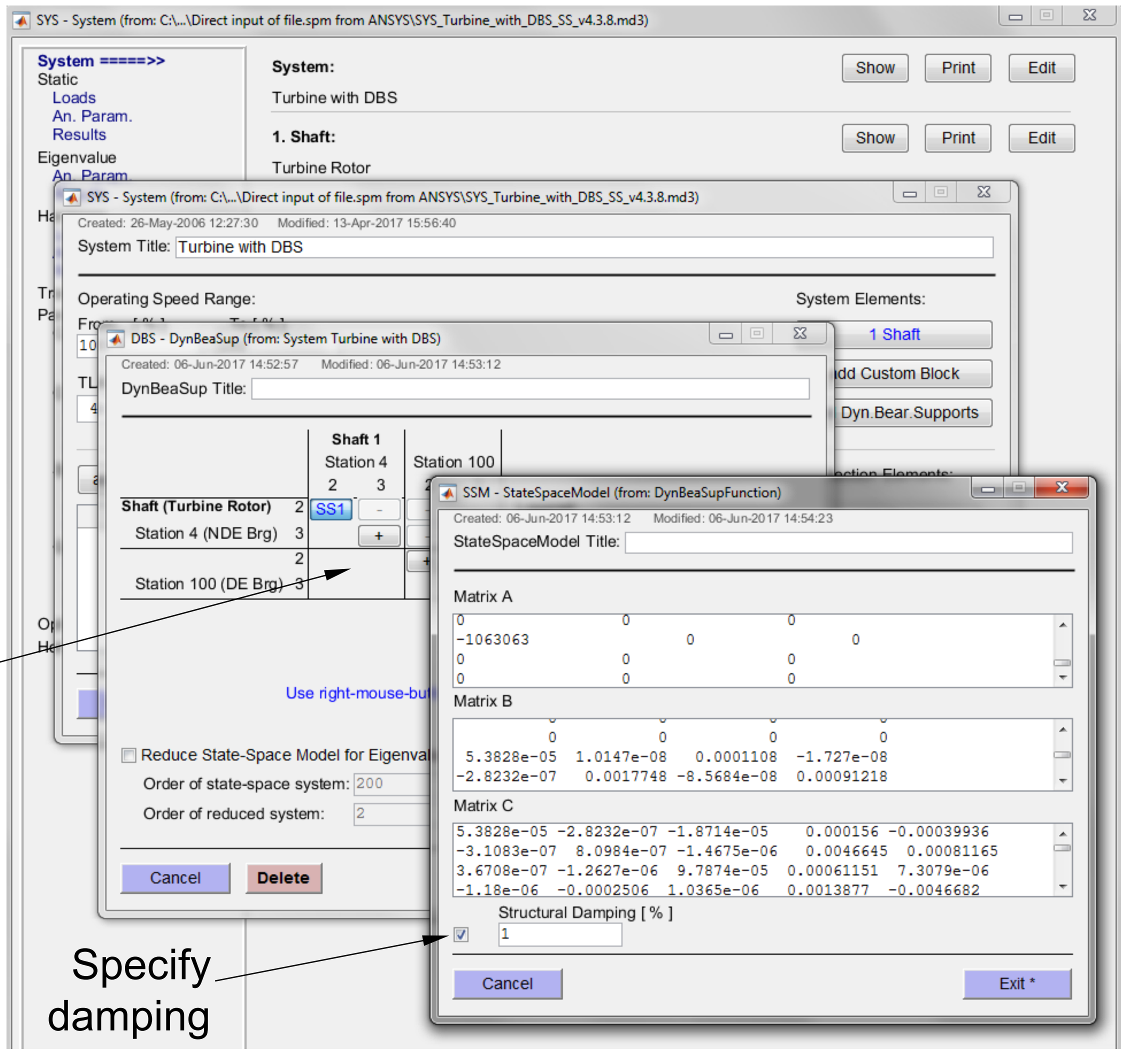
- u inputs to a system, y outputs, z states,
  A, B, C, D system, control or input, observer and direct transition matrices.

- In MADYN 2000 State Space representation is used for various components such as magnetic bearings or fluid film tilting pad bearings and coupled dynamic supports.

- Bearings: u displacement and velocities, y forces.
  Supports: u forces, y displacement and velocities. The states z are the modal coordinates of considered modes, A contains natural frequencies, B and C components of eigenvectors, D is zero.

Support Modelling with State Space
The Import GUI in MADYN 2000

DELTA JS AG



Symmetric

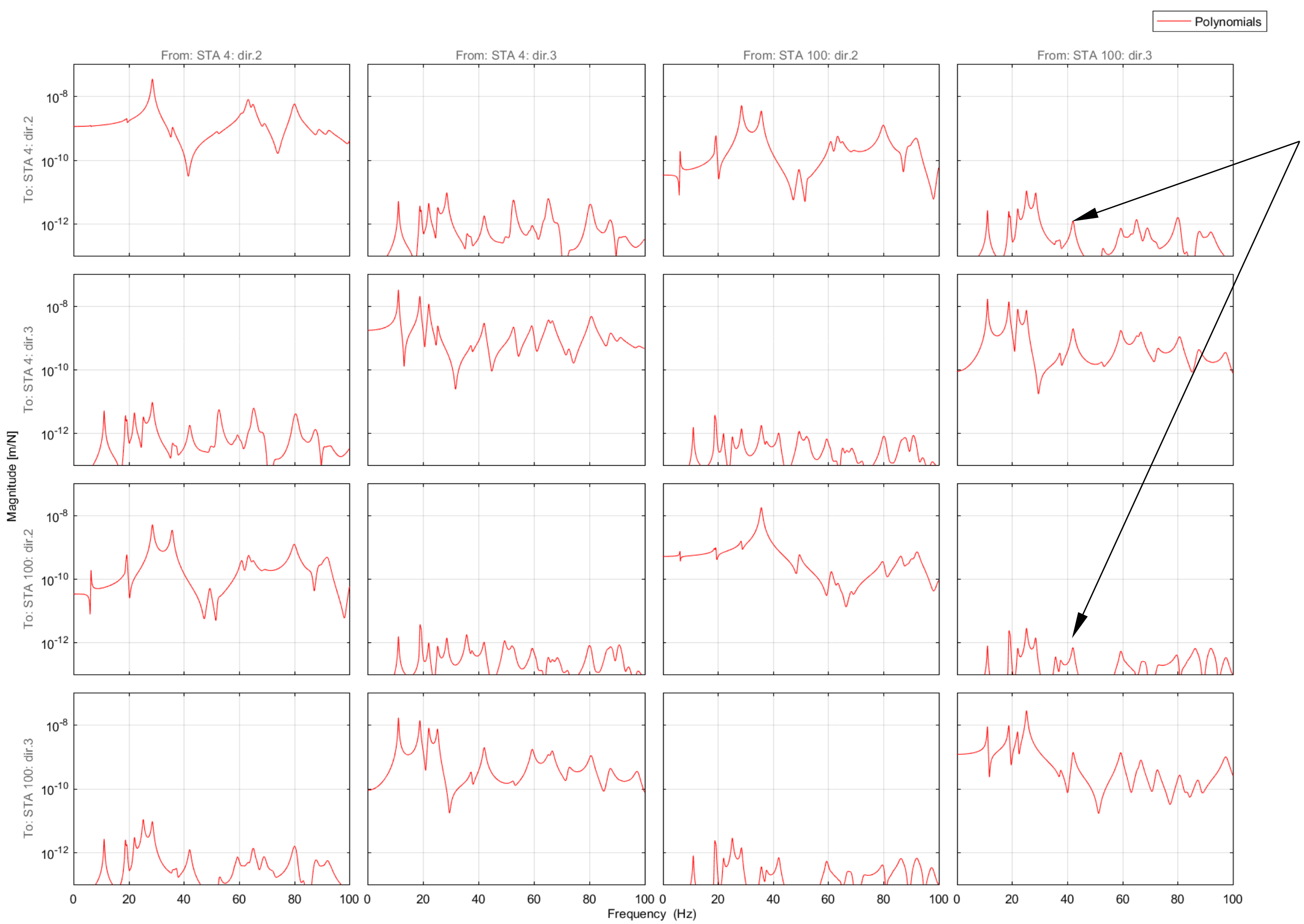
Specify damping

Natural frequencies of the casing

Frequency [Hz]	Damping Ratio [%]
6.313	1.00
11.089	1.00
18.837	1.00
18.840	1.00
19.341	1.00
20.376	1.00
22.041	1.00
25.239	1.00
28.573	1.00
35.741	1.00
37.478	1.00
42.101	1.00
49.390	1.00
52.234	1.00
52.806	1.00
58.181	1.00
58.327	1.00
59.385	1.00
61.017	1.00
63.363	1.00
64.914	1.00
65.395	1.00
66.636	1.00
68.520	1.00
68.952	1.00
69.983	1.00
72.577	1.00
79.974	1.00
80.796	1.00
83.275	1.00
83.434	1.00
86.500	1.00
87.533	1.00
88.591	1.00
88.705	1.00
90.248	1.00
90.429	1.00
90.940	1.00
92.130	1.00
93.097	1.00
94.354	1.00
97.487	1.00

The Transfer Functions

Transfer functions from the state space system.

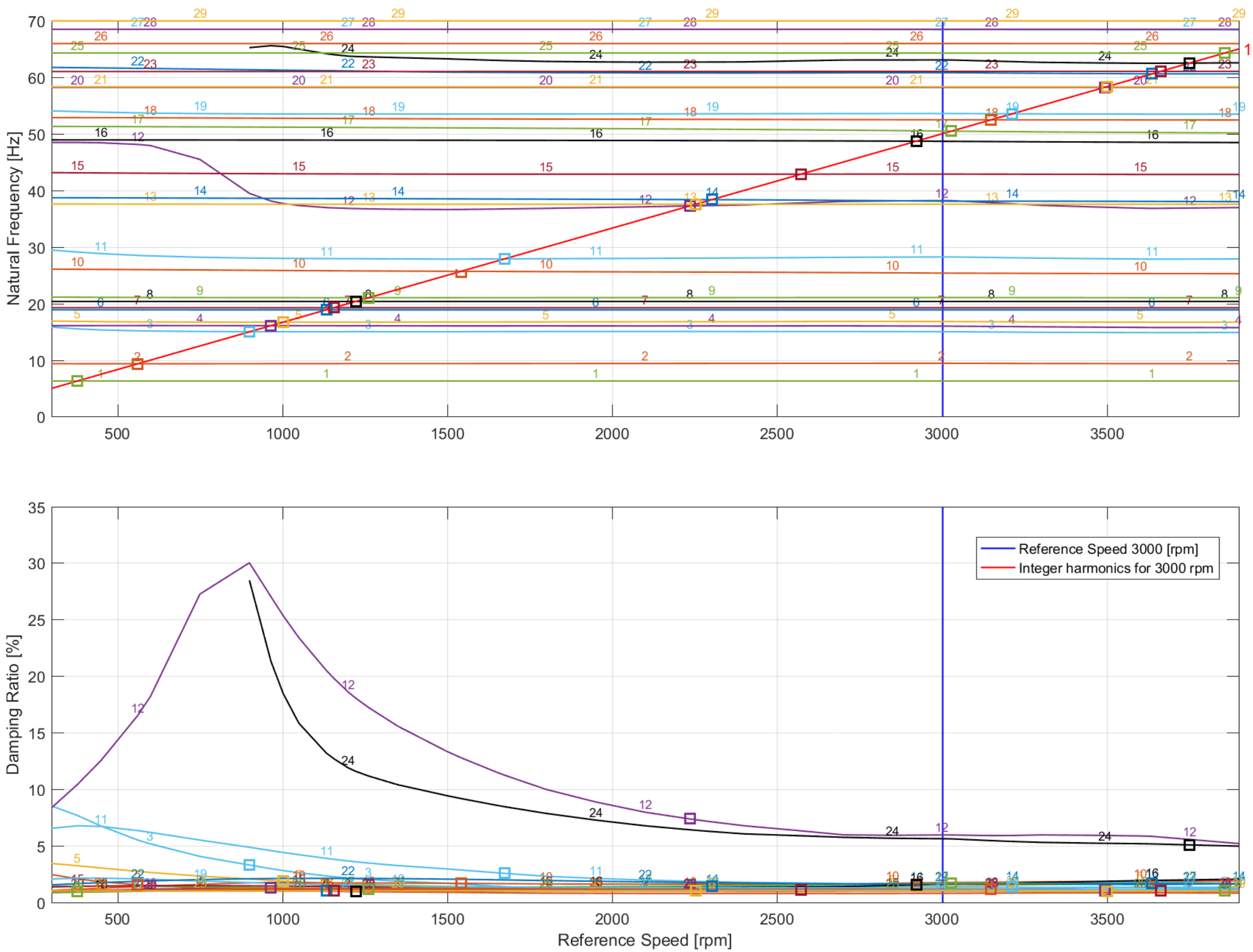


Low values indicate little coupling between the vertical and the horizontal direction

DELTA JS AG

Support Modelling with State Space

Campbell Diagram



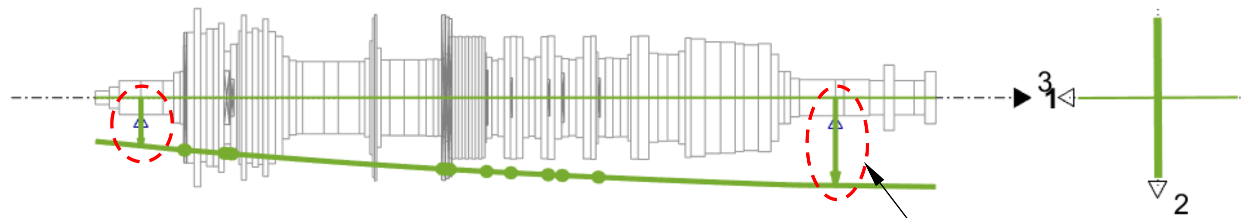
Many additional modes are caused by the casing.

Support Modelling with State Space

Examples of Critical Modes

Pure casing mode

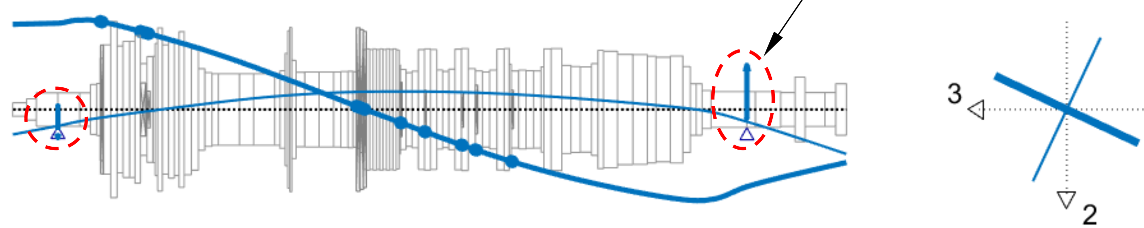
```
Mode:               1
Frequency:          6.31 Hz
                    378.6 cpm
Damping:            1.0 %
Whirling direction: +0.00
```



Arrow = Casing displacement

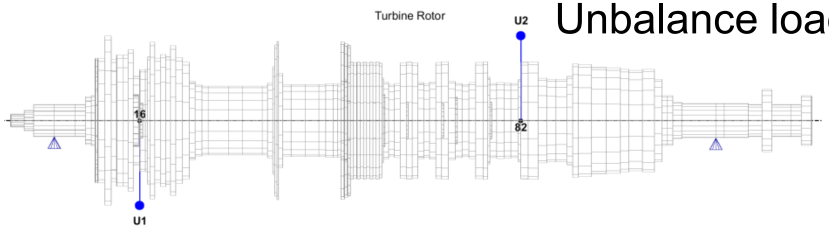
Coupled rotor-casing mode

```
Mode:               14
Frequency:          38.20 Hz
                    2292.3 cpm
Damping:            6.0 %
Whirling direction: +0.07
```



Support Modelling with State Space
Unbalance Response

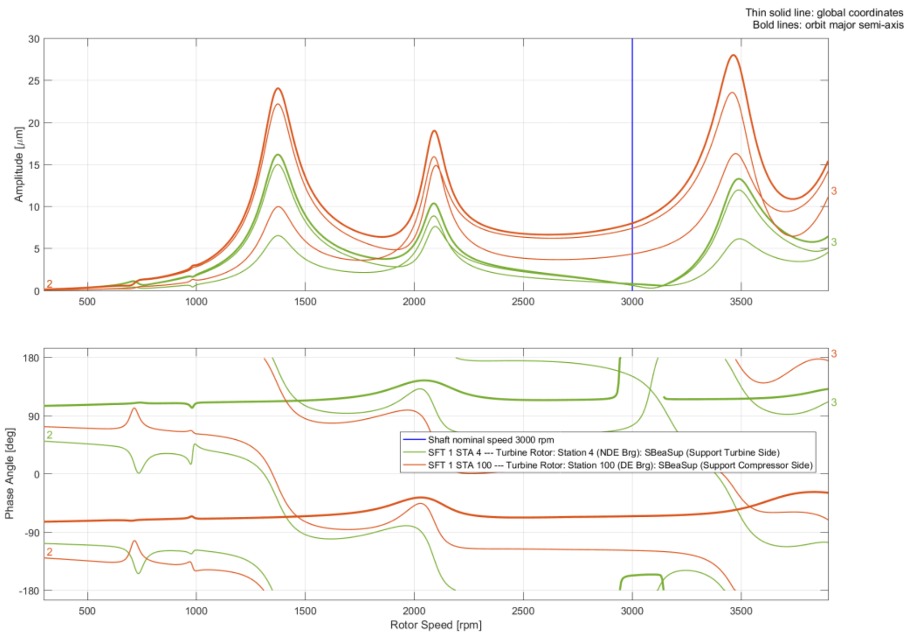
DELTA JS AG



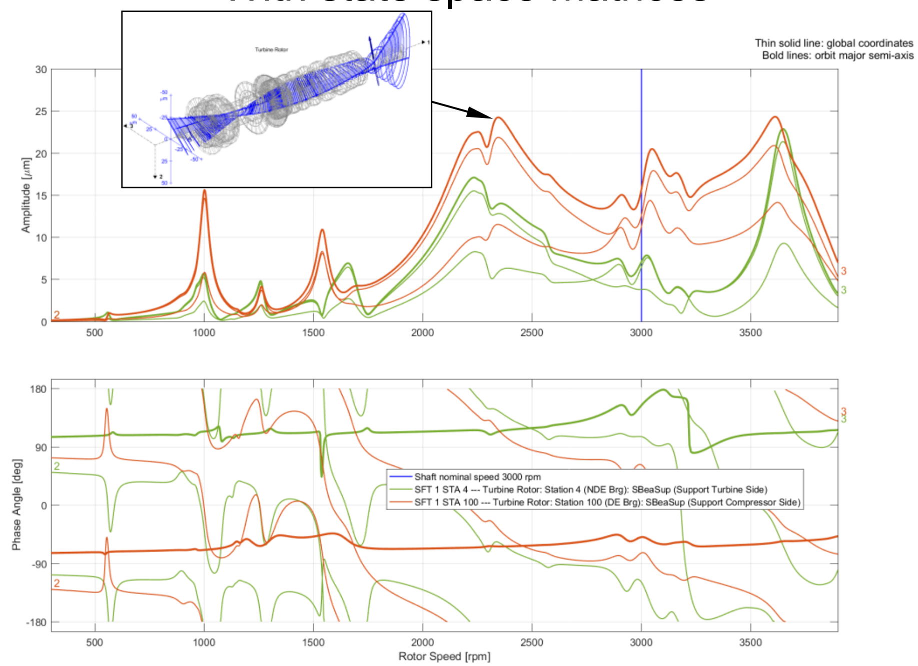
Unbalance load

Comparison of the relative shaft displacement at the bearings.

With spring & mass



With state space matrices



Conclusion

- A specialised software such as MADYN 2000 is an efficient tool for rotordynamic analyses.
- ANSYS as a general FE program is well suited to analyse complex support structures of turbomachines.
- State space matrices, which exactly describe the dynamic properties of the support structure, can be created with ANSYS and then imported into MADYN 2000.
- The presented method enables a rotordynamic model, which is both accurate and lean. Thus, it combines the best of two worlds.