Coupled Rotor-Bearing-Casing Analysis
Gekoppelte Rotor-Gleitlager-Gehäuse Berechnung
Using State Space Matrices from ANSYS in MADYN 2000

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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 rotordynamics software such as MADYN 2000 has proven to be most efficient 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.
What is Rotordynamics?

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.

\[ k_{22} = 8.5e+08 \text{ N/m} \]
\[ k_{33} = 5.6e+08 \text{ N/m} \]
\[ m_{22} = 100 \text{ kg} \]
\[ m_{33} = 100 \text{ kg} \]
Support Modelling with Spring & Mass

Rotordynamic Model – Turbine Shaft

Turbine Rotor

Support data

Bearing

Bearing

k_{32} = 8.5e+08 N/m
k_{33} = 5.6e+08 N/m
m_{22} = 100 kg
m_{33} = 100 kg

k_{22} = 1.82e+09 N/m
k_{33} = 8.2e+08 N/m
m_{22} = 100 kg
m_{33} = 100 kg
Support Modelling with Spring & Mass

Rotordynamic Model – Fluid Film Bearing

Hydrodynamic pockets (oil wedges)

Speed-dependent bearing coefficients

Displacement

Shaft position

2-Direction [µm]

3-Direction [µm]

Stiffness

Damping

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Support Modelling with Spring & Mass

Campbell Diagram and Critical Modes

Critical speeds

1xn Line

Bold line indicates plane with max. displacement

Critical speeds

1xn Line

Damping Ratio [%]

Reference Speed [rpm]

Reference Speed 3000 [rpm]

Integer harmonics for 3000 rpm

Natural Frequency [Hz]
Support Modelling with Spring & Mass

Unbalance Response

Relative shaft displacement at bearings

Pedestal velocity

Unbalance load case
Support Modelling with Transfer Functions

- 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.
Support Modelling with Transfer Functions

Calculating the TF in ANSYS

List of the response for 1N vertical harmonic excitation and 1% damping ratio.

(Transfer functions are imported into MADYN 2000 as text files.)
Support Modelling with Transfer Functions

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
• 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.
Support Modelling with State Space 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

Symmetric

Specify damping

Natural frequencies of the casing

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<th>Frequency [Hz]</th>
<th>Damping Ratio [%]</th>
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Support Modelling with State Space

The Transfer Functions

Transfer functions from the state space system.

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

Coupled rotor-casing mode

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

Arrow = Casing displacement
Support Modelling with State Space

Unbalance Response

Comparison of the relative shaft displacement at the bearings.

With spring & mass

With state space matrices

Unbalance load
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.