MADYN 2000 Version 3.6

The following new features were introduced in version 3.6:

1. Automation of Analyses
2. New Radial Fluid Film Bearing Features
3. New Feature for Displacement Loads (Misalignment)
4. Plots and Tables to Support the Magnetic Bearing Control Design
5. Material Import for Shafts from Tables in Text Files
6. Extension Points
7. Plotting Features
8. Automatic Storing of Transient Analysis Displacement Results

Apart from these feature several bugs were fixed.

Table of content:

1. Automation of Analyses

I.1 Result Placeholders

In MADYN 2000 systems results are deleted in case of model changes. However, in version 3.6 and later version only the result data are deleted. The link to analysis parameters and load case are maintained by result placeholders as indicated in fig. I.1.

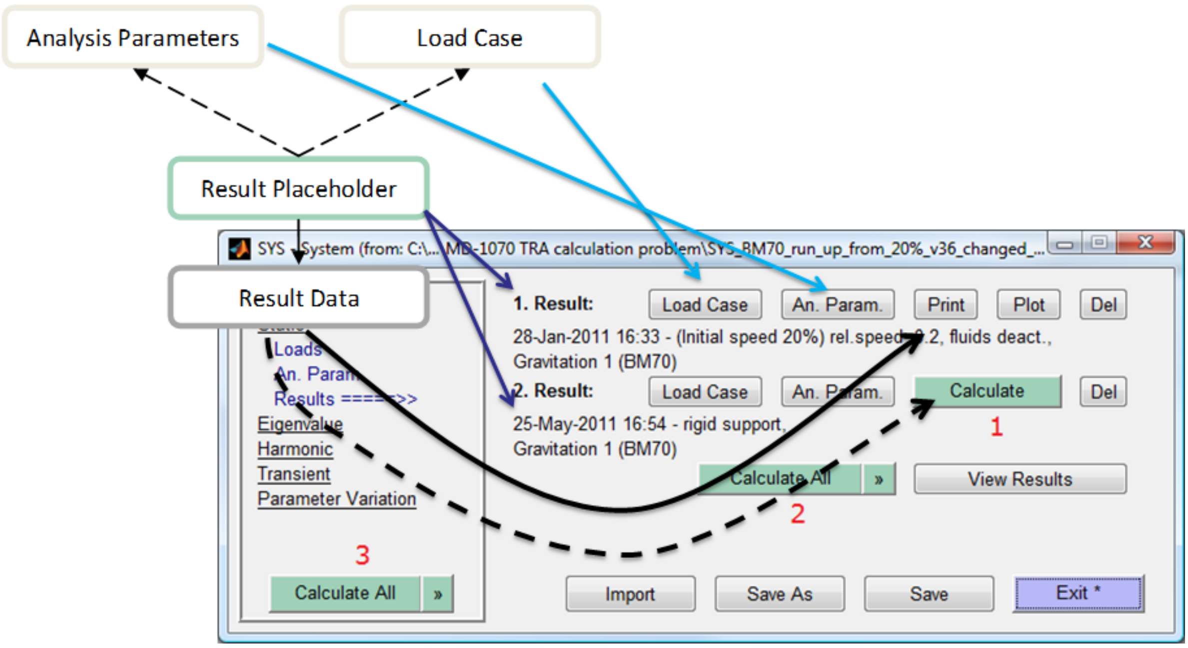


Fig. I.1: Result placeholders

Result placeholders are not only created by deletion in case of system changes, but also from analysis GUIs as shown in figure I.2. The menu item “Calculate later”, which appears by clicking on the symbol “>>” next to the “Calculate” button creates a placeholder.

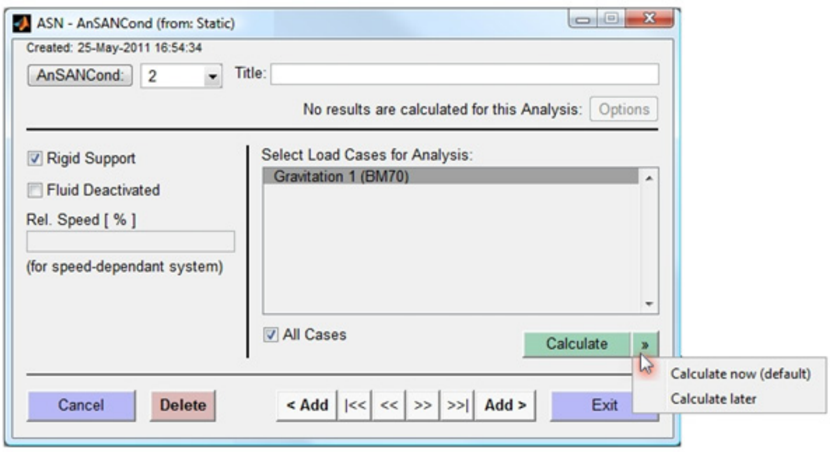


Fig. I.2: Creation of placeholder from Analysis GUIs (example for static analysis)

The placeholder contains all the information, required to actually perform the calculation. It is possible to change analysis parameters and load cases referenced from the results until the calculation is done.

In the System Explorer window result placeholders are easily distinguishable from normal results as shown in figure I.3 and obviously cannot be plotted before data is actually calculated.

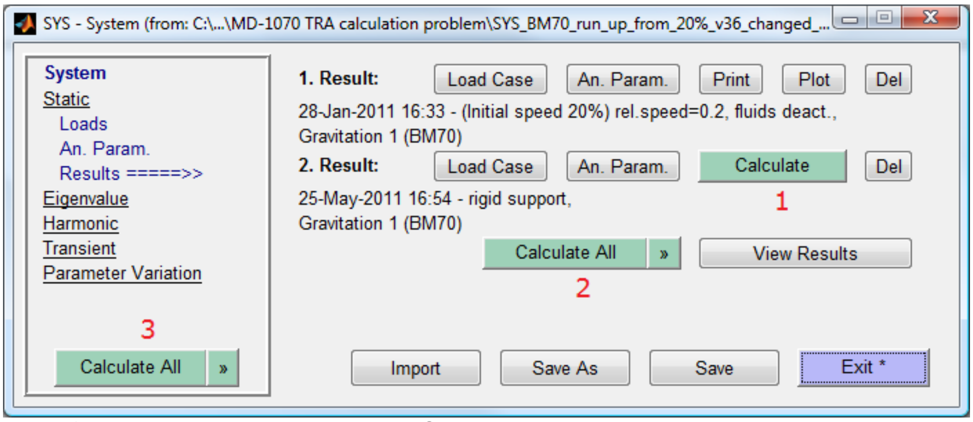


Fig. I.3: Results with placeholder in System Explorer

Up to three “Calculate” buttons appear in the System Explorer, if there are any result placeholders:

1. Calculate single result placeholders
2. Calculate all result placeholders of one analysis type (in the example Static)
3. Calculate all result placeholders in the system

Certain types of analyses may depend on the results of another analysis, for example Static result placeholder can be used as initial conditions in Transient analysis. In this case the two calculations will start automatically in the correct order. Therefore all necessary calculations can be prepared and started at once in automatic mode by one click.

In certain cases messages requiring user confirmation or answers may appear during the preparation of an analysis. To enable a fully automatic mode without user interaction an option to carry out the analysis silently exists as shown in figure I.4. The option can be selected from the menu appearing by clicking on the “>>” symbol.

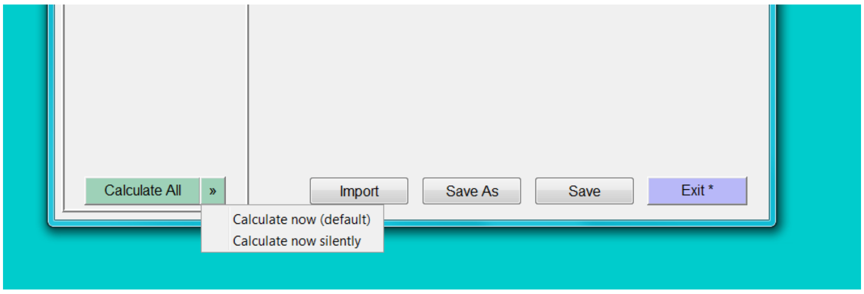


Fig. I.4: Calculate options in case of several analyses

I.2 Templates by Batch Files

All loads and analyses with their parameters can be exported to a so called "MADYN batch processing" file with the extension "mbp" by means of the "Save as" button as shown in figure I.5.

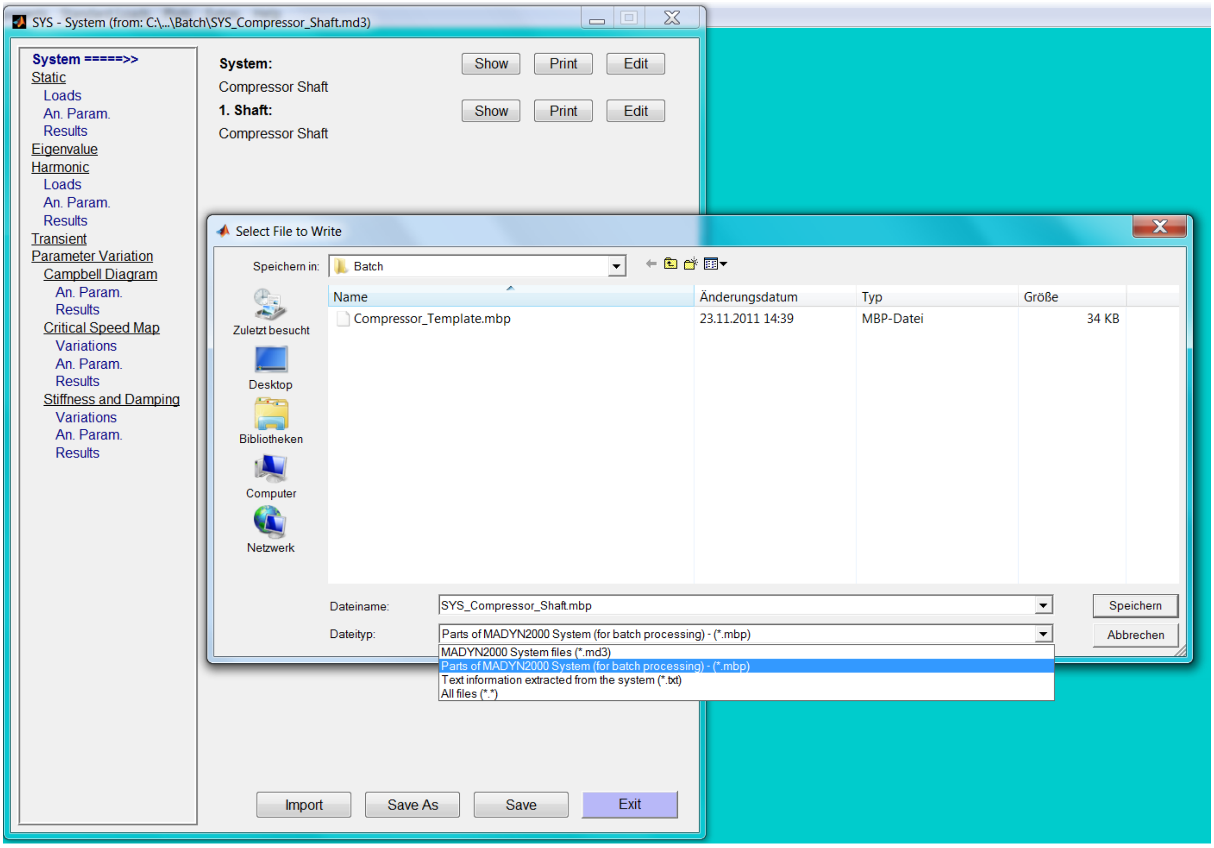


Fig. I.5: Export to a batch processing file

This batch file can be imported to any other system. Corresponding loads, analysis parameters and result placeholders will be created in the new system. Since the new system may have a completely different model with other stations and shafts all objects (shafts, stations…), which are referenced in loads or analyses (selecting certain result for example requires reference to shafts and stations) must have denotations to enable an export. The new system to which the batch file is imported should have the same denotations, otherwise the loads and analyses parameters cannot be created.

Before the batch file is created a window with the content of the file is shown (see figure I.6). In case any object has a missing denotation it is highlighted (in figure I.6 it is Station 60). The objects by which an object is referenced (e.g. a load case or analysis) are also shown (bottom of the window in figure I.6). The missing denotation can be entered in the edit field at the button.

In case a denotation is missing during import a corresponding message appears (see for example figure I.7).

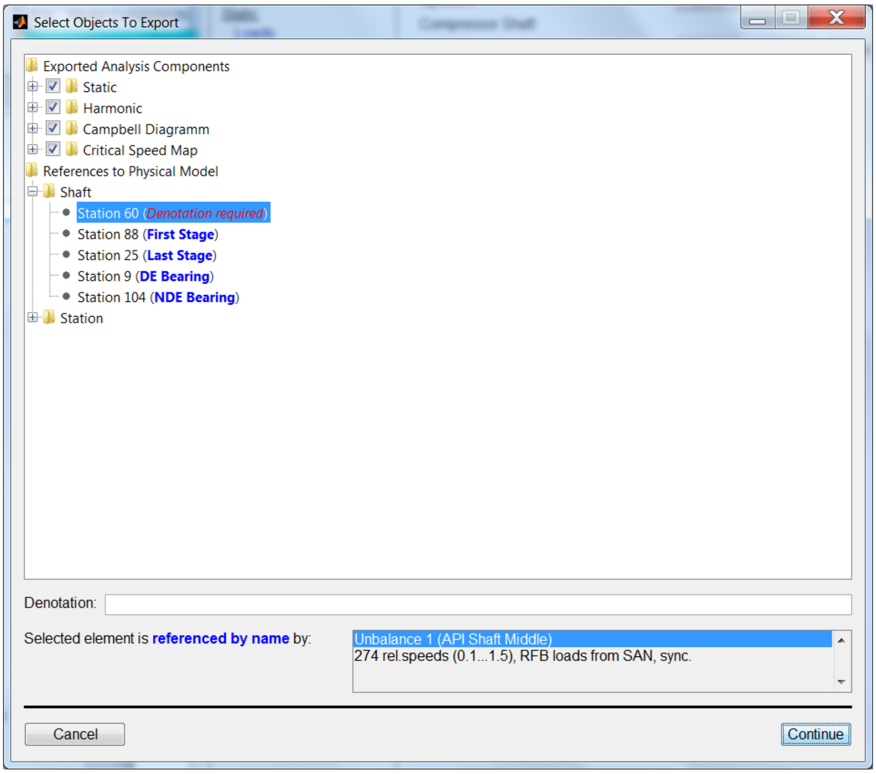


Fig. I.6: Content of batch processing file

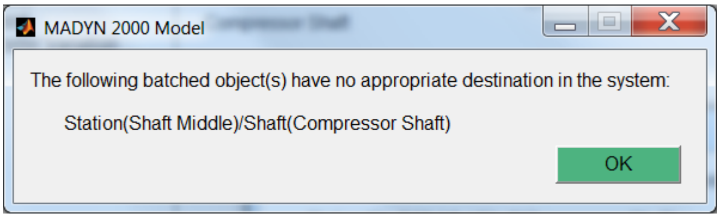


Fig. I.7: Error message in case of missing denotation during import

I.3 Command Lines

Usually, rotor dynamics analysis is just one step in a complex engineering process. Therefore a command-line interface to MADYN 2000 is introduced to speed-up and simplify integration of MADYN 2000 into in-house software systems.

This chapter describes low-level technical details on how to run MADYN 2000 in automated mode. If you are not familiar with the concept of Command-line Interface or basics of scripting in Windows, it is recommended to learn more about these topics. Alternatively, it is possible to execute external programs from scripts in other programming languages.

<u>Commands</u>

Start menu icon points to “MD3Start.exe”. This helper application shows ‘Loading’ screen and redirects messages and warnings from underlying console application to the log file. For the scripts calling MADYN 2000 in Batch mode, it is necessary to execute underlying console application “MD3.exe” directly and optionally redirect messages and warnings to different log files.

The program can be started with optional command-line arguments:

MD3.exe <System File> <command> <parameter> …

The first argument “System File” is a file name of MADYN 2000 System, which will be opened in user interface when the application starts. Additionally it is possible to specify several pairs of arguments: command and its parameter.

Available commands are listed in the following table, in order of precedence:

Command	Description	Possible Parameters
Execute	Reads and executes commands from a text file. Commands should be entered.	**File name**, .txt extension is recommended
Import	Reads MADYN 2000 batch file and imports it to opened system.	**File name**, *.mbp
Calculate	Calculate data for empty result placeholders that are present in the system or were imported.	‘**all’** – finer control is planned for future versions
Check	Check currently open model for possible errors, like missing objects	**‘optional’** – any problems will be reported as warnings ‘**required**’ – model will not be saved if check fails
Quit	Save the system and close MADYN 2000 after performing all operations	Output **File name**, *.md3

If “Quit” command is not provided, user interface will remain open after performing the commands. Otherwise application terminates.

When application terminates, scripts can check exit code (e.g. using MS-DOS ErrorLevel command).

Exit Code	Meaning
0	No errors, program was closed by the user.
1	No errors, program terminated after performing commands.
> 9	Error while running commands. Text output may contain details.
> 90	Internal error. See error log for details.

A Simple Example

To get a quick idea about running MADYN 2000 from command-line, you can start with learning examples that are installed to “My documents\MADYN 2000\Examples\Batch processing”.

Open example file from “1. Simple Use\run_example_1.bat” in text editor. Be aware, that simple double-click on the file will cause it to start instead of opening it for edit.

On the line 8 you will find the main command. Let us examine its parts:

md3	"SYS_dummy.md3"	Calculate	all	Quit	SYS_dummy_calculated.md3
1	*2*	*3*	*4*	*5*	*6*

1. *md3* – the name of executable file of MADYN 2000 with console output
2. *"SYS_dummy.md3"* – system to open
3. *Calculate* – first command
4. *all* – parameter for the first command
5. *Quit* – second command
6. *SYS_dummy_calculated.md3* – parameter for the second command

Example 2 in the folder does exactly the same, but keeps the commands and their parameters in a separate text file, “example_commands.txt”.

Use double quotes “ to specify a file, if its name contains spaces.

You can try running those examples. “SYS_dummy.md3” will be loaded (a sample system that contains some result placeholders), and then calculate all of them and save result to “SYS_dummy_calculated.md3”. Of course, it is possible to open both systems in MADYN2000 to see their contents.

More Examples for Command Lines

To open a system and add loads and analysis parameters from batch files, calculate all prepared analyses one can execute this command-line:

```
md3.exe “c:\...\SYS_Example.md3”
Import “c:\...\Library\Standard Loads.mbp”
Import “c:\...\Library\Standard Analysis.mbp”
Calculate all
```

This should be specified in one line as startup parameters to md3.exe. Alternatively, it is possible to save some commands in a text file (e.g. “madyn_commands.txt”) and run them using “Execute” command.

The content of “madyn_commands.txt” then is:

```
Import “c:\...\Library\Standard Analysis.mbp”
Import “c:\...\Library\Standard Loads.mbp”
Calculate all
```

Startup parameters for md3.exe are:

```
md3.exe “c:\...\SYS_Example.md3”
Execute “c:\...\madyn_commands.txt”
Quit “c:\...\SYS_Example_updated.md3”
```

According to command precedence, MADYN2000 will do the following:

1. Open SYS_Example.md3
2. Read additional commands from madyn_commands.txt
3. Perform all imports
4. Calculate all pending results
5. Save resulting system to “SYS_Example_updated.md3” and quit MADYN2000

File with MADYN2000 commands can contain comments in lines starting with # or %.

It is not possible to analyse several MADYN 2000 systems during one execution. To work on several systems, you might use any external programming or scripting languages, like Windows Batch files, Perl or MATLAB.

The folder “2. Multiple processing” contains a Windows batch file “run_example_2.bat”, which starts MADYN 2000 for two systems containing result place holders and stores the system with calculated results in a folder “…\out”.

The folder “3. Update systems” contains an example for a script in MATLAB, which updates systems in a folder to the latest MADYN 2000 version by the command “Check”.

2. New Radial Fluid Film Bearing Features

2.1 Overview of New Features

For tilting pad bearings the pad thickness has a slight influence on the kinematics of a pad. Therefore this parameter is introduced as a variable in version 3.6. Until now it was defined as 20% of the bearing diameter.

Several further new features for radial fluid film bearings were introduced in version 3.6. Table 2.1 gives an overview of all available features for the different analysis types “DIN table (DinTab)”, “constant adiabatic (c_ad)” and “variable adiabatic (v_ad)”. It corresponds to table II.6.1 in the documentation. The features highlighted in grey fields are new feature in version 3.6.

Table 2.1: Features for different analysis types. Grey fields: New features in version 3.6.

	Feature	Available for Analysis Type
Geometry	Fixed and tilting pads with different preload, curvature / support angles	All analyses
	Hydrodynamic pockets*	All analyses
	Pressure dam bearing*	All analyses
Physical fluid effects	Turbulence (Reynolds number)	Constant adiabatic Variable adiabatic
	2-phase flow in cavitation zone*	Constant adiabatic (option) Variable adiabatic (option)
Features regarding fluid supply, surrounding fluid and seals	Analysis of oil temperature from inlet temperature	DIN Table (→ mean temperature) Variable adiabatic (→ 3-dim. temp. distr.)
	Oil supply pressure**	DIN table with Qp Variable adiabatic
	Oil supply conditions and axial sealing*: • Sealed,*** • defined flow,**** • optimum (→ area between pads has oil supply temp.)	Variable adiabatic, tilting pads only
	• Ambient pressure*	Constant adiabatic (2-phase flow) Variable adiabatic (2-phase flow)
Thermo elasticity	Thermal deformation of pads and journal*	Variable adiabatic
Mechanical effects	Pad support stiffness & damping*	Variable adiabatic, tilting pads only
	Canting*	All analysis types

* Available for analysis with ALP3T 4.3.
** In case of DIN table available for analysis with ALP3T 4.3.
*** Sealing clearance defined relative to shaft radius.
**** The default defined flow is calculated as follows: $Q = u\ R\ \Psi\ B$, with u = 50m/s as circumferential speed.

2.2 Dependencies and Interpolation

Dimensioned bearing coefficients are interpolated from the dimensionless stored bearing coefficients in case of “standard bearings” and “user defined” bearings. In previous versions the interpolation was done by the So-number, which can lead to wrong result in some cases, because of other dependencies. Same So-numbers can yield different results for the same bearing and lubricant, if the speed and force are not the same. Table 2.2 gives an overview of dependencies for different analysis types.

Table 2.2: Dependencies of different analysis types

Analysis Type	Dependency
DIN table without Qp[1)]	So-number
DIN table with Qp[1)]	So-number, dimensioned speed n and Force F
Constant adiabatic	So-number, Re-number, ambient pressure
Variable adiabatic	So-number, Re-number, Pr-number, further parameters depending on considered features (see table 2.1)

[1)] Qp: Additional oil flow due to inlet pressure. This flow violates the So-similarity.

In version 3.6 the interpolation and the validity of dimensionless data created with certain dimensioned forces and speeds is more restricted, in order to prevent a misuse of the dimensionless tables.

For the deletion of the dimensionless data in the RFB object in case of any changes of the bearing geometry or the lubricant the following applies in version 3.6:

- For the analysis types “constant adiabatic” and “variable adiabatic” the user can activate a check box “So-similarity”. In this case it is assumed, that the results only depend on the So-number and other dependencies such as the Re-number are ignored. In case of lubricant changes or changes of its temperature the results of the analysis are maintained. The same applies for geometry changes, which do not violate the So similarity (maintenance of the preload and ratio width / diameter). For other geometry changes the results are deleted.
- In case “So-similarity” is not active, results for analysis type “variable adiabatic” are deleted for any change. For analysis type “constant adiabatic” the behaviour is the same as with “So-similarity”, since the dependency on the Re-number is not as strong as in case of “variable adiabatic” analysis.
- Analysis type “DIN table” without considering Qp is the only analysis, where the So-similarity fully applies. Geometry changes, which maintain the So-similarity therefore do not cause deletion of the results. Changes of the lubricant or its mean temperature for which the table is calculated cause a deletion of the results. Change of the inlet temperature, from which the actual mean temperature is calculated, maintain the results.

For the interpolation of dimensioned bearing coefficients from dimensionless tables in case of analyses such as EIG, CDG, HAR…, or in case of “List Results” in the RFB GUI after a load change the rules according to table 2.3 apply. The additional required Re-number, dimensioned force and speed are stored in the dimensionless table created by version 3.6. If tables from earlier versions without this information are used, So similarity applies.

Table 2.3: Interpolation in case of different bearing and analysis types

Bearing Type	Analysis Type	Interpolation
User defined	DIN without Qp	Interpolation by So-number and direction
	DIN with Qp	Interpolation by So-number, direction and dimensioned F, n
	Constant adiabatic	Interpolation by So-number and direction; check of Re-number if check box “So-similarity” is not active.
	Variable adiabatic	Interpolation by So-number and direction. Additionally by dimensioned F, n if check box “So-similarity” is not active.
Standard	DIN without Qp	Interpolation by So-number and direction
	DIN with Qp	Interpolation by So-number and direction; dimensioned F, n are also used if they are present in the table.
	Constant adiabatic	Interpolation by So-number and direction; check of Re-number if check box “So-similarity” is not active.
	Variable adiabatic	Interpolation by So-number and direction; check of Re-number if check box “So-similarity” is not active.

Interpolation by the dimensioned force F [N] and speed n [rps] means that the actual force and speed must be in the range of the dimensioned forces, speeds and directions in the table. For the force magnitude and speed a tolerance of 10% applies, for the angle $\Delta\Phi$. A pre-interpolation is carried out before the actual interpolation according to the So-number.

The check of the Re-number means, that a warning appears, if the actual Re-number deviates by more than 10% from the Re-number in the table at the interpolated So-number and direction. In case of “constant adiabatic” analysis the warning only appears only if the Re-number at the same time is above 2000 (→ turbulent flow). It should be noted, that for “variable adiabatic” analysis this check does not fully ensure, that the dimensionless table can be applied to the actual bearing, load and speed, because of further dependencies.

2.3 Changes in User Interface for Hydrodynamic Pockets and Pressure Dam

For the modelling of the hydrodynamic pockets and pressure dam bearing the user interface for the pad definition is extended. It is shown in figure 2.1 for a 3-pad bearing with hydrodynamic pockets and in figure 2.3 for a pressure dam bearing.

The GUI now has a drop down menu “Hydrodynamic Model”, which offers three options: “Normal”, “Pockets” and “Pressure Dam”. In case of “Normal” the edit fields for the definition of the pockets and the dam do not appear.

The meaning of the inputs can be explained with the new clearance plots, which are shown in figure 2.2 for the pad with hydrodynamic pocket and in figure 2.4 for the pad with pressure dam. The clearance plot for the complete bearing is explained in chapter 2.5.

For the bearing with hydrodynamic pocket the “Curvature Centre”, the “Clearance Ratio” and the “Theor. Depth” define the dashed line in figure 2.2, which is the “theoretical pocket clearance”. In the present case the theoretical depth corresponds to the distance between the pad clearance line and the pocket line at the angle 0 degree (because pad and pocket curvature centre are both 180^o). The theoretical depth shifts the pocket clearance line. Since the pocket curvature is larger (clearance ratio 6) than the pad curvature (clearance ratio 3) the two lines intersect. The angle “End Angle at Pad Start” (the angle, where the pocket ends on the left side) and “Start Angle at Pad End” (the angle, where the pocket starts on the right side) define the range, where the pocket clearance line applies. It must be noted, that the pocket must not end and start exactly at the intersecting points of the pad and pocket line, i.e. a step can occur.

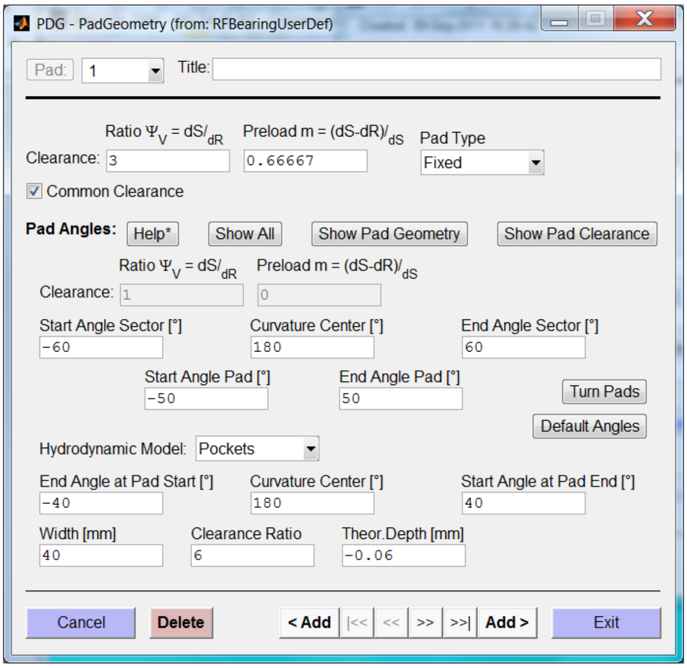


Fig. 2.1: User interface for hydrodynamic pockets

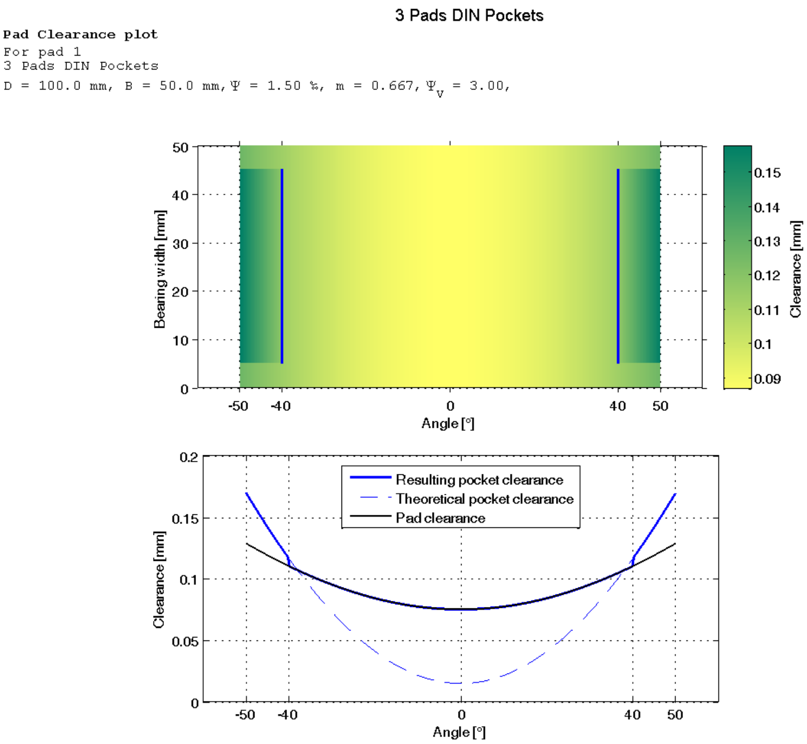


Fig. 2.2: Clearance plot for the pad in fig. 2.1

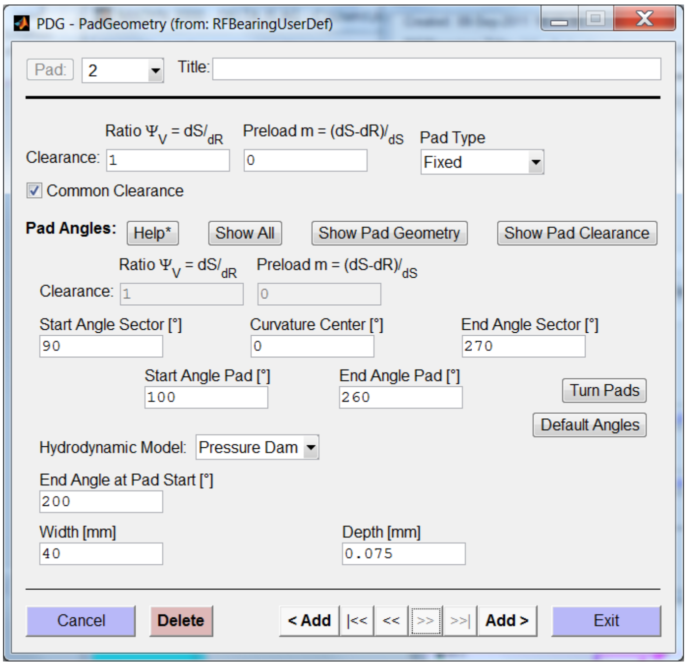


Fig. 2.3: User Interface for pressure dam

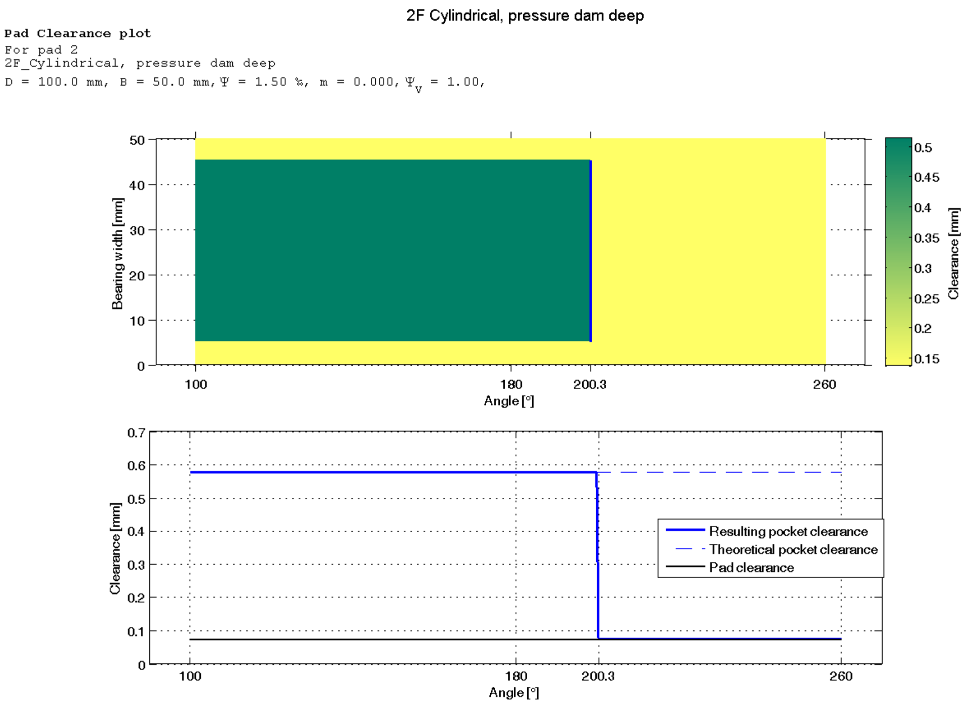


Fig. 2.4: Clearance plot for the pressure dam in fig. 2.3

The pressure dam can only be defined for 2-lobe bearings in the 2nd pad, since the pressure dam should always be opposite of the loaded pad. It is a simplified hydrodynamic pocket with a constant depth. Only the depth and the end angle of the pocket have to be defined.

2.4 Changes in User Interface for further New RFB Features

As can be seen in table 2.1 several further new features for RFBs were introduced, which require new inputs. In the following the corresponding changes in the GUIs are shown.

<u>Pad Thickness</u> (for tilting pad bearings)

As explained in chapter 2.1 the pad thickness is a new input parameter for tilting pad bearings. The RFB GUI with the corresponding edit field is shown in fig. 2.5. The default value is 20% of the bearing diameter.

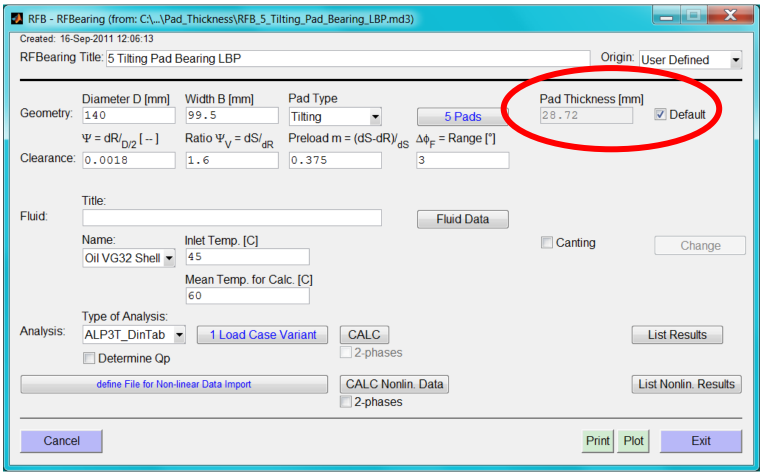


Fig. 2.5: RFB GUI with edit field for pad thickness

<u>Oil supply conditions and axial sealing</u> (for tilting pad bearings with variable adiabatic analysis)

In fig. 2.6 the GUI for a tilting pad bearing and variable adiabatic analysis with the pull down menu to select the oil supply condition and the axial sealing is shown. The option “Sealed” requires the input of the sealing clearance as shown in fig. 2.7. The input is relative to the shaft radius. The default value is two times the bearing clearance. The option “Unsealed Defined Flow” needs a flow as input as shown in fig. 2.8. For the explanation of the default value see table 2.1.

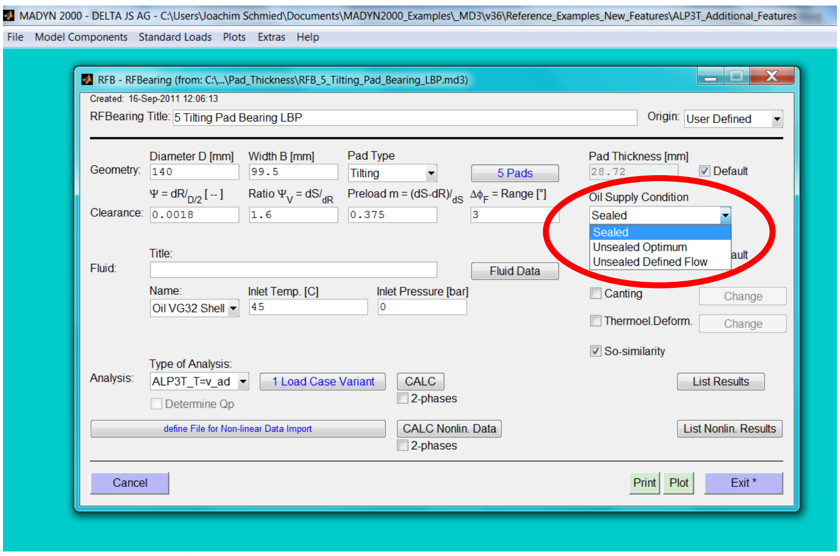


Fig. 2.6: RFB GUI with oil supply and sealing condition

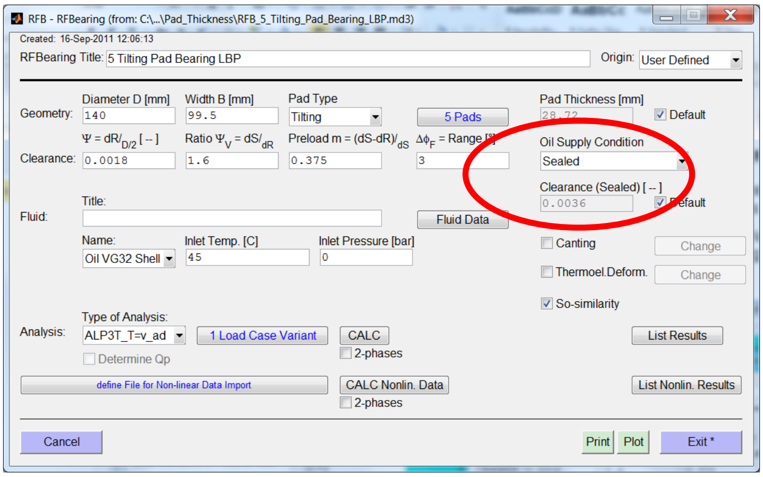


Fig. 2.7: RFB GUI for a sealed bearing with the sealing clearance

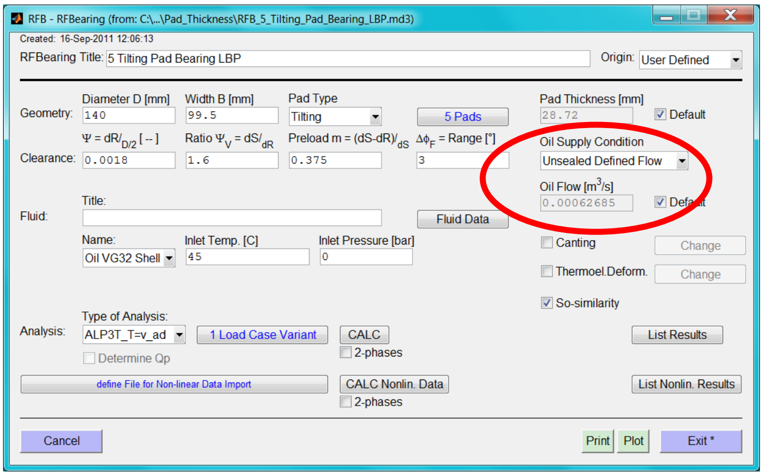


Fig. 2.8: RFB GUI with defined flow

The option unsealed optimum does not require an additional input. For this option is assumed, that the temperature between the pads corresponds to the oil inlet temperature.

Ambient pressure (for 2-phase flow)

For all analyses with 2-phase flow an ambient pressure can be defined. Such pressure has an influence on the cavitation. For high ambient pressure the cavitation can be completely suppressed. The RFB GUI with the corresponding input field is shown in fig. 2.9.

Thermo elastic pad deformation (for variable adiabatic analysis)

For variable adiabatic analysis the thermo elastic deformation can be considered. It requires the input of thermal expansion coefficients and a Young's modulus. The corresponding window with input fields is shown in 2.10.

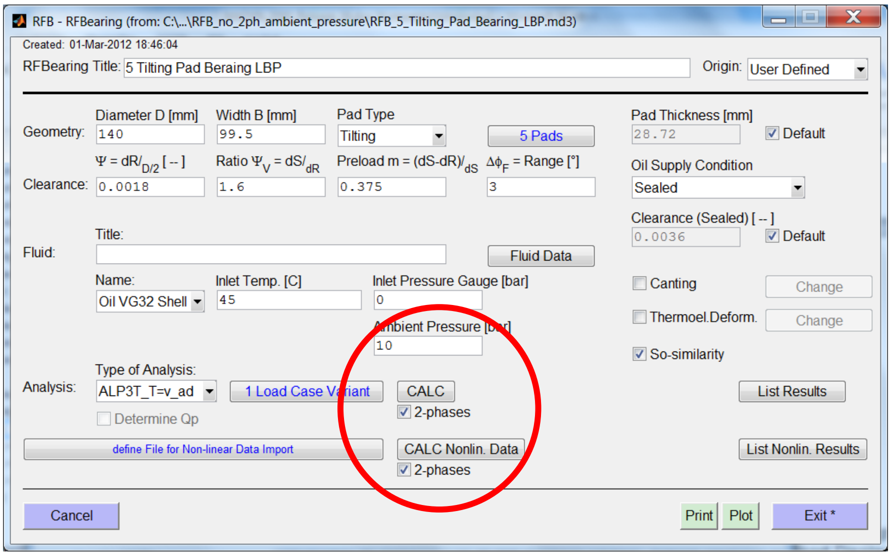


Fig. 2.9: RFB GUI with input field for ambient pressure

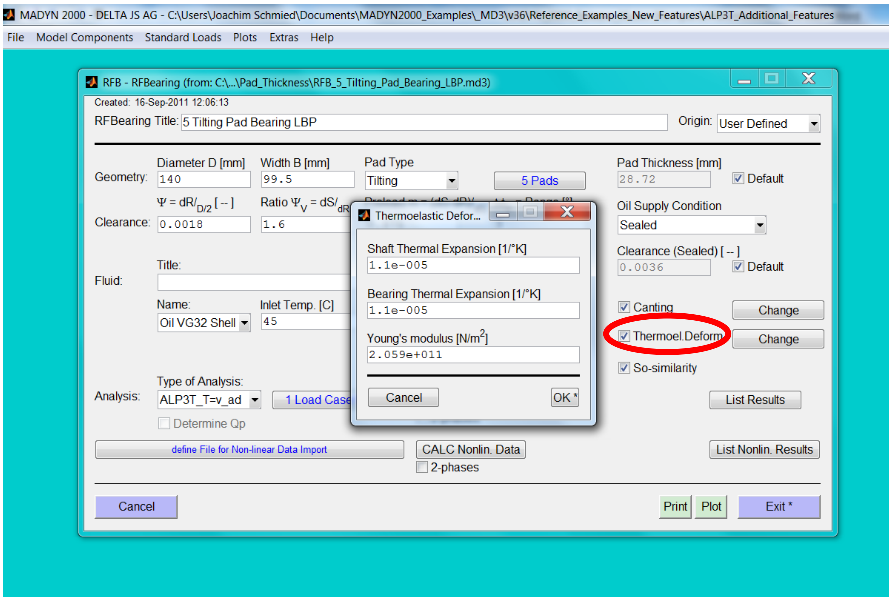


Fig. 2.10: RFB GUI with window for inputs for the thermo elastic deformation

<u>Pad support and stiffness</u> (for tilting pad bearings with variable adiabatic analysis)

Pad support stiffness and damping coefficients for the radial direction and the tilting can be defined for tilting pad bearings and variable adiabatic analysis. The pad GUI with the corresponding edit fields is shown in fig. 2.11.

<u>Canting</u>

Canting can be defined for all bearing and analysis types as shown in fig. 2.12. The input is relative to the radial bearing clearance. The coordinate system is the load oriented Glienicke system (also see II.6.3 in the documentation), i.e. the 2G direction corresponds to the load direction.

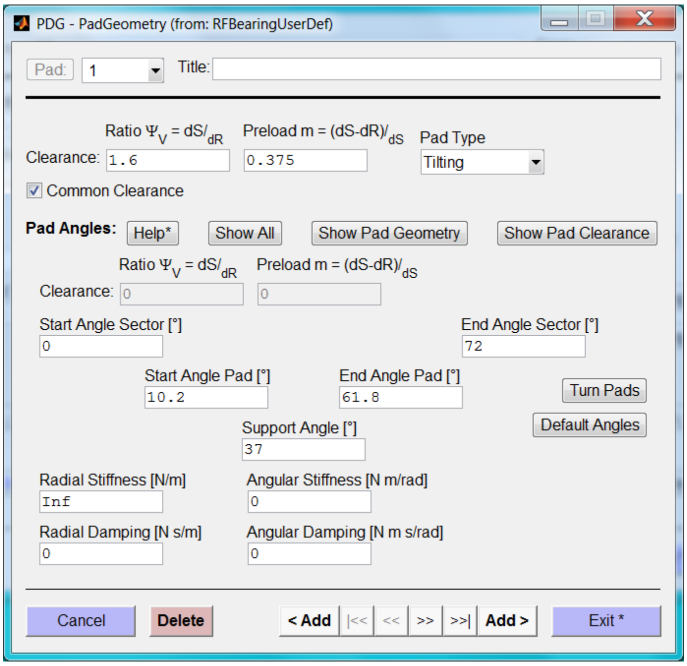


Fig. 2.11: Pad GUI for tilting pad bearing and v_ad analysis for pad support stiffness and damping

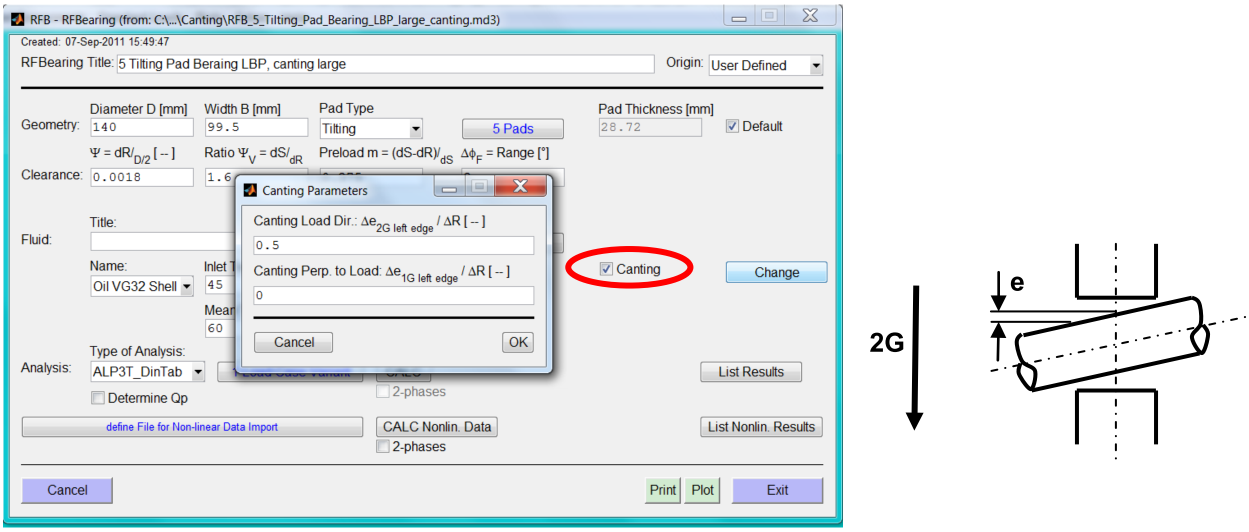


Fig. 2.12: RFB GUI with input fields for canting with the sketch for the meaning of e

2.5 Clearance Plot

The clearance plot was already used in chapter 2.3 explaining the pressure dam bearing and bearings with hydrodynamic pockets. The clearance plots of individual pads were shown. The plots were invoked from the pad GUI.

Clearance plots are also available for the whole bearing. In figure 2.5 the RFB GUI with the plot menu to select the clearance plot is shown. The resulting plot is shown in figure 2.6.

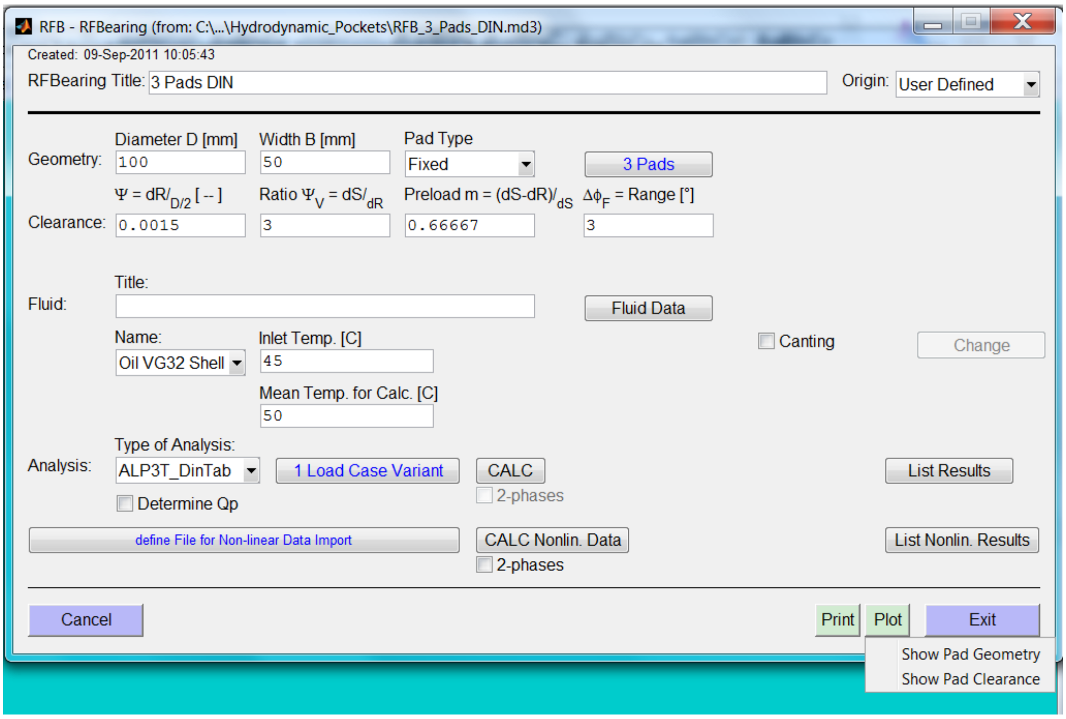


Fig. 2.5: RFB GUI with menu to call the clearance plot

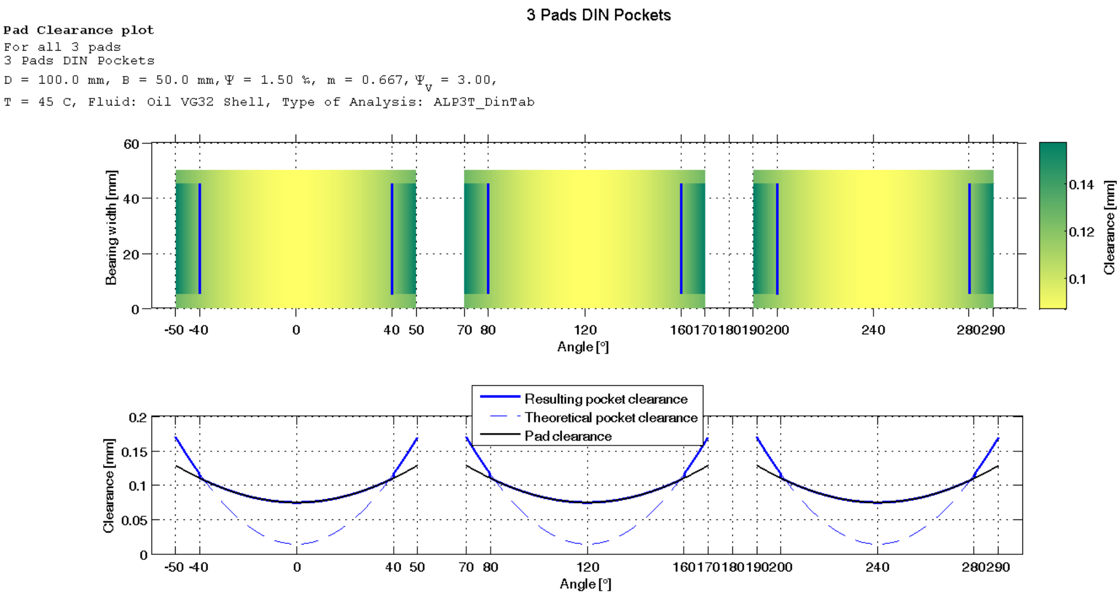


Fig. 2.6: Clearance plot of a complete 3-pad bearing with hydrodynamic pockets

3. New Feature for Displacement Loads (Misalignment)

Displacement loads in SAN for alignment studies can be applied at the shaft (option “Radial Shaft Displacement at Support”) or at the support (option “Radial Bearing Support Displacement”). In the latter case it is possible in version 3.6 to define the displacement only in one of the two radial directions (either in 2-direction or in 3-direction) as is shown in figure 3.1.

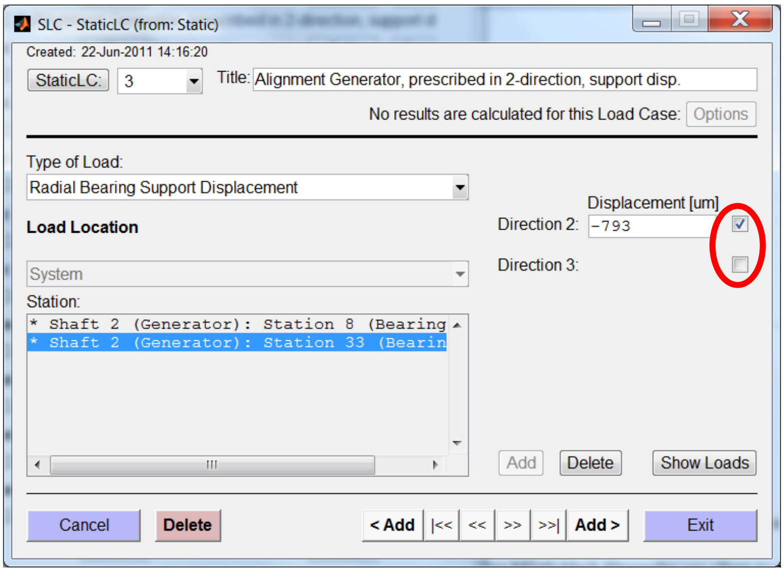


Fig.3.1: Defining prescribed radial support displacements

The two edit fields to define the displacement can be activated separately by a check box. The support displacement in the non-activated direction is not defined. After the analysis it will result in a value defined by the bearing force and stiffness of the support.

4. Plots and Tables to Support the Magnetic Bearing Control Design

To help designing and assessing magnetic bearing controllers some special diagrams and tables are offered.

The magnetic bearing sensitivity according to ISO 14839-3 is available since version 3.5. Additionally the Nyquist plot is available in version 3.6, which is another presentation of the result of the harmonic response analysis “Magnetic Bearing Sensitivity”.

Moreover tables for the observability and controllability of a magnetic bearing are available.

4.1 Nyquist Plot

The Nyquist plot is closely related to the sensitivity plot (see figure 4.1). It is more common in controls theory and based on the open loop transfer function $G_O = G_p\, G_r$ of a control loop as shown in figure 4.2. In the Nyquist plot the transfer function G_O is shown as polar plot (see figure 4.3) with real and imaginary axes.

The relation between the sensitivity G_S and the open loop transfer function G_O is as follows:

$$G_s = (F_{Excitation} - F_{Response})/F_{Excitation} = F/F_{Excitation} = 1 / (1+G_O) \qquad (4.1)$$

It should be noted, that the concept of the Nyquist plot is for single input, single output systems. Rotors on magnetic bearings actually are multiple input, multiple output systems. Nevertheless, the sensitivity and Nyquist plot are applied in practice and proved to be useful. In the Nyquist plot and sensitivity plot of a specific bearing controller the other bearings are participating as part of the plant.

The point “Dmin” in the Nyquist plot is the minimum distance to the point -1. Stable systems cross the real axis on the right side of this point. Crossing the axis at -1 means the system is at the threshold to instability.

The following relation between the minimum distance and the sensitivity applies:

$$|G_s|_{max} = 1/D_{min} \qquad (4.2)$$

The larger the distance to -1, the smaller the sensitivity and the more robust the system (margin to stability threshold).

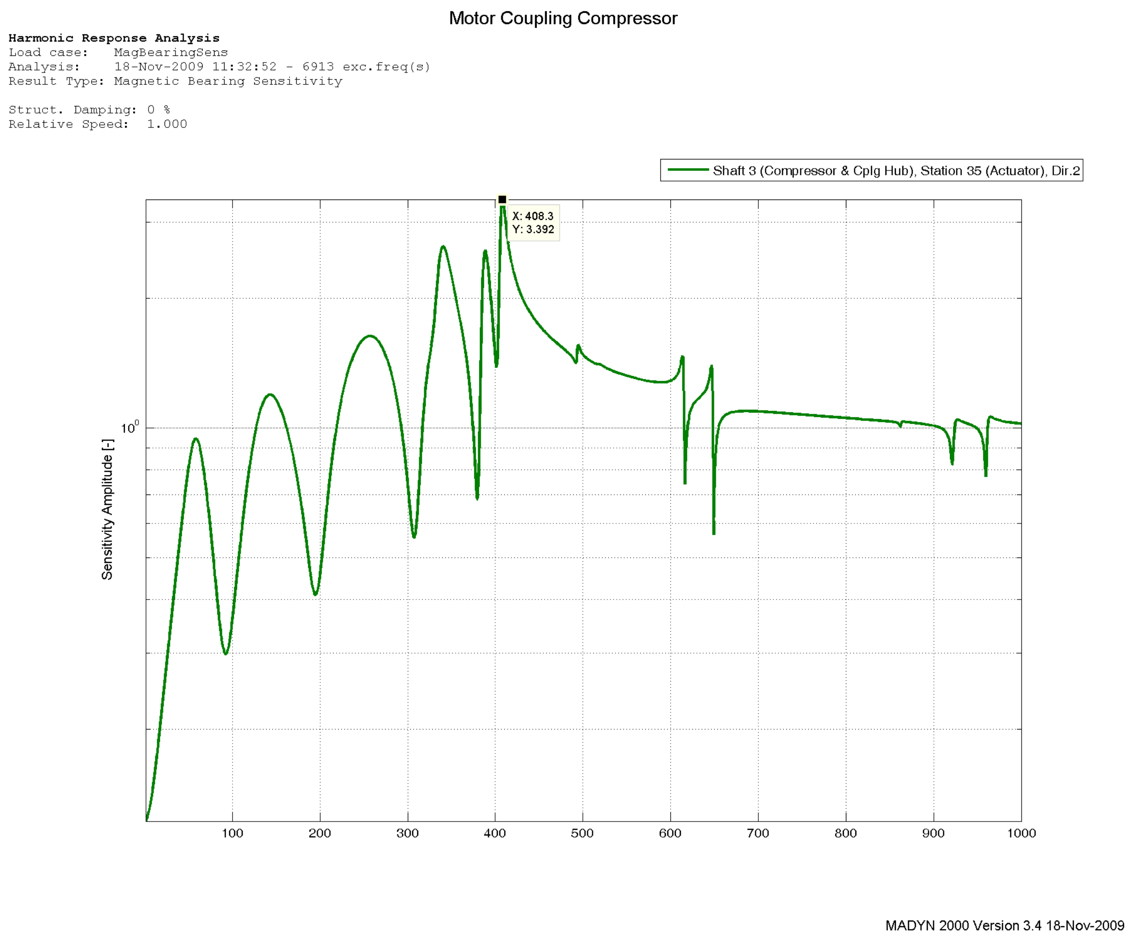


Fig. 4.1: Magnetic bearing sensitivity plot

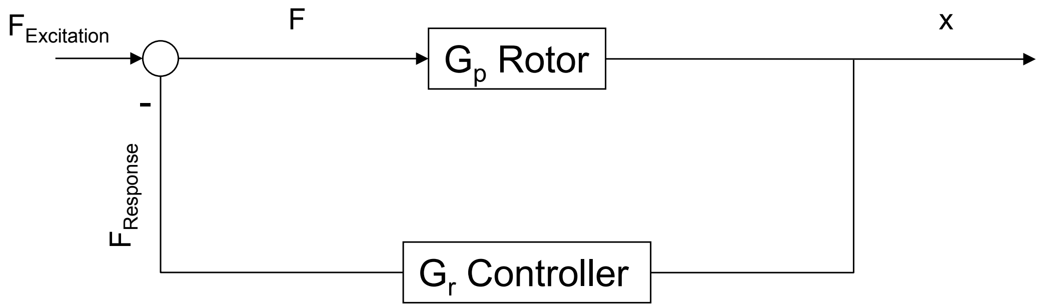


Fig. 4.2: Control loop for rotor (plant) and magnetic bearing controller

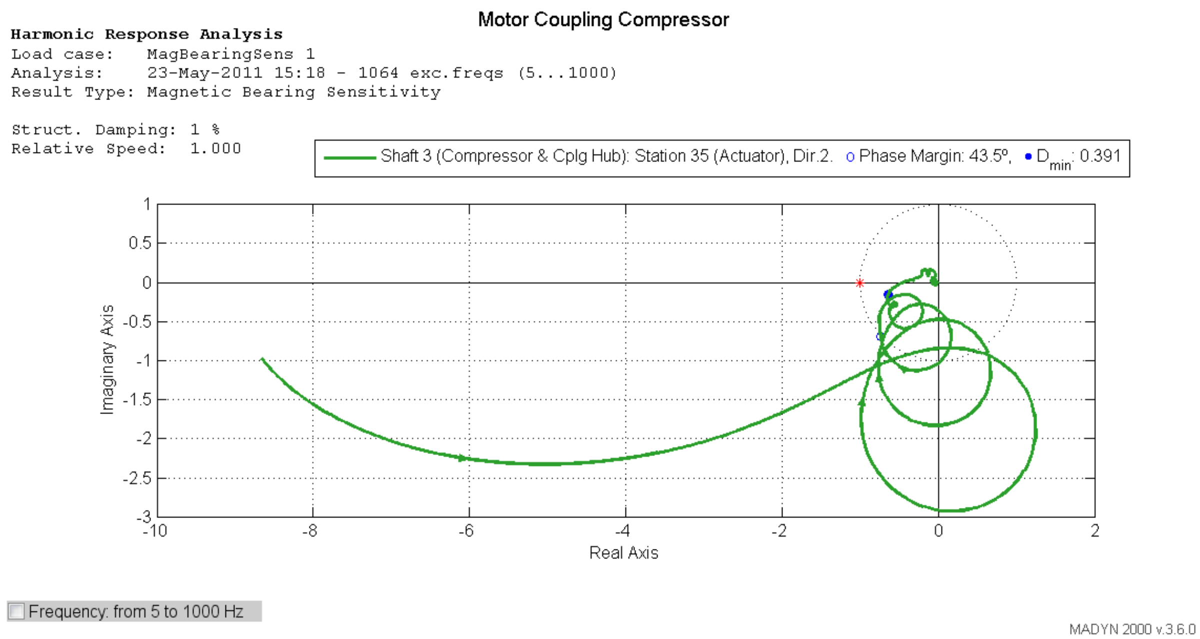


Fig. 4.3: Nyquist Plot

4.2 Observability and Controllability Table

For the assessment of the suitability of rotors for magnetic bearings and for the interpretation of results in closed loop condition it is useful to check the controllability and observabilty of natural modes. A natural mode is well observable by a bearing, if it has a large deflection at the sensor; it is well controllable, if it has a large deflection at the actuator.

In the following a observability / controllability table is shown for a free rotor with four magnetic bearings.

Observability and Controllability report

Bearing 1: Shaft 1 Station 05 Motor NDE Sensor
Bearing 1: Shaft 1 Station 06 Motor NDE Actuator
Bearing 2: Shaft 1 Station 25 Motor DE Sensor
Bearing 2: Shaft 1 Station 24 Motor DE Actuator
Bearing 3: Shaft 3 Station 09 Compressor DE Sensor
Bearing 3: Shaft 3 Station 10 Compressor DE Actuator
Bearing 4: Shaft 3 Station 36 Compressor NDE Sensor
Bearing 4: Shaft 3 Station 35 Compressor NDE Actuator

Mode	Freq	s1-05	a1-06	dA1	s1-25	a1-24	dA2	s3-09	a3-10	dA3	s3-36	a3-35	dA4
1	0.52	0.93	0.88	0	0.32	0.37	0	0.16	0.19	0	0.76	0.73	0
2	0.88	0.99	0.97	0	0.85	0.87	0	0.74	0.73	0	0.57	0.58	0
3	0.93	0.49	0.51	0	0.68	0.66	0	0.82	0.83	0	0.98	0.97	0
4	2.02	0.48	0.45	0	0.06	0.10	0	0.34	0.36	0	0.94	0.91	0
5	4.74	0.34	0.27	0	0.45	0.38	0	0.41	0.36	0	0.86	0.80	0
6	17.14	0.69	0.58	0	0.54	0.43	0	0.72	0.66	0	0.72	0.65	0
7	49.31	0.34	0.26	0	0.44	0.38	0	0.87	0.86	0	0.77	0.66	0
8	60.40	0.47	0.38	0	0.49	0.41	0	0.76	0.74	0	0.78	0.68	0
9	180.05	0.10	0.07	0	0.05	0.06	0	0.54	0.41	0	0.64	0.48	0
10	188.05	0.10	0.08	0	0.06	0.07	0	0.54	0.40	0	0.65	0.49	0
11	291.37	0.24	0.17	0	0.05	0.05	180	0.20	0.25	0	0.30	0.18	0
12	308.49	0.24	0.17	0	0.03	0.06	180	0.21	0.25	0	0.28	0.16	0
13	374.74	0.31	0.20	0	0.19	0.05	0	0.20	0.01	0	0.43	0.19	0
14	396.57	0.31	0.20	0	0.17	0.04	0	0.18	0.02	180	0.41	0.17	0
15	491.45	0.34	0.19	0	0.29	0.18	0	0.32	0.27	0	0.17	0.02	0
16	516.66	0.36	0.21	0	0.30	0.18	0	0.30	0.25	0	0.15	0.00	0
17	614.61	0.18	0.09	0	0.12	0.12	0	0.22	0.40	0	0.18	0.12	180
18	646.78	0.18	0.09	0	0.12	0.12	0	0.26	0.43	0	0.16	0.14	180
19	809.10	0.37	0.12	0	0.07	0.13	180	0.23	0.14	0	0.00	0.12	180
20	853.83	0.34	0.11	0	0.06	0.12	180	0.23	0.14	0	0.00	0.13	0
21	919.87	0.24	0.06	0	0.16	0.00	0	0.62	0.61	0	0.07	0.40	0
22	957.52	0.29	0.07	0	0.18	0.00	180	0.59	0.58	0	0.08	0.41	0

The “s” in the headline of the table indicates columns for sensors, the “a” for actuators. The following numbers correspond to the shaft and station numbers of the sensor and actuator. “dA..” stands for the angle difference between sensor and actuator.

The values in the sensor columns correspond to the observability of a mode by a bearing and those in the actuator columns to the controllability. They are the deflection of the rotor at the sensor and actuator position, respectively, in relation to the maximum deflection of the mode. An angle difference of 180 degree means, that there is a node between sensor and actuator. Note, that for closed loop systems the angles can take any value, due to the 3-dimensionality of the mode shape.

The observability and controllability table is available in all prints of PAR and EIG analyses in case a system has magnetic bearings. Moreover it can be created from the MADYN menu of the plot window for the eigenvalue plots “Damping and Frequency” as well as “Damping and Frequencies, RMB TF”.

5. Material Import for Shafts from Tables in Text Files

Shaft material properties can now be defined in text files for import to MADYN 2000 with the help of SIF (**S**haft **I**nterface **F**ile).

They can be directly defined in “MassSetionData”. In table 5.1 the complete set of data are shown as in the documentation. The new material data are highlighted in grey fields.

Table 5.1: “MassSectionData”. Grey fields are newly available in version 3.6.

Identifier for data*	Field of Object	Remarks and Default Values
Length	SEC	
TotLen		Total length: Sum of length of all previous sections. Values are redundant and are ignored.
Conical	SEC	0: Cylindrical section (default), 1: Conical section In case of a conical section 2 consecutive lines in the file must have the same “Number” and a “1” in the “Conical” column. The first line of such a pair then corresponds to the left and the second line to the right cross section. All MAS data of the second line must be zero.
IDsb	SEC	Default (if no input): 0
ODsb	SEC	
IDmb	SEC	Default (if no input): IDsb
ODmb	SEC	Default (if no input): ODsb
IDst	SEC	Default (if no input): IDsb
ODst	SEC	Default (if no input): ODsb
IDmt	SEC	Default (if no input): IDmb
ODmt	SEC	Default (if no input): ODmb
addmass	SEC	Default (if no input): 0
addinertiab	SEC	Default (if no input): 0
addinertiap	SEC	Default (if no input): 0
Temperature	SEC	Default (if no input): 20°C
E	MAT**	Default (if no input): 2.059e11 N/m^2
mue	MAT**	Default (if no input): 0.3
rho	MAT**	Default (if no input): 7’850 kg/m^3
M	MAS	Default (if no input): 0
Thetap	MAS	Default (if no input): 0
Thetae	MAS	Default (if no input): 0
Centre	MAS	Default (if no input): 0
klateral	MAS	Default (if no input): inf
krotational	MAS	Default (if no input): inf
Denotation	STA	Must always be the last column.
NotchB	STA	Default (if no input): 1
NotchT	STA	Default (if no input): 1

In the following a few lines of an example with columns for the material data are shown.

```
Shaft Title
* #    Conical     Length  ODsb       E    mue    rho       M   Temperature  Denotation
*         [-]       [mm]   [mm]      MPa    --    kg/m^3  [kg]      [°C]
1          0       166.7  130.0     2.1e5  0.3    7850    0.0       40
2          0        23.3  140.0     2.2e5  0.2    7880    0.0       40
3          0        60.0  130.0     1.2e5  0.3    8080    1.0       40    'Coupling connection'
```

Alternatively to directly importing material data in “MassSectionData” they can also be defined by the file name of a material object as shown in the following. For defining materials in this way the following rules apply: The material column must be the last column. In case there is a denotation column and a line has no denotation, then an empty value “''” must be entered as denotation. The file with the material object must be in the same folder as the file with the “MassSetionData”.

```
Shaft with materials from file
*      M   Length ODmb   IDmb   ODsb  IDsb  Denotation     Material
  1   0.00 0.2500 2.2440 0.0000 2.244 0.000      ''       'MAT_Steel.mat'
  2   0.00 0.2810 1.9840 0.0000 1.984 0.000      ''       'MAT_Steel.mat'
  3   1.85 0.4410 2.2440 0.0000 2.244 0.000 Coupling end 'MAT_Steel.mat'
  4   0.00 1.0000 2.2440 0.0000 2.244 0.000      ''
  5  13.87 1.0100 2.2440 0.0000 2.244 0.000      ''
  6   0.00 0.8990 3.2500 0.0000 3.250 0.000      ''
  7   0.00 1.0000 3.2500 0.0000 3.250 0.000      ''
  8   0.00 0.5000 3.6250 0.0000 3.625 0.000      ''
  9   0.00 0.5920 3.6250 0.0000 3.625 0.000      ''
 10   0.00 1.6080 4.0000 0.0000 4.000 0.000      ''
```

6. Extension Points

For some purposes it may useful to interrupt normal MADYN2000 calculations and adjust intermediate calculated results. This can be the case for the application of new methods developed by the user.

MADYN 2000 can be configured to call external functions during some steps of calculation. For example

- to modify inputs for ALP3T to carry out calculations according to own experience or specifications instead of using the standard inputs created by MADYN 2000,
- to change calculated State-Space matrices for DBS (see chapter II.12 of the documentation for the meaning of DBS).

Currently extension points for the above mentioned items are provided. They are described in the following. DELTA JS is open to provide further extensions on request.

6.1 General Explanations by Extension Point EIG_DBS

For Eigenvalue analyses with Dynamic Bearing Supports (DBS) the polynomial transfer functions of the supports (see chapter II.12 of the documentation) are transformed to state space matrices. This section describes how to apply your own transformation or how to modify state space matrices by your own MATLAB function with the help of an extension point.

The function call of your own function should be as follows[1]:

function SS = myUpdateSystemMatrices(input)

“SS” should be a MATLAB structure with the following four fields for the 2-dimensional state space matrices created by the function: A, B, C and D.

“input” is a structure with the following six fields: A, B, C, D, Numerator, Denominator. The fields A, B, C, D contain the original state space matrices created by MADYN 2000. The further two fields contain cell arrays for the numerator and denominator polynomial coefficients of the DBS transfer functions. The dimension of the cell arrays corresponds to the full matrix of transfer functions.

In the subfolder “Extensions” of the “Examples” folder which is provided with the installation you find a template function “test_cbSystemMatrices_function”, which creates the state space matrices from the polynomial transfer functions in the same way as MADYN 2000.

[1] The name “myUpdateSystemMatrices” can be replaced by any other function name.

To apply your own MATLAB function, it must be added to the MATLAB path. It is made accessible by MADYN 2000 with the help of the function “MADYN2000Extension.m” and the JAVA library “MADYN2000Extension.jar”, which can be found in the example subfolder “Extensions”. The following commands must be entered in MATLAB:

```
server = MADYN2000Extension;
server.publish('EIG_DBS', @myUpdateSystemMatrices);
```

The example subfolder “Extensions” contains the function “example_MADYN2000Extension” with the same commands. Alternatively to typing these commands you can run this function.

Now your function is published and can be called from MADYN 2000 or other applications running locally on your computer. As usual, you can use MATLAB debugger to enable step-by-step execution of your function. Any errors thrown during the calculation will be sent back to MADYN 2000 and terminate eigenvalue analysis.

Once the function is published, you must go back to MADYN 2000 and open the “Configuration of Third-party Extensions” window from the main menu: Extras -> Preferences -> Third-party Extensions.

In the window you will see a table with rows for every available Extension Method. In the row “EIG_DBS” you can now select “This Computer” option, if MATLAB with published function is running on the same computer. Otherwise select “Another Computer” and enter the corresponding network name to the “Details” column.

By default MADYN2000Extension library accepts only local requests, originating from your computer. If you wish to allow incoming network connections, please construct it with parameters:

```
server = MADYN2000Extension('network');
```

It must be noted, that once the extension is enabled, it will always be used.

Alternatively to functions MATLAB scripts can be used. This has the advantage, that MATLAB is not required. In the menu “Configuration of Third-party Extensions” the option “Script” has to be selected. In the field “Details” the script file including path must be specified.

6.2 Extension Point ALP3T_Input

ALP3T input commands are created within MADYN 2000. These input lines can be changed or extended by a third party function. It should be noted, that writing such a function requires deep knowledge of the program ALP3T.

The subfolder “Extensions” of the “Examples” folder provided with the installation contains the function “test_cbAlp3tInput_function” and the script “test_cbAlp3tInput_script”.

The function has the input and output “lines”, which is a cell array with the ALP3T input lines, where each cell represents a line. In the example function the ALP3T input lines with the parameters TSR, TSA, TSHA, ALFASR, ALFASA, ALFASHA are changed. The parameters are set to the values 200 and 20, respectively.

The script just adds the line “Hello” to the input file. As mentioned in chapter 6.1 the script has the advantage, that it does require MATLAB.

7. Plotting Features

7.1 Scaling of Axes

A right mouse click on the title of any plot axis of a diagram will open a window allowing a redefinition of the minimum and maximum values of the axis. In fig. 7.1 an example is shown. The window with the edit fields “Upper axis limit”, “Lower axis limit” and “Natural Frequency” appears after a right mouse click on the title “Natural Frequency [Hz]”. This feature is available for all diagram plots.

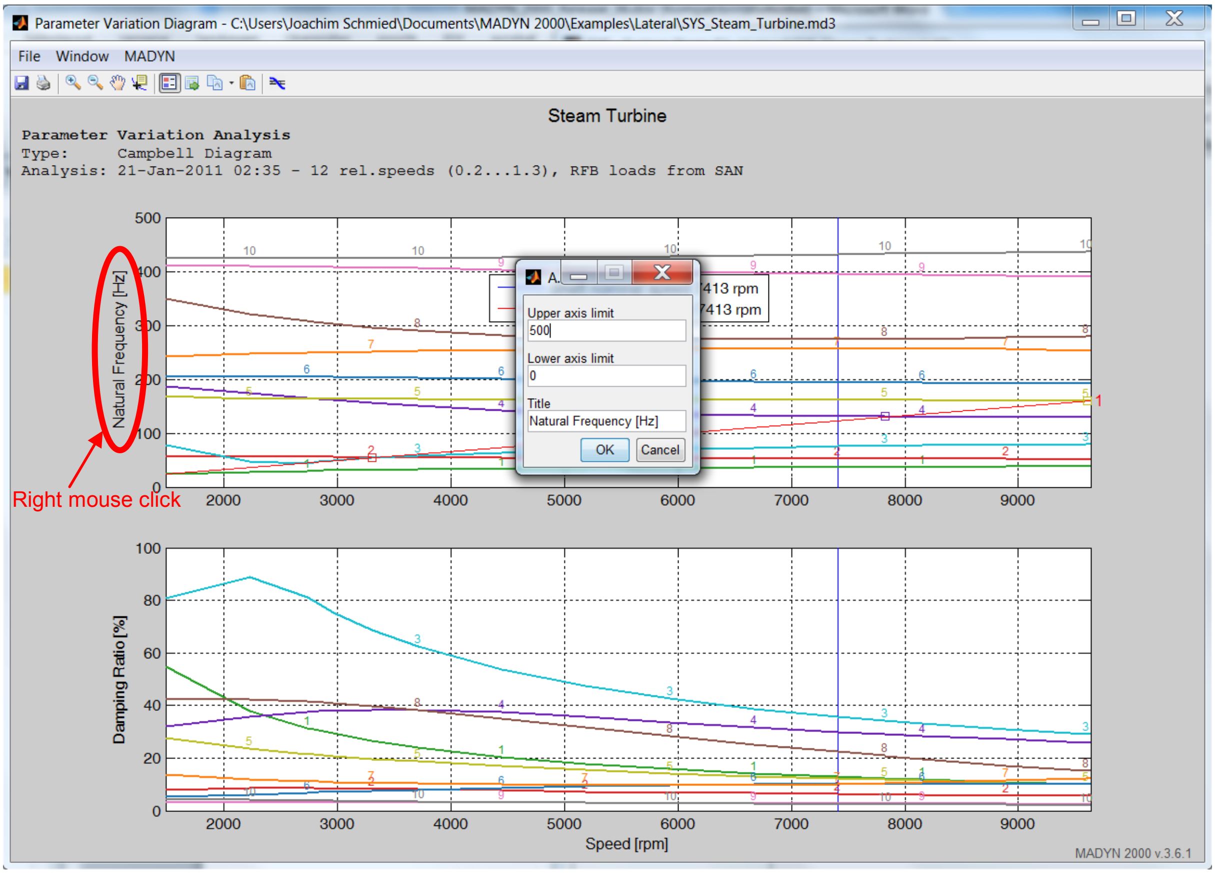
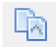
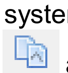


Fig. 7.1: Campbell diagram with window to refine the axis limits of the “Natural Frequency” axis

7.2 Exporting Underlying Data of Plots, Copying and Pasting Lines of Diagrams

At the top of the window in fig. 7.2 three new icons are available: , , .

The icon  allows exporting underlying data of any plot to a text file. The content of the text file is self-explaining.

The further two icons allow copying lines of a diagram to other diagrams of the same type. For example the frequency and damping lines of a mode in a Campbell diagram of one system can be copied to the Campbell diagram of another system. Copying is done with the button  and pasting with the button  in the plot windows. In fig. 7.2 the menu to select the mode for copying is shown.

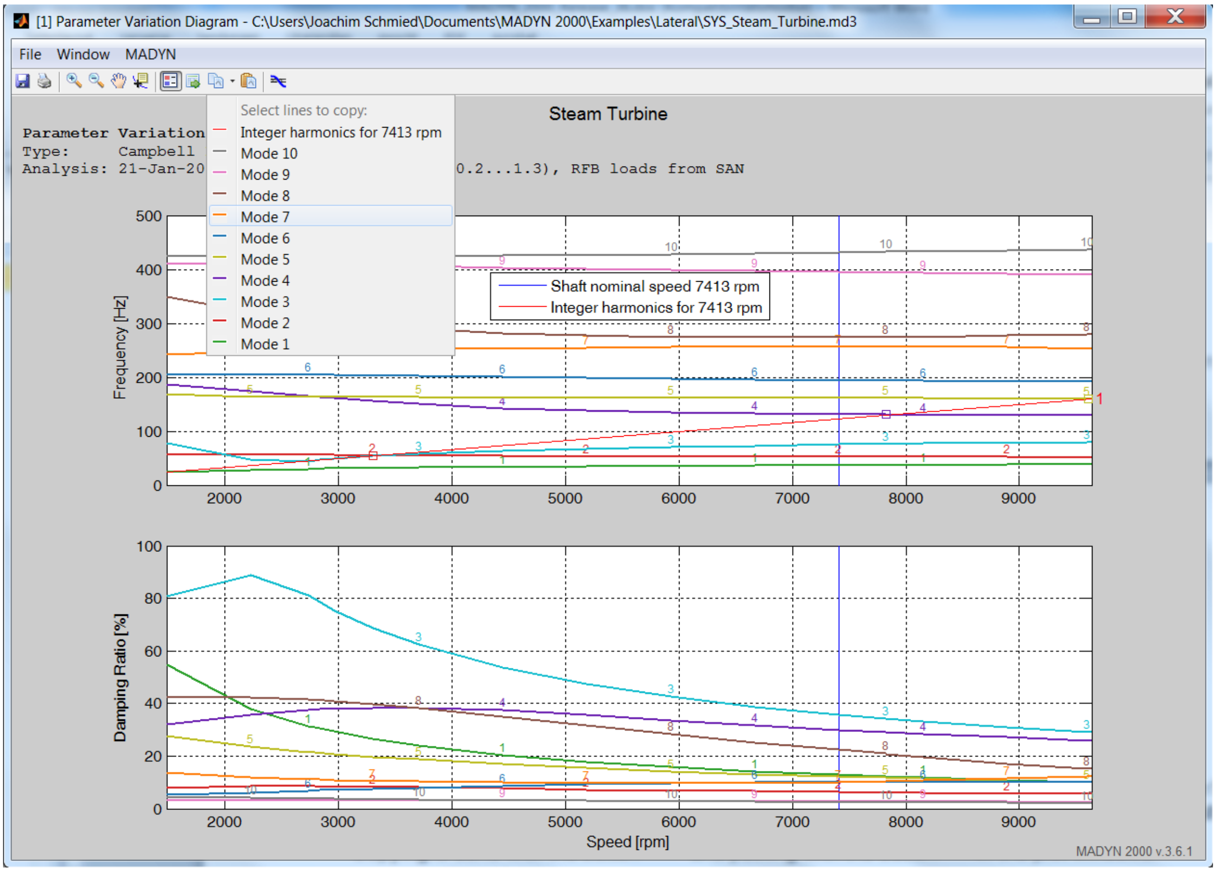


Fig. 7.2: Campbell diagram with menu to select a mode for copying

7.3 Highlighting Parameter Ranges

Some plots have non visible parameters. For example the polar plot of a transfer function has the parameter frequency, which is not visible on the axes, or an orbit plot of a time history has the parameter time, which is neither visible on the axes. These types of plots have 2 edit fields to define a parameter range, which is highlighted on the plot as shown for an orbit plot in fig. 7.3. The range can be shifted by means of a scroll bar.

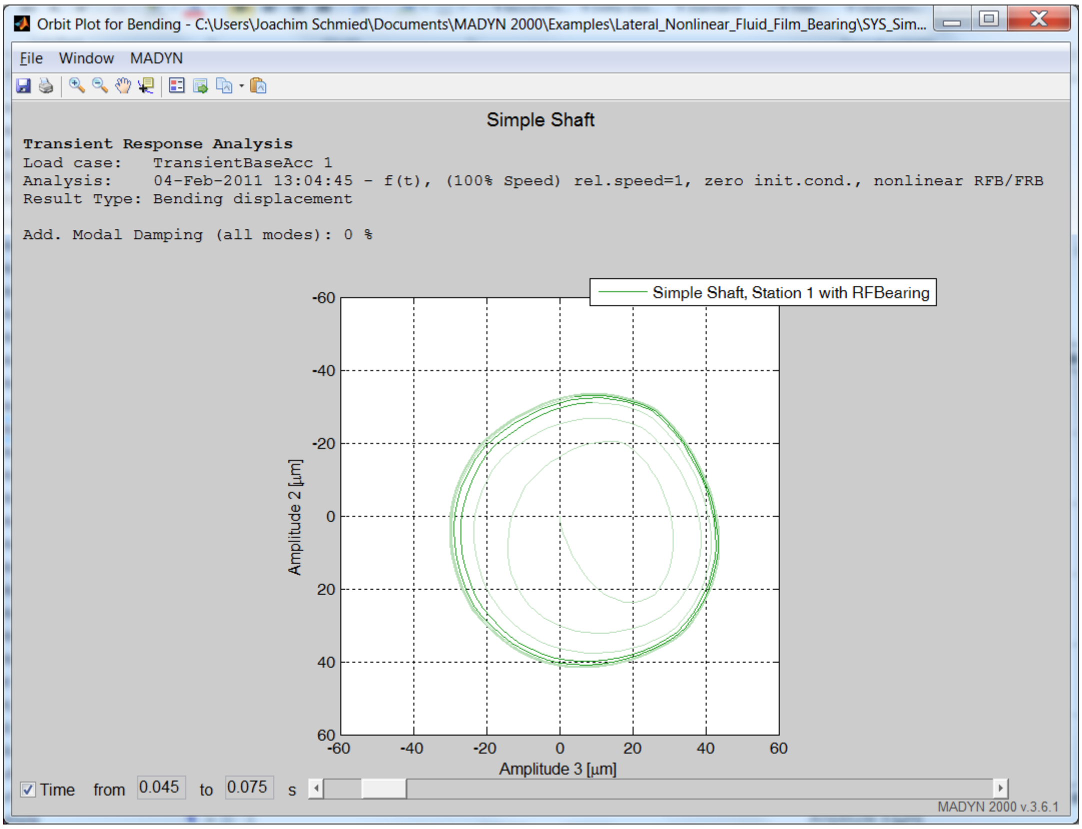


Fig. 7.3: Orbit with highlighted time range (0.045s to 0.075s)

7.4 Transient Analysis Plots

For time history plots of run ups (analysis type n(t)) it is possible to switch the time axis to speed axis in the axes menu. Spectra and waterfall plots processed from the time history are then also shown as a function of speed. A time history plot of a run up as a function of speed and time is shown in fig. 7.4 and fig. 7.5, respectively. It is a run up of the example “simple shaft” described in the release notes of version 3.4 and 3.5.

Shape plots for displacements are also available for transient analyses since version 3.6.1. They can be invoked from the usual controls in the system explorer. Moreover the window with time history plots has the icon to create shape plots.

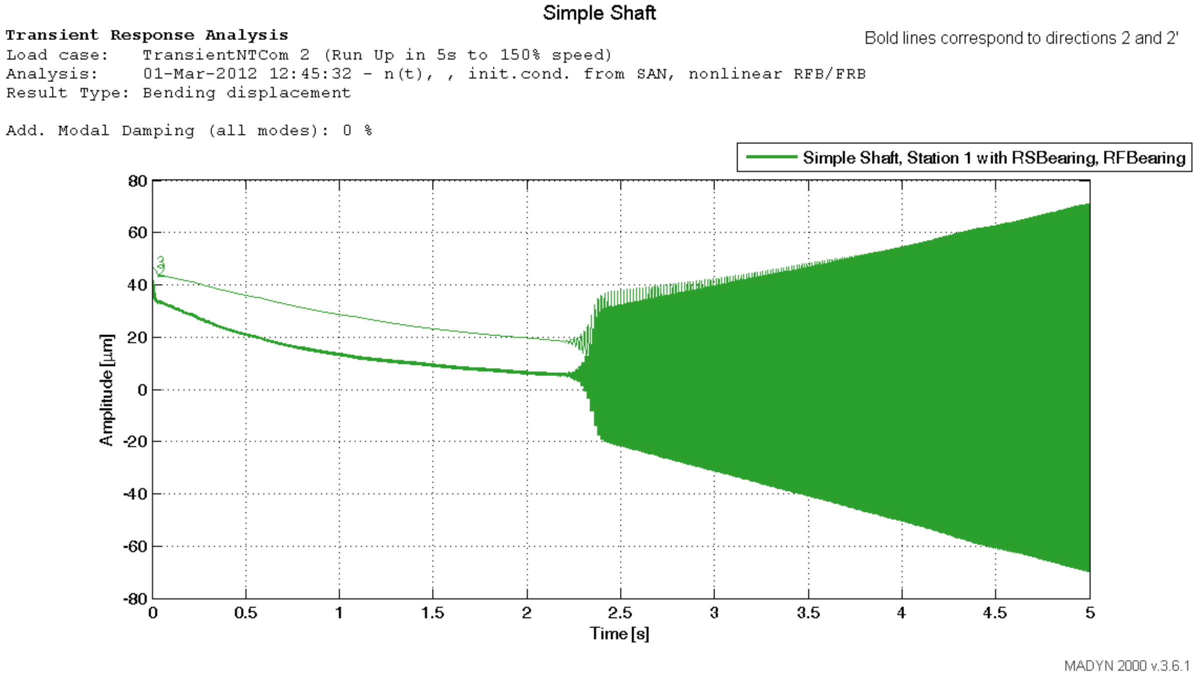


Fig. 7.4: Time history plot with icon to create shape plots

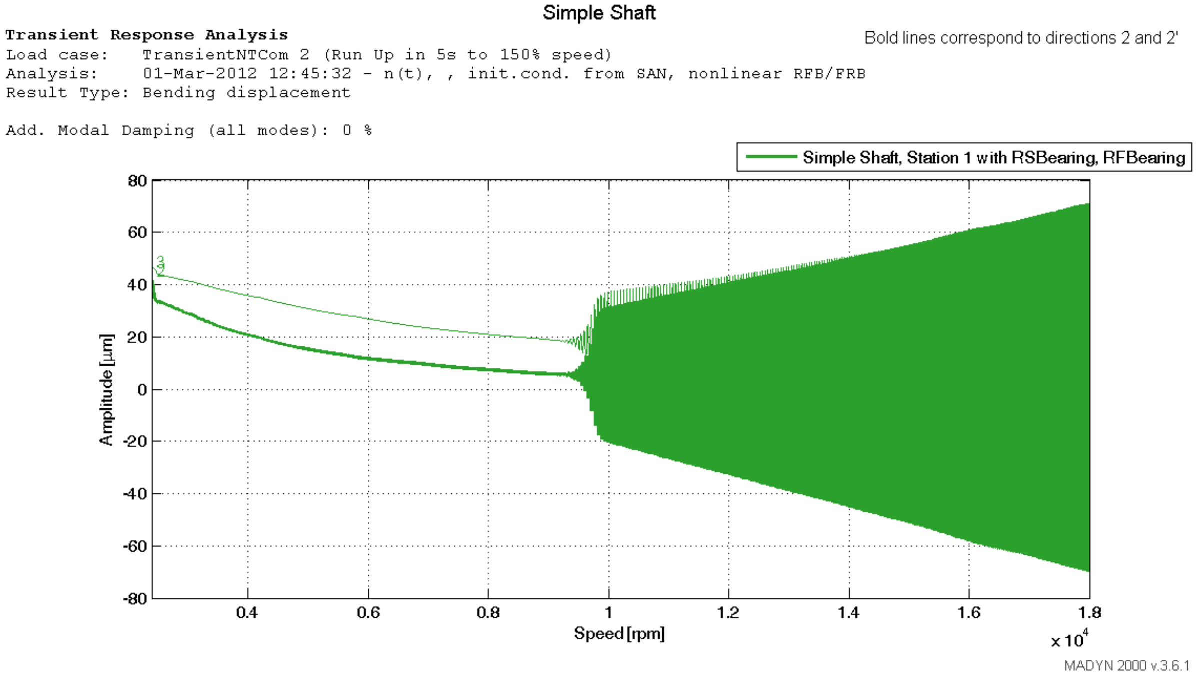
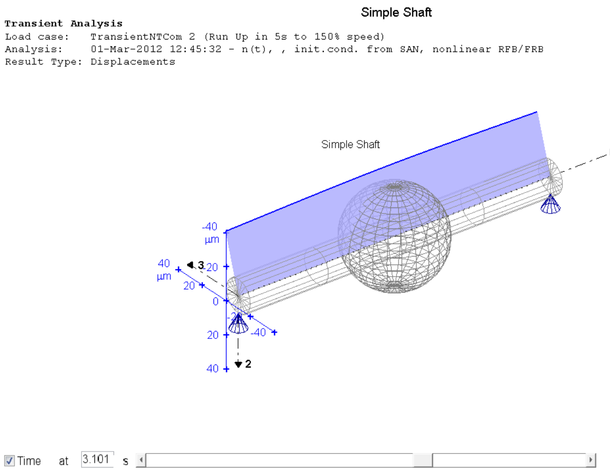
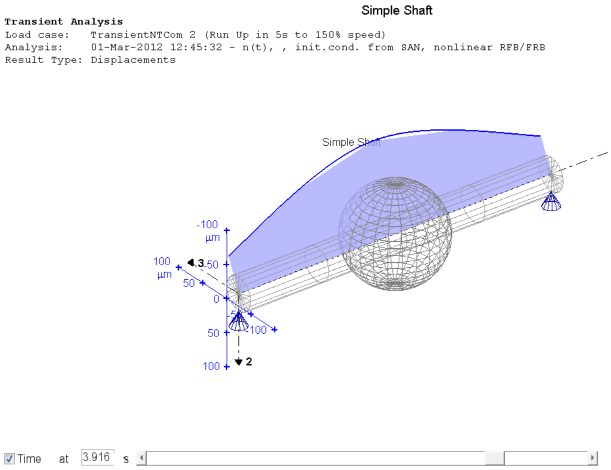


Fig. 7.5: Time history plot as a function of speed

The shape plots of the time history in figure 7.4 at the approximate time instants 3s, 4s, 5s are shown in fig. 7.6. The edit field in the pot window allows setting another time. Additionally the time can be varied with a scroll bar.





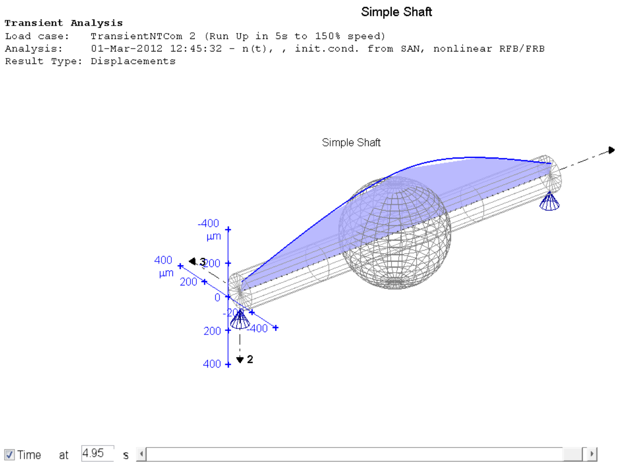


Fig. 7.6: Shape plots of the run up at about 3s, 4s, 5s

Transient shape plots are also available, if not all displacements have been stored. However, the shapes then may be quite coarse.

8. Automatic Storing of Transient Analysis Displacement Results

The storing of the results in transient analysis has been changed. In previous versions it was necessary to store all displacements in order to use the final result of a transient analysis as initial conditions. In version 3.6 all displacements are stored automatically independent of the result selection at the following instants:

- The last step,
- every 1000 time steps.

Storing includes the velocities, which is determined from the displacements of two time steps.

Storage at the last step now allows using any transient analysis §as initial condition.

Storage after 1000 time allows continuing a long transient analysis in case it was interrupted due to time limits or convergence problems. This is an issue especially for nonlinear analyses.