MADYN 2000 Version 3.5

The following new features were introduced in version 3.5:

1. Transient run ups and downs of speed dependent systems
2. Processing of transient time histories (spectra, waterfall plots)
3. Analysis of the critical speeds and associated mode shapes in Campbell diagrams
4. For transient run ups with nonlinear bearing characteristics the speed dependent oil temperature can be considered in case of analysis type DIN.
5. For floating ring bearings additional effects for the ring speed analysis can be considered.
6. The influence of the supply pressure can be considered in the DIN analysis of fluid film bearings.
7. Nonlinear bearing characteristics can be plotted.
8. In the undamped critical speed map stiffness lines of fluid film bearings can be plotted.
9. The rest mode method has been implemented for transient analysis. In some cases it allows considering the influence of neglected modes in a transient analysis.
10. Introduction of new icons in some plots.

In the following chapters these features are described more in detail.

Moreover bugs have been corrected, further input checks were introduced and the following smaller features and improvements were implemented:

- Colours in parameter variation diagrams and compact mode shape plots are matching.
- Plot title and information can be edited by a double mouse click.
- Analyses can be interrupted by closing the window with the progress bar. This is especially useful in case of long analyses.
- Streamlining of the main menu bar: The menu items “**Analyses**” and “**Results**” have been eliminated, since the system explorer allows much easier starting analyses and plotting results of a system. All items related to plotting have been summarised under a new “**Plot**” menu. The “**Model**” menu has been renamed to “**Model Components**” and the “System” item has been removed from it, since systems can be created and opened from the “**File**” menu.
- The black window is eliminated. This window was used for MATLAB error messages. In case a MATLAB error occurs now a message window is opened. The message is also written to a log file. The log file can be opened from the menu item “Open log file” in the “File” menu of the main MADYN 2000 menu bar.
- Clicking on MD3-files in the Microsoft WINDOWS explorer starts MADYN 2000.

1. Transient Run Ups and Downs of Speed Dependent Systems

Transient analyses in MADYN 2000 are modal analyses, i.e. natural modes of the system with left and right eigenvectors must be present before starting it. Lateral systems with both bending directions activated are speed dependent due to the gyroscopic effect. They are also speed dependent when supported on fluid film bearings. Due to the speed dependence, the natural modes are also speed dependent. For this reason a Campbell diagram including the left eigenvectors must be calculated before a transient analysis covering several speeds can be started.

For transient run ups and downs new load types n(t) have been introduced. For these load types the speed can be defined as a function of time. There are three n(t) types as can be seen in the “Add” menu of the “Transient Loads” pane of the system explorer as shown in figure 1.1.

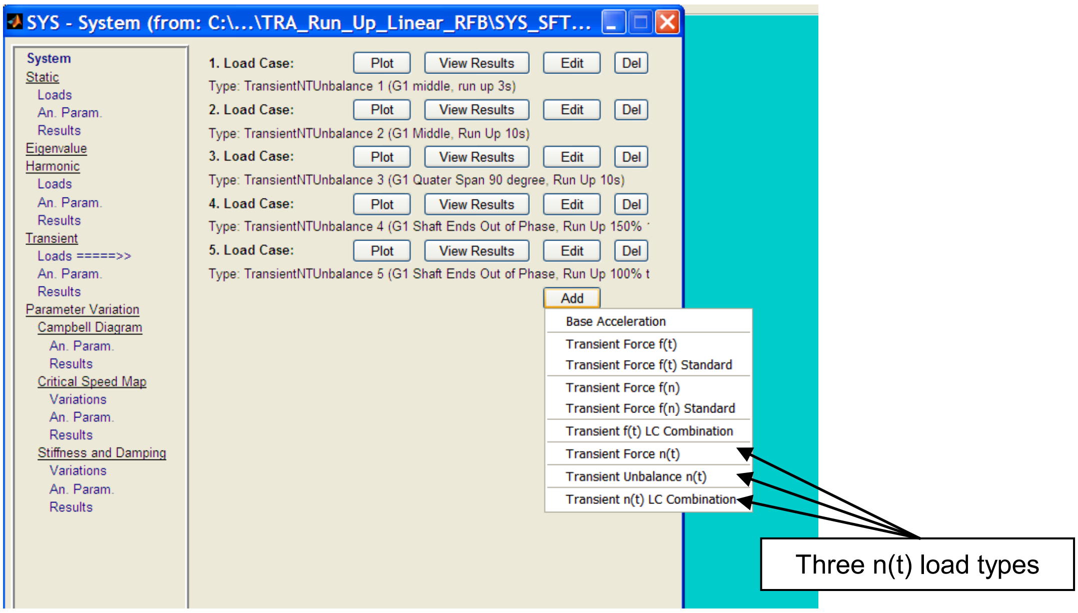


Figure 1.1: Menu to create n(t) transient loads

The load GUI opened from this menu for “Transient Unbalance” n(t) is new and shown in figure 1.2. It corresponds to the load GUI to define unbalance loads for harmonic response analyses. The load GUI “Force n(t)” is the same as for other transient loads. Both n(t) GUIs have a function button as all transient load GUIs to define n(t) excitation functions.

The function for “Force n(t)” is shown in figure 1.3 and for “Unbalance n(t)” in figure 1.4. The definition of the speed as a function of time is common in both functions. The GUIs in the two figures show the default values, meaning that the speed linearly changes from 10% to 100% in the time range from 0 to 1 second.

The unbalance excitation function does not need any further parameter. For the force excitation function a combination of speed multiples with frequency multiples can be defined. The GUI opened by the “Add…” button of the force excitation function GUI is shown in figure 1.5. The definition of a 1xn speed multiple with amplitude 1 in the speed range from 10% to 100% is shown in this GUI. Several such combinations of frequency and speed multiples can be superimposed. The frequency applying for the excitation is defined in the excitation function GUI in the edit field “f[Hz]”.

“Transient n(t) LC Combination” allows combining “Transient Force n(t)”, “Transient Unbalance n(t)” and “Base Acceleration” load cases.

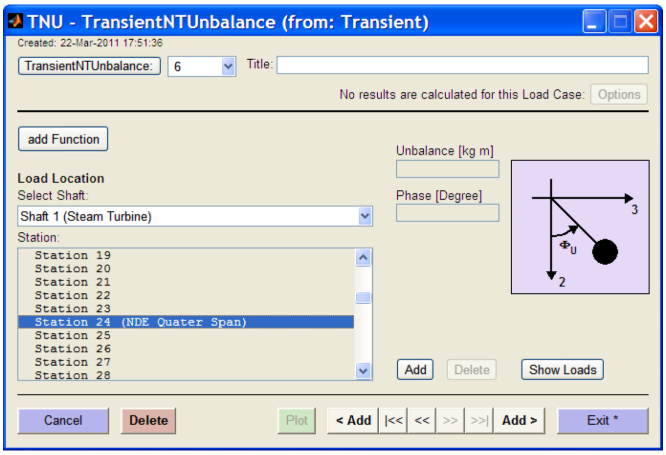


Figure 1.2: GUI for Unbalance n(t) loads

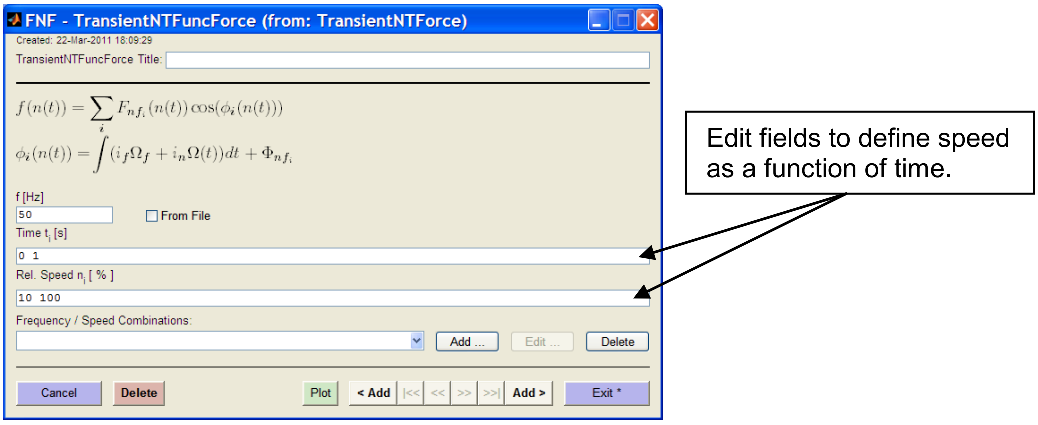


Figure 1.3: GUI for the n(t) force excitation function

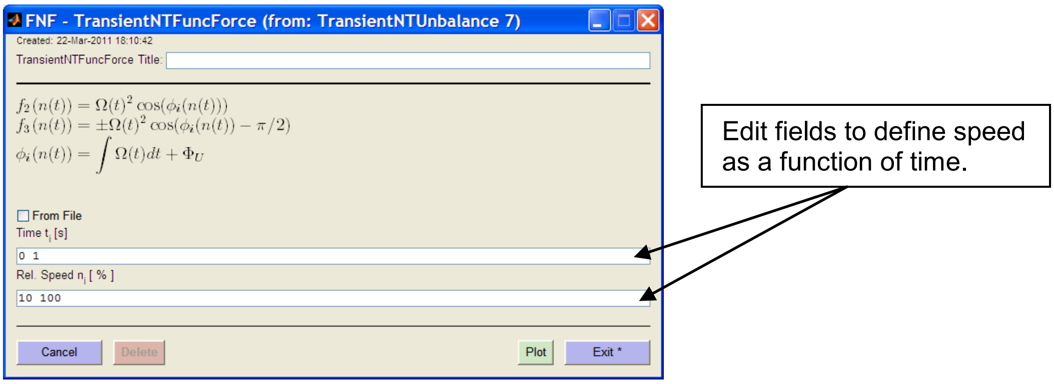


Figure 1.4: GUI for the n(t) unbalance excitation function

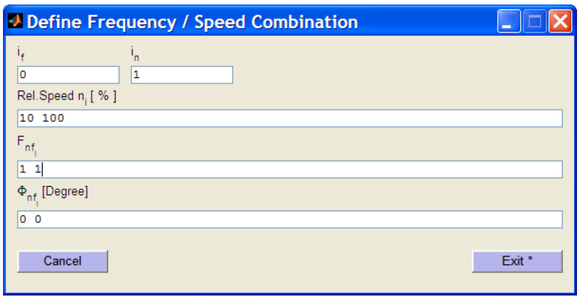


Figure 1.5: GUI to define a function with for the n(t) force excitation function

The GUI to define the analysis parameter of a transient analysis is shown in figure 1.6. It now has an additional radio button to define an analysis with n(t) excitation.

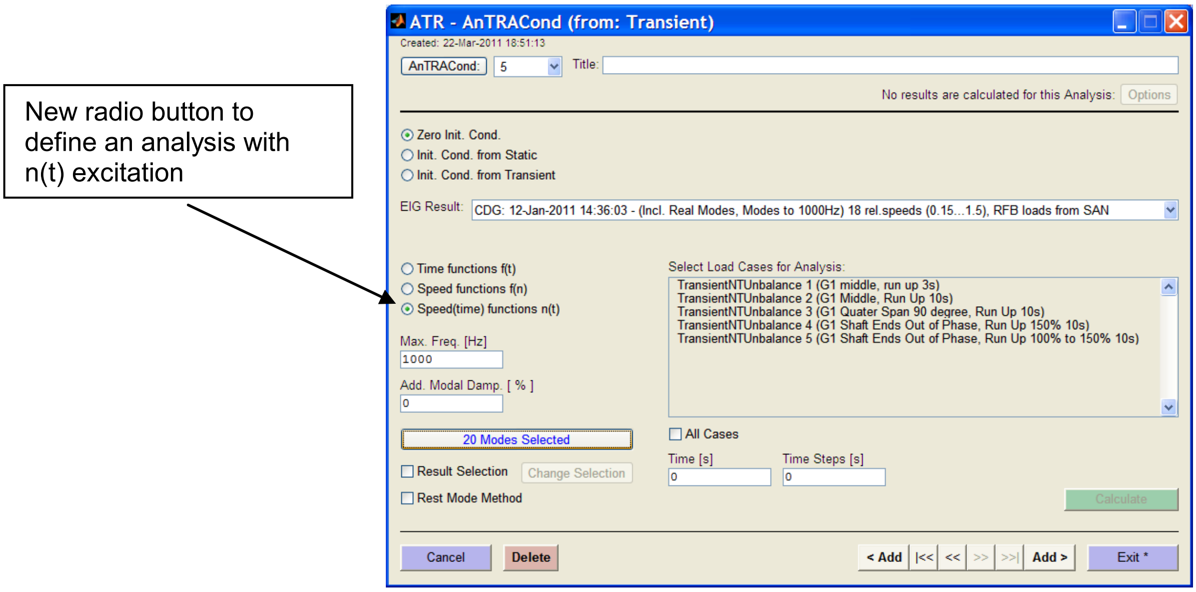


Figure 1.6: Transient analysis GUI with n(t) selection

The necessary natural modes must be selected among CDG results in case of an n(t) excitation, EIG results cannot be selected. For f(t) or f(n) excitation both EIG and CDG results can be selected.

Clicking on the mode button, which shows the number of selected modes, opens the mode management GUI shown in figure 1.7. In the list of the GUI the speed range, the frequency range and the damping range of each mode of the Campbell diagram is shown. Individual modes may have different speed ranges, because they may exceed the damping limit set in the analysis in a certain speed range. The mode management GUI allows selecting and eliminating modes. Selected modes are marked with a star.

To calculate a run up all considered modes must either cover the whole speed range of n(t) or of the Campbell diagram. If the speed range n(t) exceeds the speed range of the Campbell diagram, the modes at minimum and maximum speed, respectively, will be taken in the range outside the Campbell diagram speed range. Modes which have a smaller speed range then defined in the Campbell diagram and do not cover the whole n(t) range are eliminated. Moreover modes, which turn from complex to real within the speed range, cannot be considered. An error message appears, if such modes are not eliminated. This is the case for mode 3 and 7 in the example of figure 1.7.

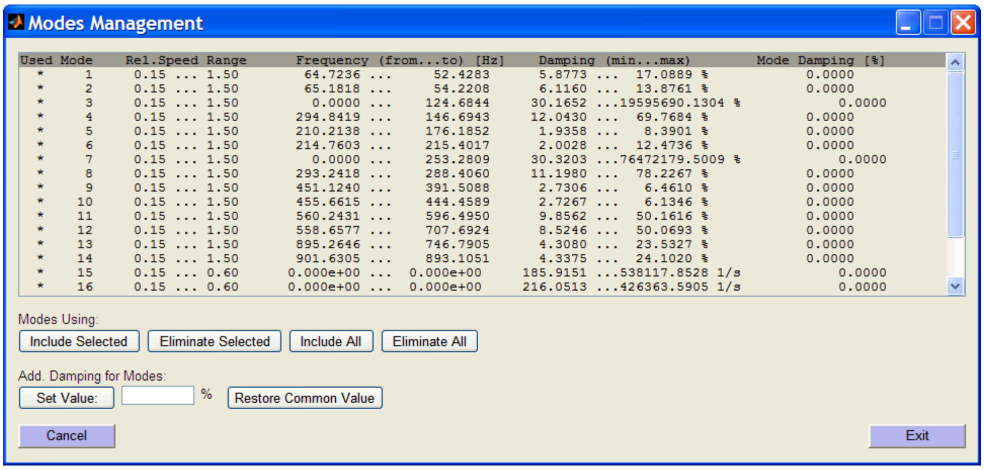


Figure 1.7: Mode management GUI

Results (response at the bearings and the shaft middle) of a transient run up in 10s with unbalance excitation (unbalance according to G1 in the shaft middle) are shown in figure 1.8. The resonance curve for the same unbalance excitation calculated by a harmonic response calculation is shown in figure 1.9. It can be seen, that the envelope of the transient response corresponding to the amplitude agrees very well with the amplitude in 3-direction of the resonance curve. The response in 2-direction as well as the response at station 11 cannot be seen in figure 1.8, because they are hidden. However, they can be seen in figure 2.2 of the next chapter, where only the envelope is drawn and not the complete time history. For faster run ups and for systems with lower damping the transient response amplitudes and the harmonic response amplitudes, which represent the results of a quasi stationary response at certain speeds, must not agree to the same extent.

In figure 1.10 the time history of a run up of a simple shaft from 20% speed to 100% with an unbalance of G2.5 is shown. It is the same simple shaft as described in the release notes for version 3.1 to 3.3. Up to about 0.75 seconds the time history only consists of the synchronous vibration from the unbalance. After that, the shaft becomes unstable (oil whirl) and a high sub-synchronous vibration arises. Its level increases with further speed increase.

The static position of the shaft is also well visible in the time history plot as well as the orbit plot in figure 1.11. The analysis starts at 20% speed. The initial conditions are from a static analysis also at 20% speed. There is no impact at the start of the analysis, which means that the static position according to the Gümbel curve coincides well with the static position due to the nonlinear bearing characteristics. The centering of the shaft with increasing speed is also clearly visible.

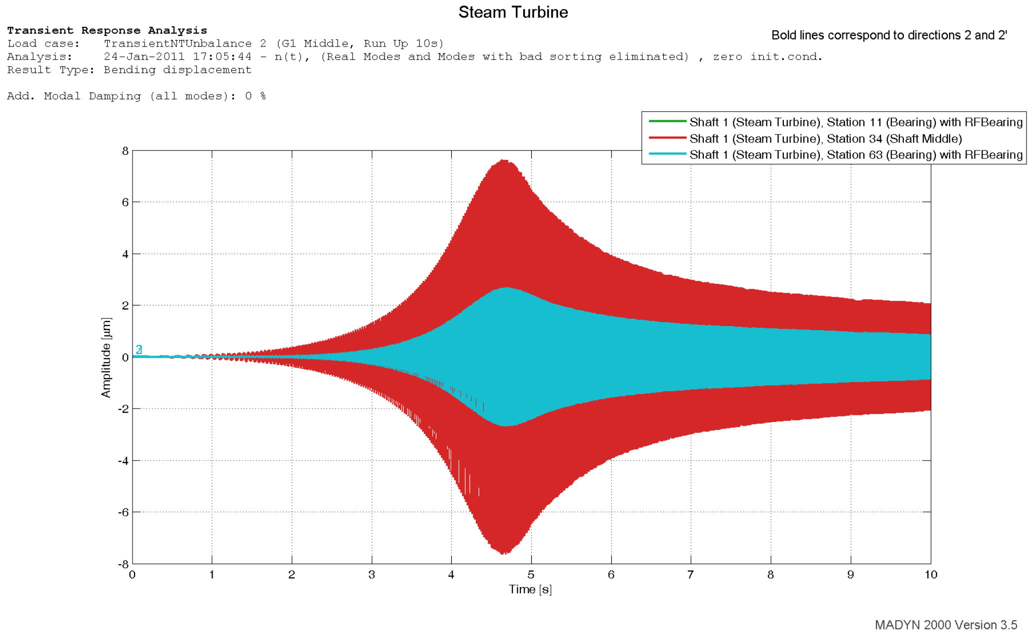


Figure 1.8: Transient response of a run up in 10s to nominal speed with unbalance excitation

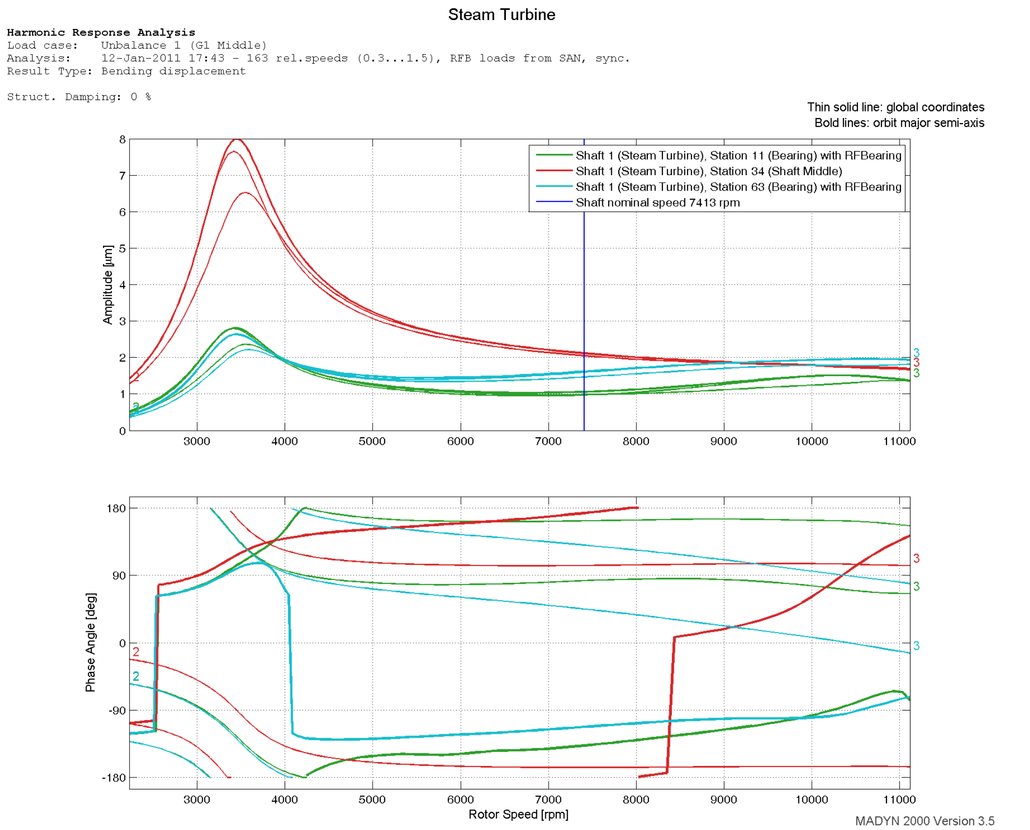


Figure 1.9: Resonance curve for the same unbalance as in figure 1.8 calculated by a harmonic response analysis

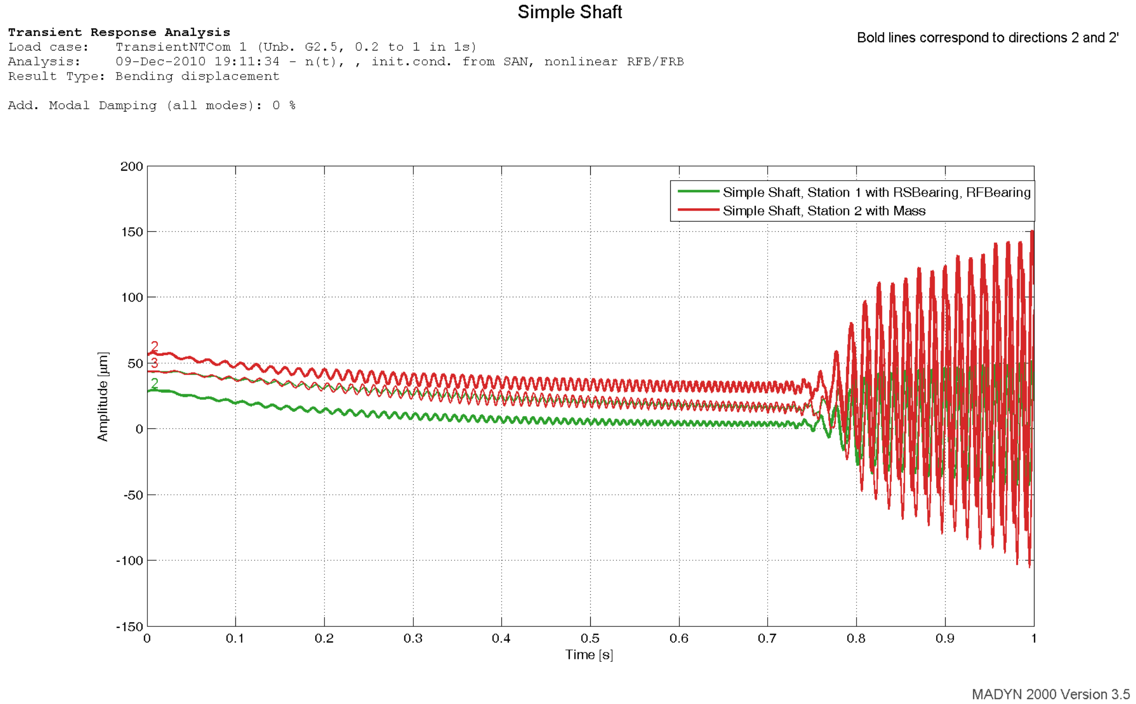


Figure 1.10: Run up of a simple shaft in cylindrical bearings with unbalance G2.5 into the unstable speed range (oil whirl)

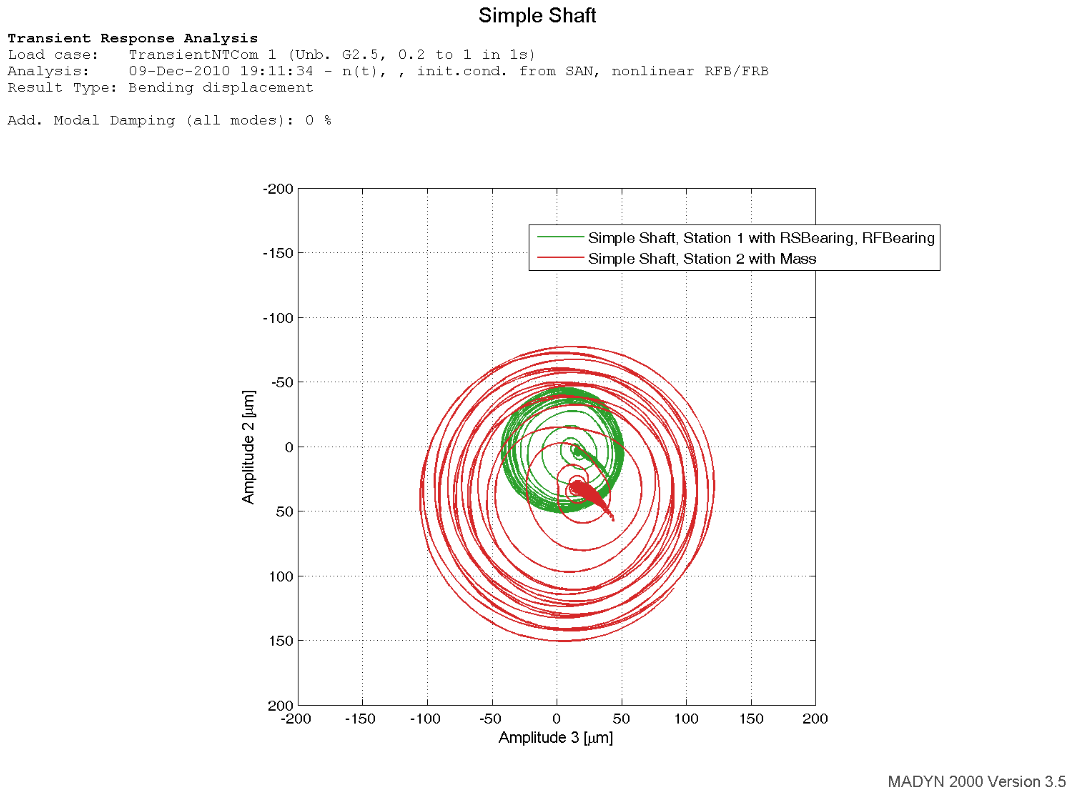


Figure 1.11: Orbits of the time histories in figure 1.10

2. Processing of Transient Time Histories

The window of the transient response results contains several icons for the processing of the time histories as shown in figure 2.1.

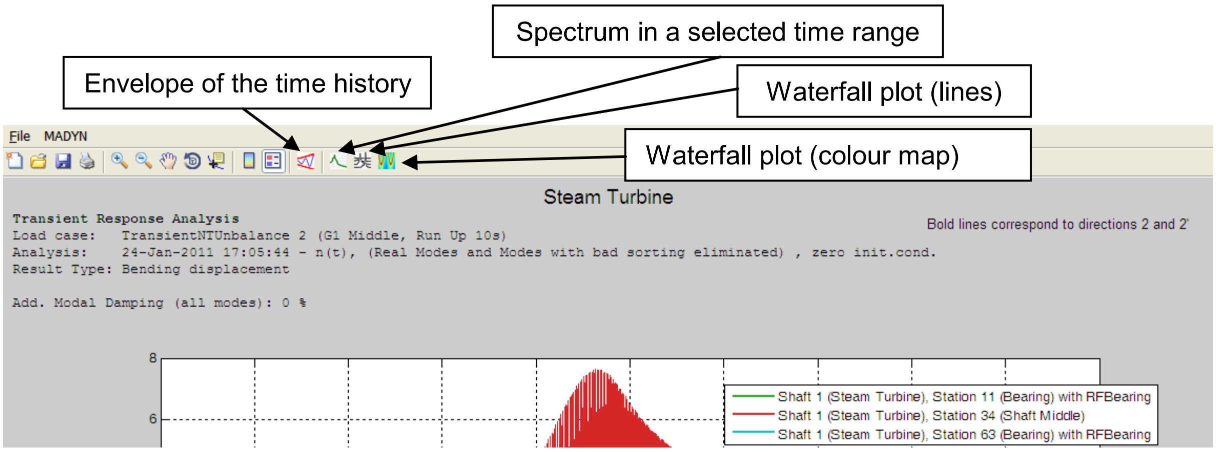


Figure 2.1: Window of the transient time history results with icons for processing

Clicking on the icon for the envelope creates the plot in figure 2.2. It is created from the time history in figure 1.8.

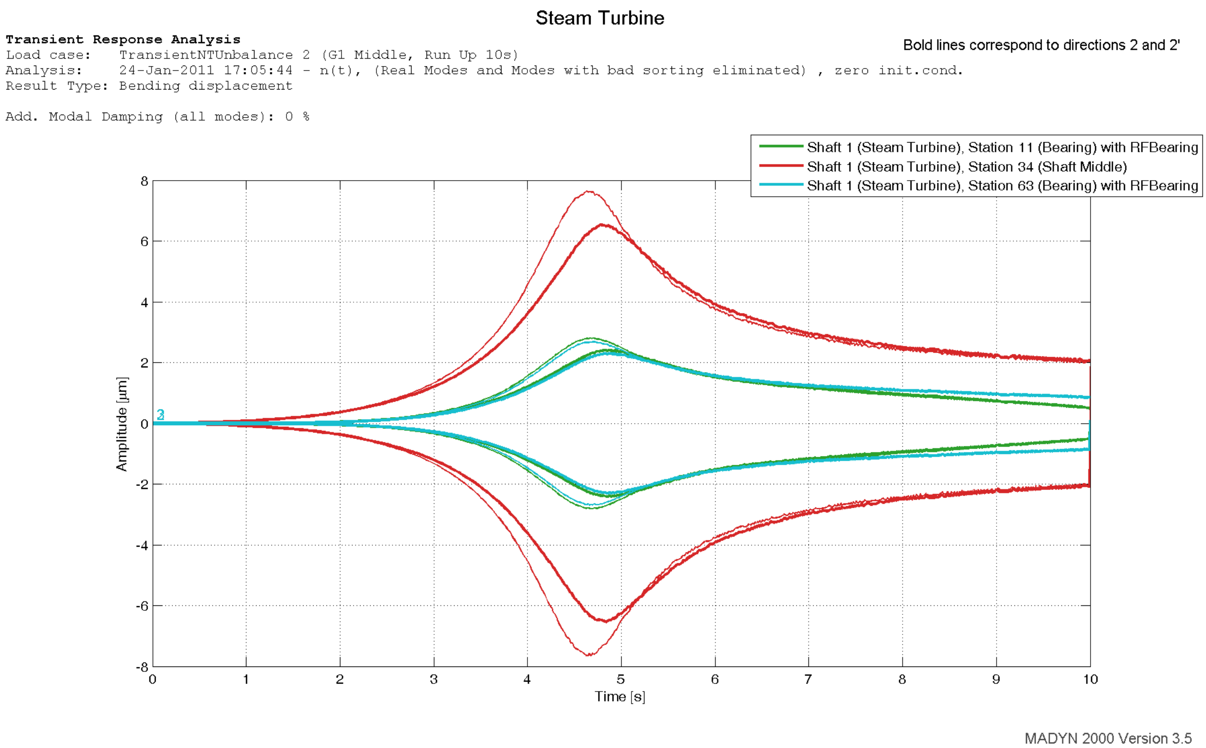


Figure 2.2: Envelope of the time history in figure 1.8

A click on the icon for the spectrum creates lines to select a time range (see figure 2.3). After the time range is selected the spectrum according to figure 2.4 is created.

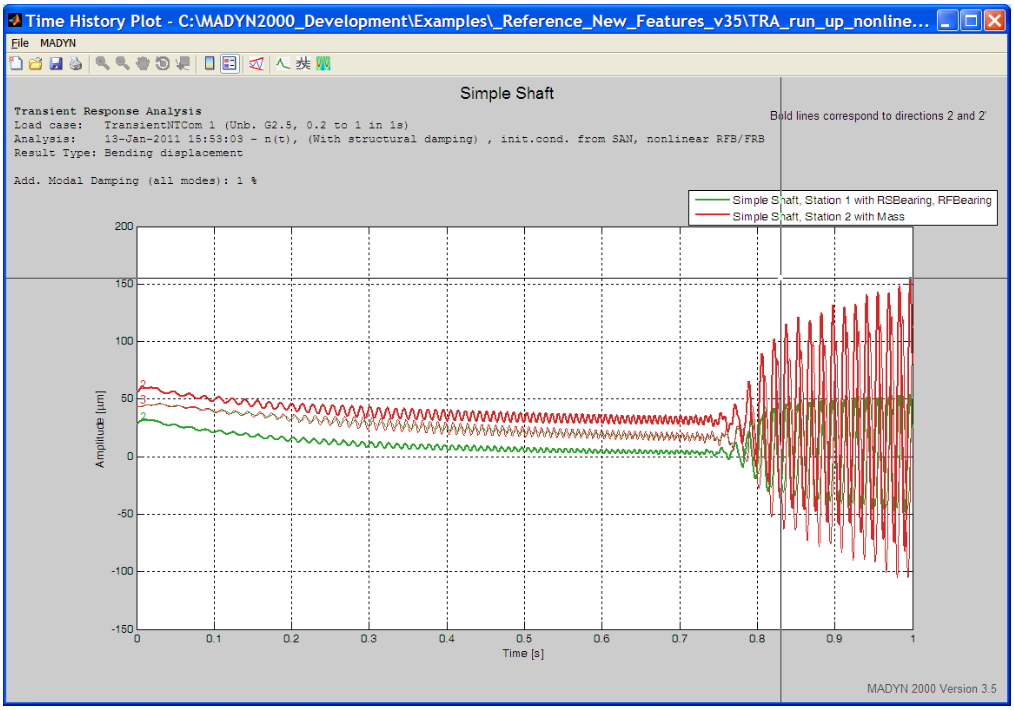


Figure 2.3: Lines for the selection of a time range for the spectrum

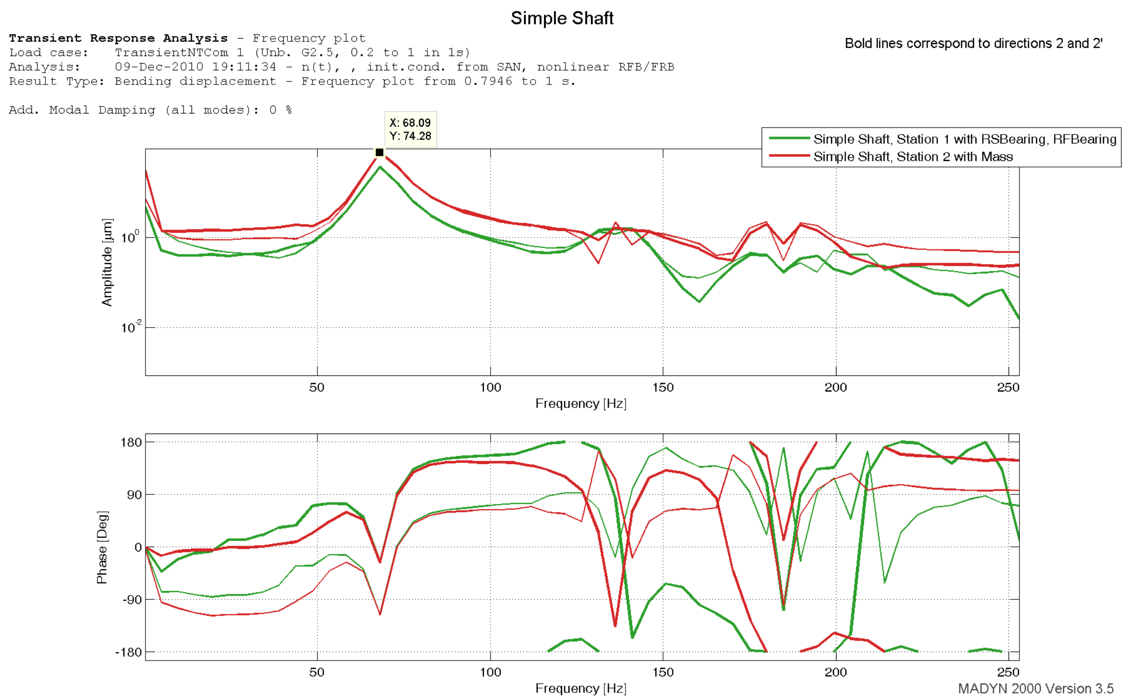


Figure 2.4: Spectrum of the time history in figure 1.10 in the unstable range (0.8s to 1s)

The two different types of waterfall plot are shown in figure 2.5 and 2.6.

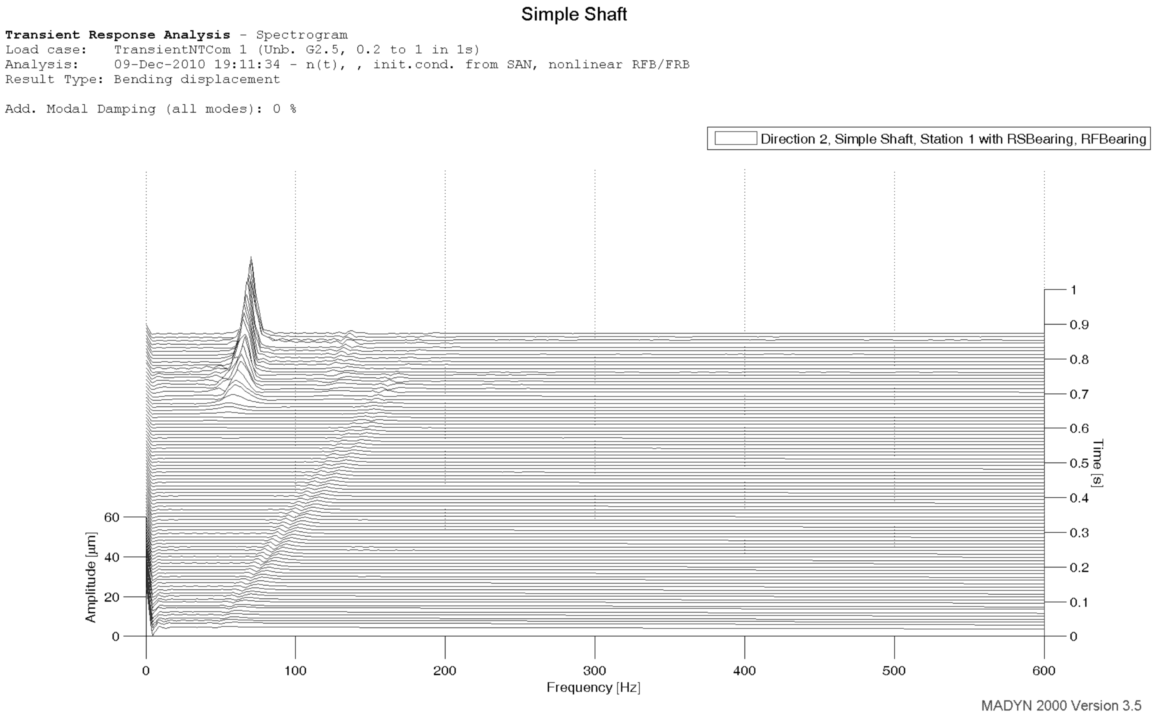


Figure 2.5: Waterfall plot (lines) of the time history in figure 1.10

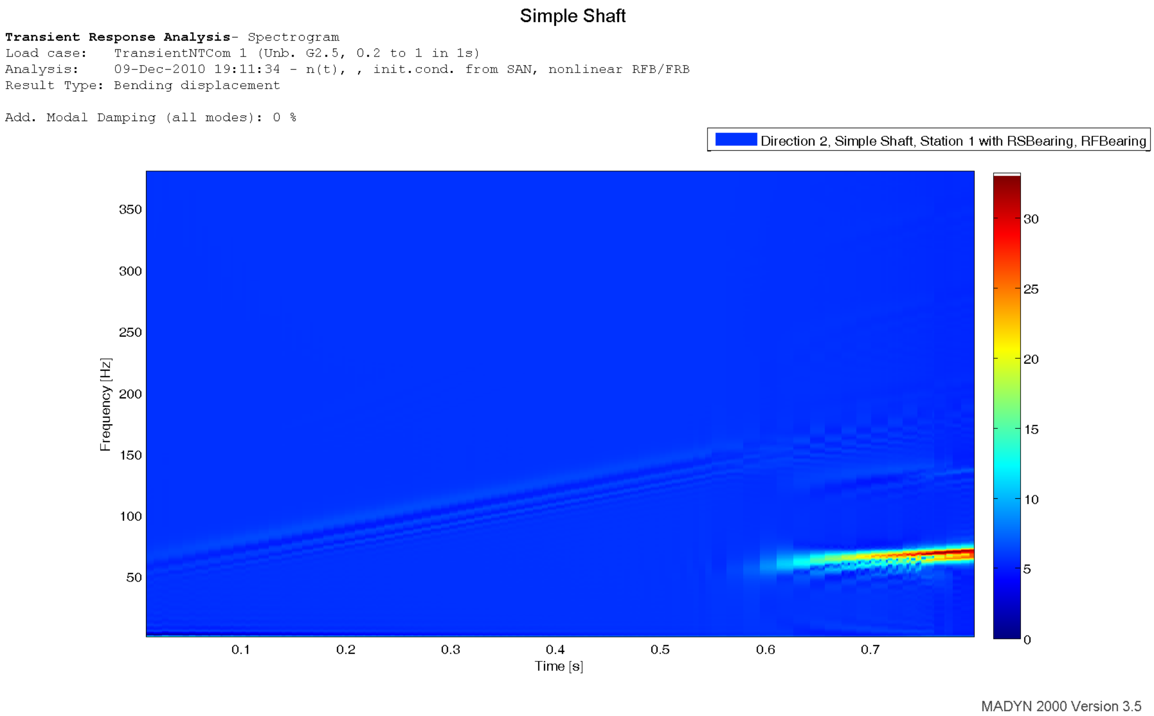


Figure 2.6: Waterfall plot (colour map) of the time history in figure 1.10

Mathematical details to the creation of the spectra and waterfall plots are described in chapter V.3.4 of the MADYN 2000 documentation.

3. Analysis of the Critical Speeds and Associated Mode Shapes in Campbell Diagrams

Critical speeds can be calculated from Campbell diagrams by activating the corresponding check box in the Campbell diagram analysis GUI (see figure 3.1).

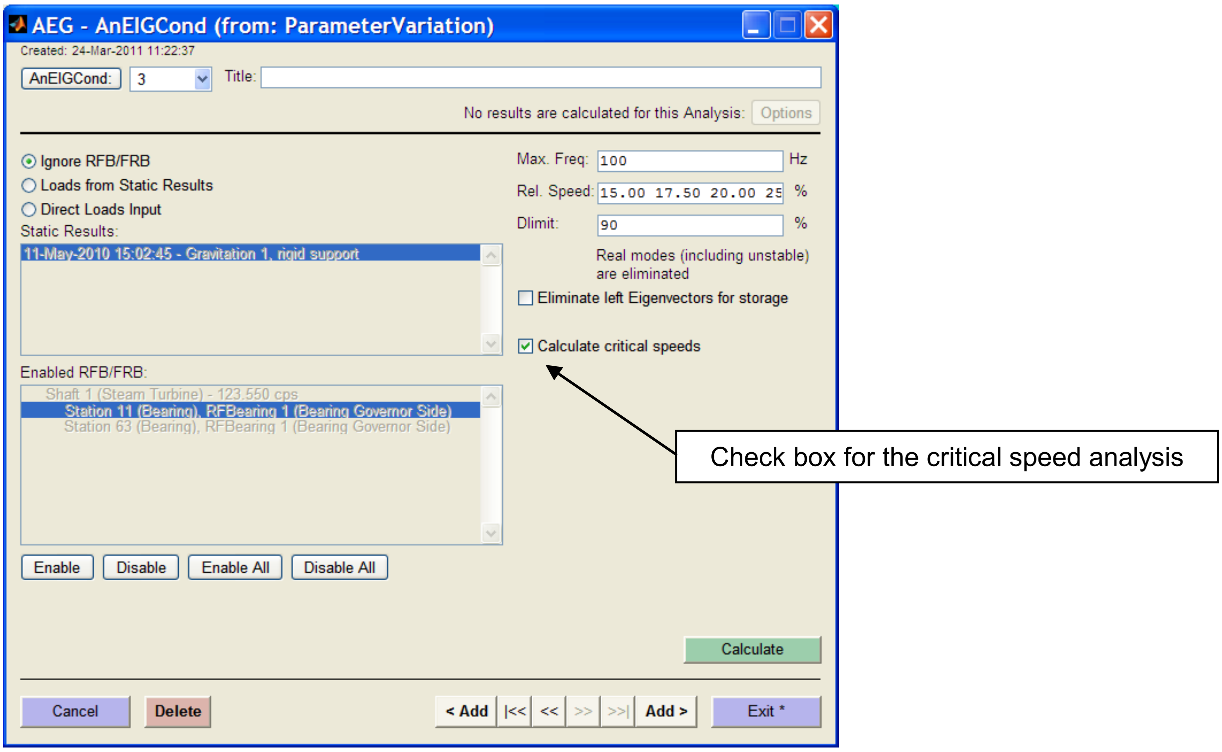


Figure 3.1: Campbell diagram analysis GUI with check box for critical speed analysis

Critical speeds are then calculated and marked in the Campbell diagram, as shown in figure 3.2. A new item in the MADYN menu allows plotting the shapes in compact form in the critical speeds only (also see figure 3.2).

The shapes in the critical speeds can be seen in figure 3.3. Note, that the colours in the shape plots now match the colours in the Campbell diagram.

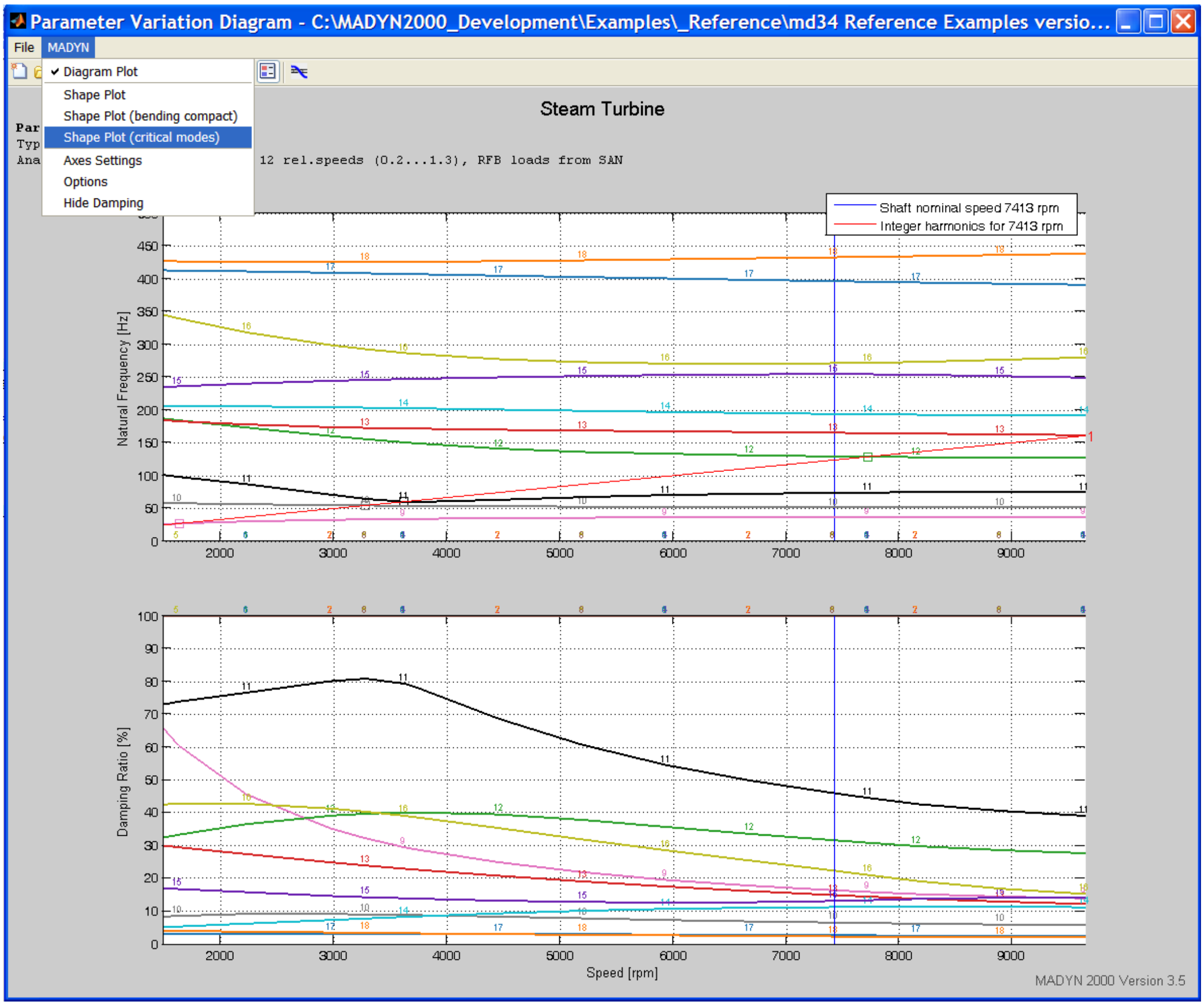


Figure 3.2: Campbell diagram with Critical speeds and menu to plot the associated mode shapes

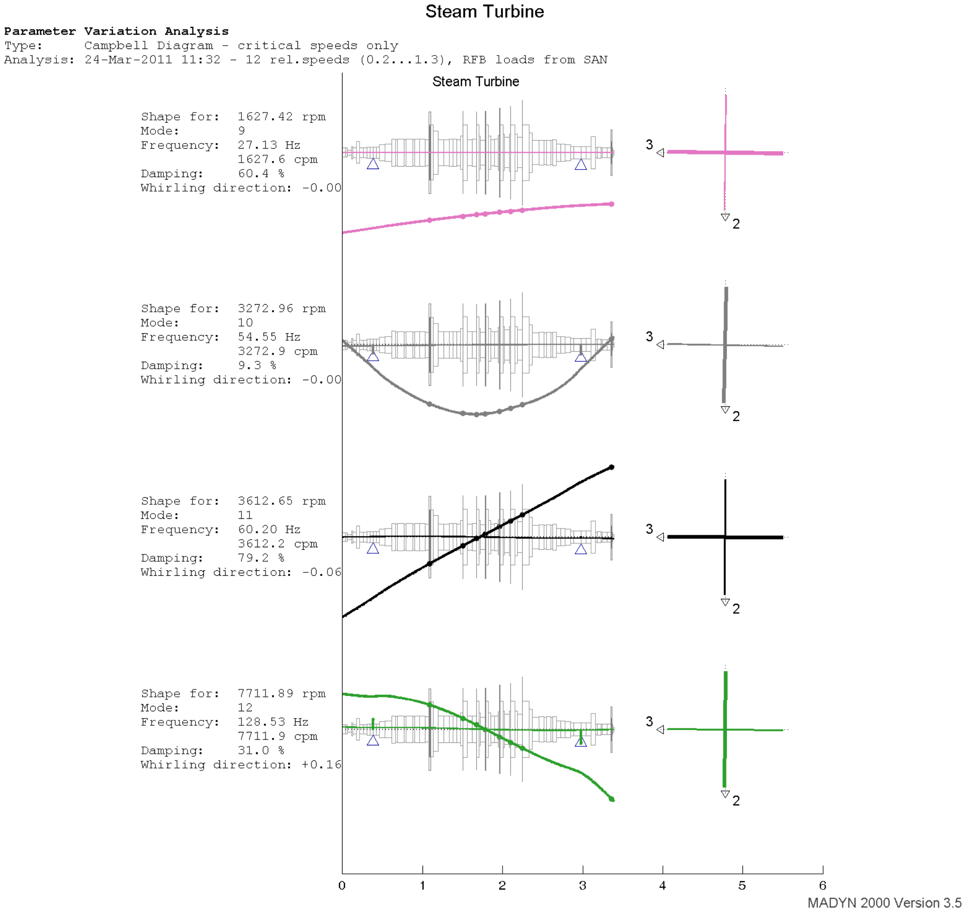


Figure 3.3: Mode shapes in the critical speeds

4. Transient Analyses with Nonlinear Fluid Film Bearing Characteristics considering the Speed Dependent Oil Temperature

The most suitable analysis type to consider the speed dependence of the oil temperature for nonlinear bearing characteristics is by the analysis type “DinTab”. For analysis type “c_ad” the temperature is constant and can therefore only be correctly considered for one speed. For analysis type “v_ad” the 3-dimensional temperature distribution also only applies for one speed.

Analysis type “DinTab” strictly speaking does not allow any analysis with 2-phase flow as it is highly recommended for non-linear analyses. Nevertheless this analysis type has been introduced now for “DinTab” to calculate the nonlinear characteristics (see figure 4.1). The dimensionless nonlinear table then is calculated as for analysis type “c_ad”. The actual speed dependent mean temperature in a transient analysis with nonlinear bearings then can be considered, if the linear DIN table is present.

The transient analysis GUI and the nonlinear bearing selection GUI are shown in figure 4.2. In case both the linear DIN and nonlinear table exist, the check box “Nonlinear RFB/FRB DinTab Tmean(n)” can be activated. The bearing then is marked by a (D) beside the star for the nonlinear characteristics. The static load for which the mean temperature is calculated from the linear DIN table, has to be defined either by selecting static results or by direct load input as for other analysis types.

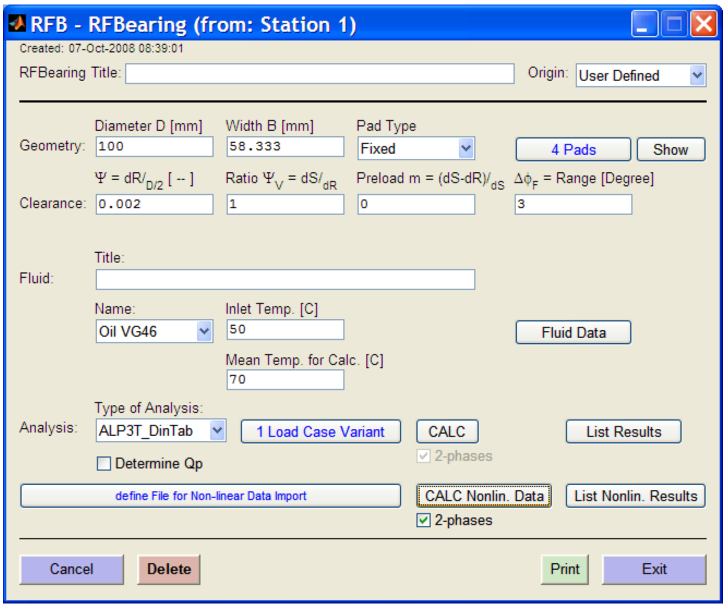


Figure 4.1: RFB GUI for analysis type ALP3T_DinTab and nonlinear characteristics with 2-phase

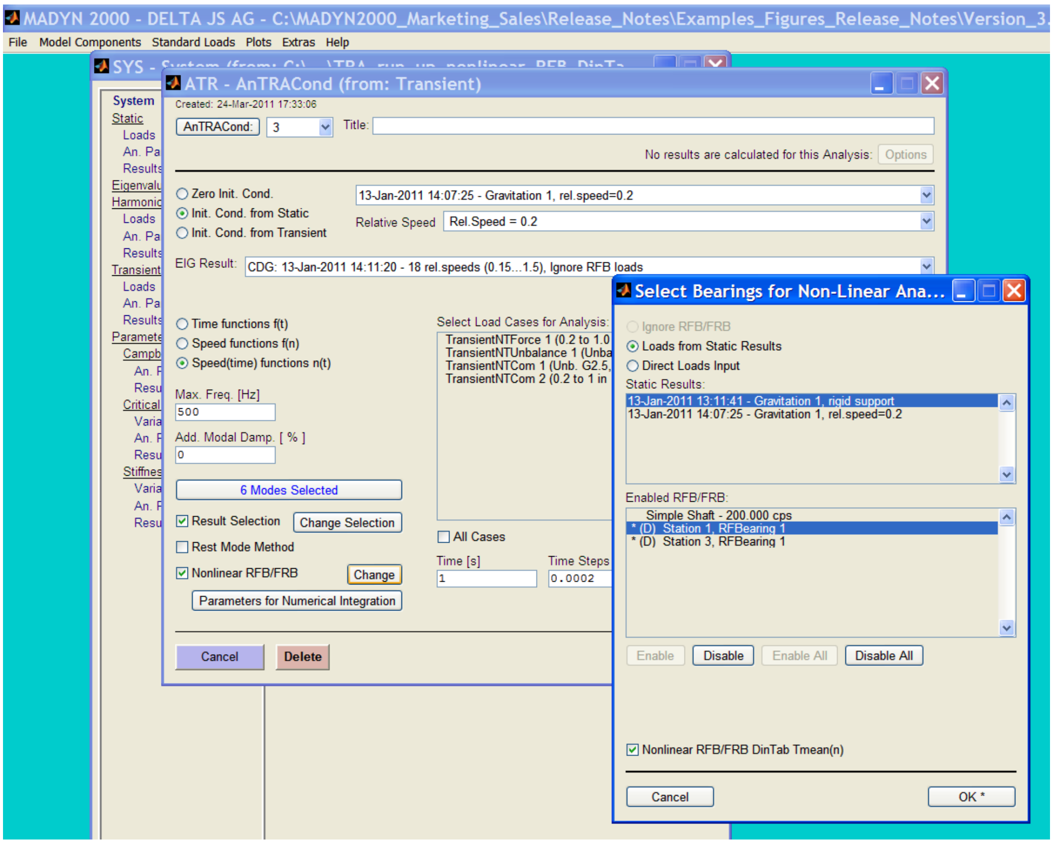


Figure 4.2: Transient analysis GUI with Bearing GUI for nonlinear bearings

5. Extended Ring Speed Analysis for Floating Ring Bearings

Until now the ring speed of floating ring bearings could be calculated according to a formula considering the bearing geometry (equation II.7.1 in the documentation) or it could be manually defined as a function of speed (option “User Defined”). These options are still available and can be selected for newly defined floating ring bearings for which tables have not yet been calculate (see figure 5.1). For constant adiabatic analysis and analysis according to DIN the two new options “f(viscosity” and f(viscosity, ecc.)” are available. They can be selected as shown in figure 5.2 in case the linear table have been calculated. The ring speed is then calculated according to the formulae II.7.2 and II.7.3 of the documentation.

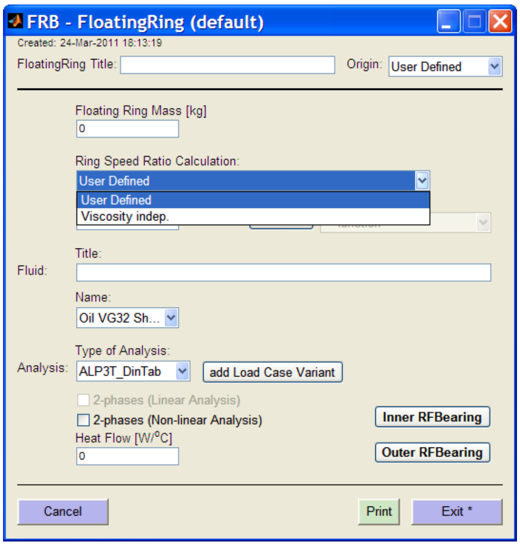


Figure 5.1: Options to define the ring speed for newly defined FRBs

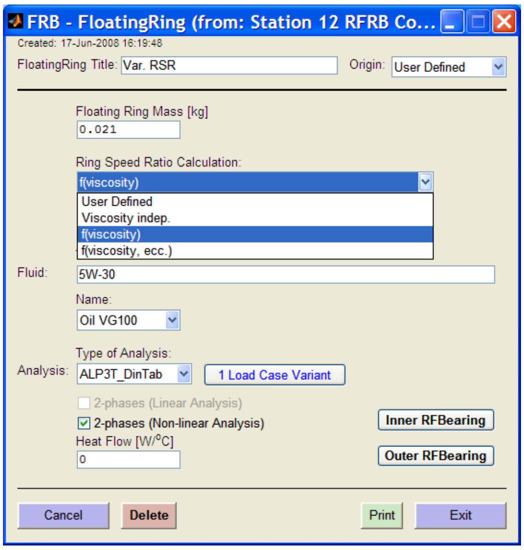


Figure 5.2: Additional options to define the ring speeds for “DinTab” and “c_ad”

The ring speed ratio (ratio of the ring speed to the rotor speed) becomes speed dependent in the following cases:

- Analysis type “DinTab”, “Ring Speed Ratio Calculation” with “f(viscosity)” or “f(viscosity, ecc.)”
- Analysis type “c_ad”, “Ring Speed Ratio Calculation” with “f(viscosity, ecc.)”

In both cases the ring speed ratio is iteratively calculated from the linear table with the load case defined in the RFB / FRB. In these cases the button “Show f(Speed)” is active (see figure 5.3) allowing to plot the ring speed ratio as a function of speed as shown in figure 5.4. In an actual rotor analysis (EIG, CDG, HAR) the ring speed ratio is calculated with the bearing load and speed defined in the analysis.

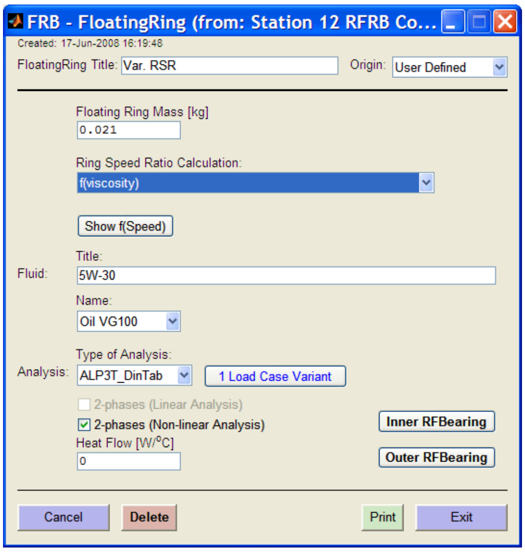


Figure 5.3: FRB GUI with “Show f(Speed)” button in case of speed dependent ring speed ratio

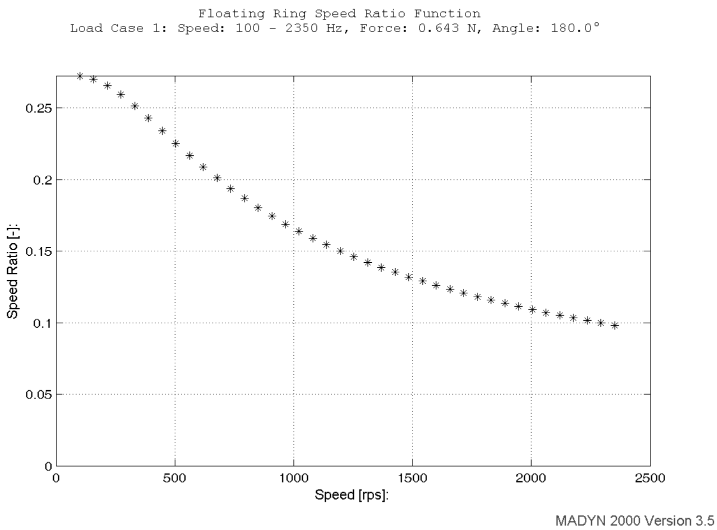


Figure 5.4: Ring speed ratio as a function of speed

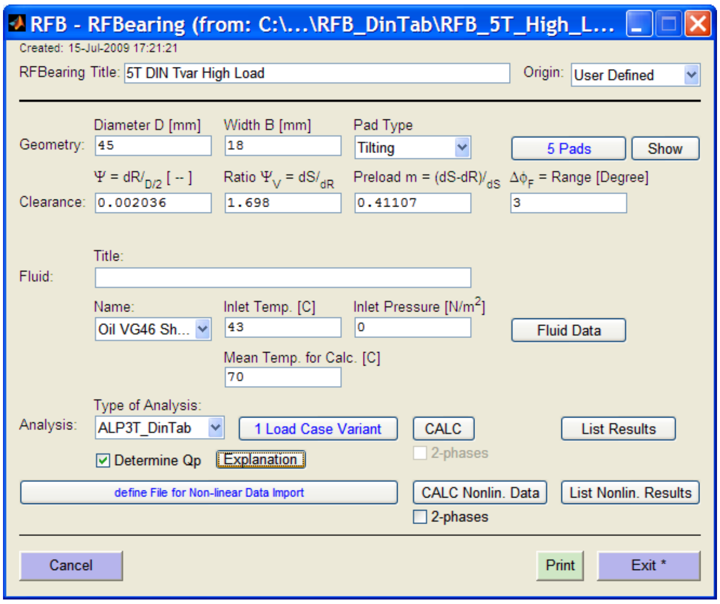
For the analysis type “DinTab” the heat flow between inner and outer oil film can be defined (see edit field “Heat Flow [W/^{o}C]” in the FRB GUI (figures 5.1 to 5.3).

6. Oil Supply Pressure in the DIN Analysis

Until now the oil supply pressure of a bearing can be considered for the analysis type “v_ad”. In version 3.5 it can also be considered for the analysis type “DinTab”. For this purpose the check box “Determine Qp” (see figure 6.1) has to be activated. The dimensionless oil flow Qp* is then calculated (see chapter II.6 of the MADYN 2000 documentation). The meaning of Qp[1] is explained in figure 6.2, which appears by pressing the button “Explanation” in the RFB GUI. The calculation of Qp* requires an additional ALP3T analysis with certain boundary conditions, which is automatically carried out.

In case the check box is active, the edit field “Inlet Pressure” appears. Note, that the creation of the DIN table does not require a definition of an inlet pressure. It can be defined after the bearing calculation or changed at any other time, without the necessity of a recalculation.

Defining an inlet pressure will cause the additional oil flow Qp, which provides additional cooling. This oil flow is especially important, in case there is little oil exchange between the pads due to the bearing load and / or bearing geometry, e.g. for cylindrical bearings with low load. The oil then is whirling in the bearing without being squeezed out at the side and being replaced by fresh oil. The consideration of the oil flow due to the supply pressure considerably reduces the mean oil film temperature of the bearing in such cases.



Figur 6.1: RFB GUI for “DinTab” analysis with check box “Determine Qp”

[1] Qp is dimensioned, whereas Qp* is dimensionless. The reference oil flow is Qo as explained in chapter 6.4 of the documentation.

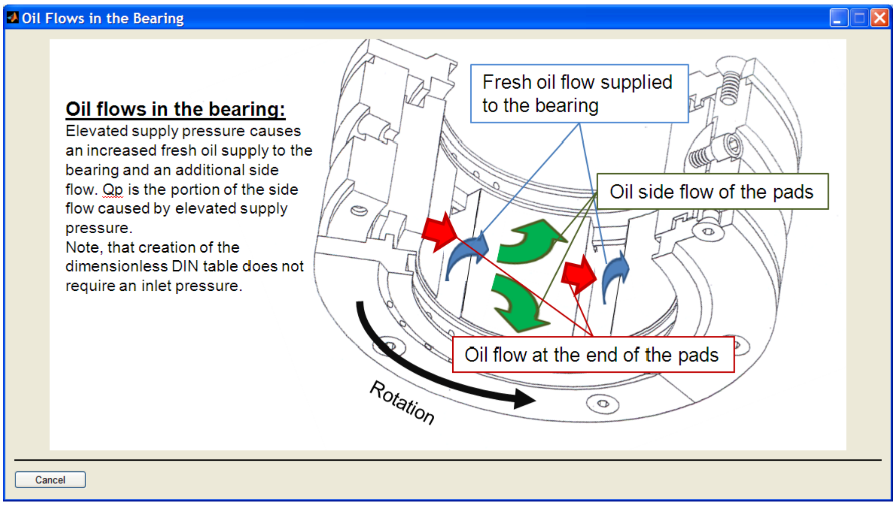


Figure 6.2: Oil flows in the bearing for the explanation of Qp

7. Plot of the Nonlinear Bearing Characteristics

From the results window for nonlinear analyses shown in figure 7.1 the nonlinear characteristics can be plotted. Two buttons are available for this purpose: One for the portion of the force caused by the rotation depending on the journal position (Sommerfeld-force) and one caused by the journal velocity at different journal positions (damping coefficients).

The resulting plots are shown in figure 7.2 and figure 7.3. In each plot the journal position is defined by the dimensionless eccentricity “eps” and the angular position “gamma”. In the 3-dimensional plot of the Sommerfeld-force, the 3rd dimension corresponds to the square root of the force magnitude. The same applies for the arrow length. The components BETA-XX, BETA-XY, BETA-YX and BETA-YY of the damping coefficients apply for the coordinate system in figure II.6.4 of the MADYN 2000 documentation.

A third button is available to plot the stiffness coefficients at different journal positions, although they are not used in nonlinear analyses.

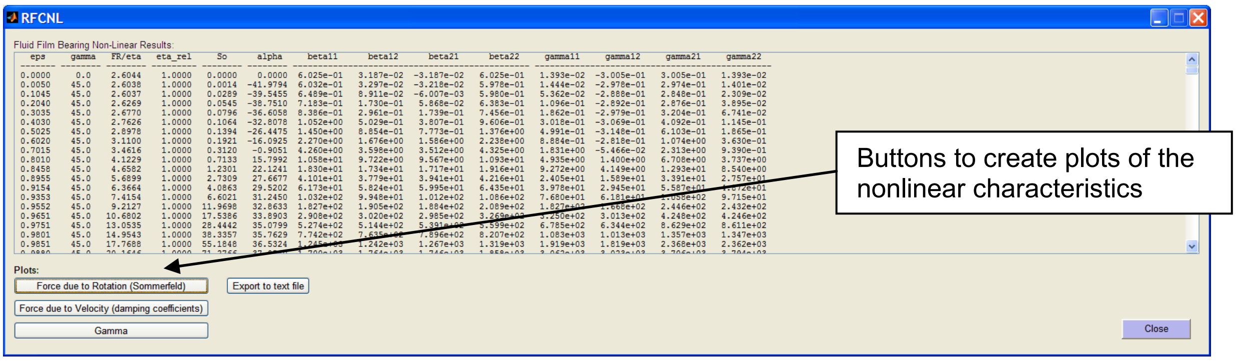
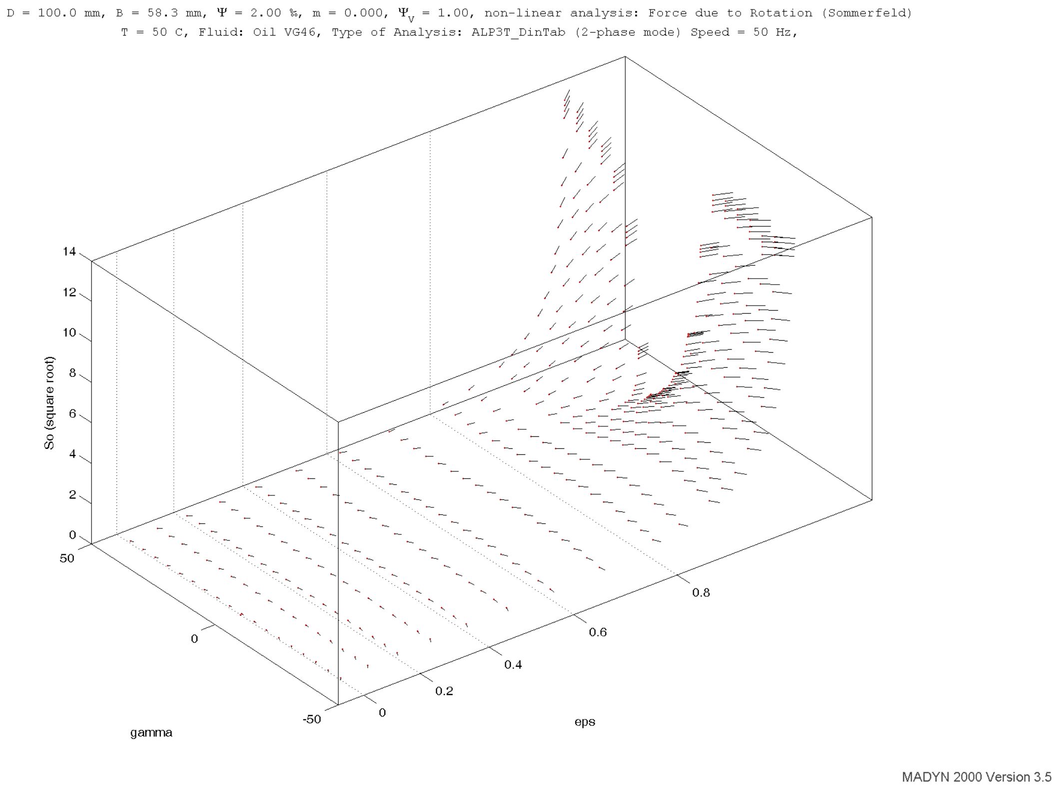


Figure 7.1: List results window with buttons to plot the nonlinear bearing characteristics



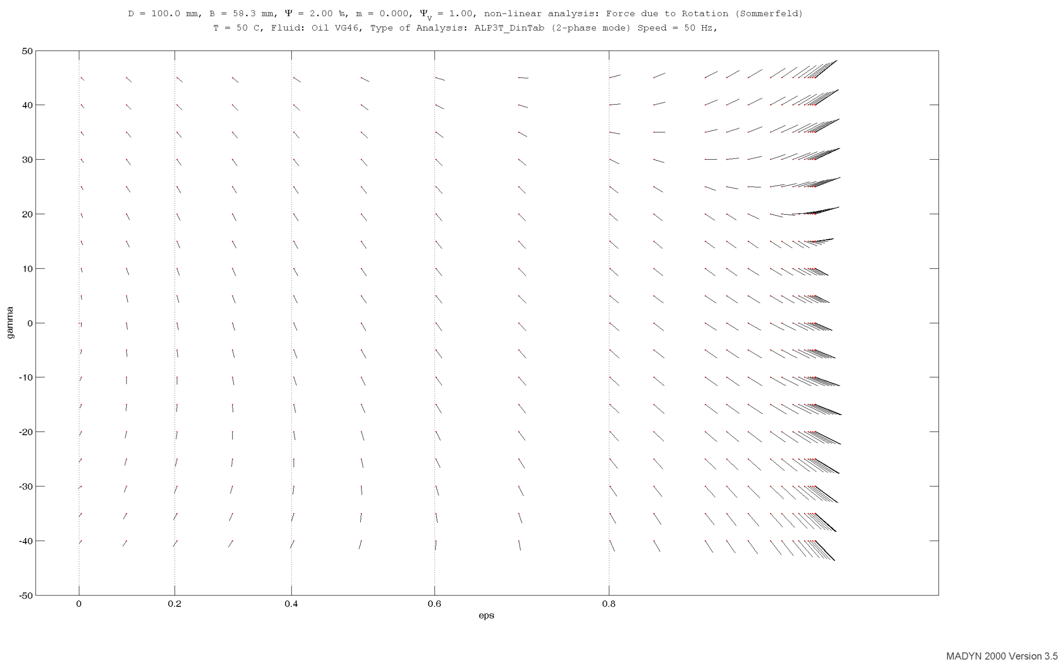


Figure 7.2: Plot of the Sommerfeld-force as a function of the journal position

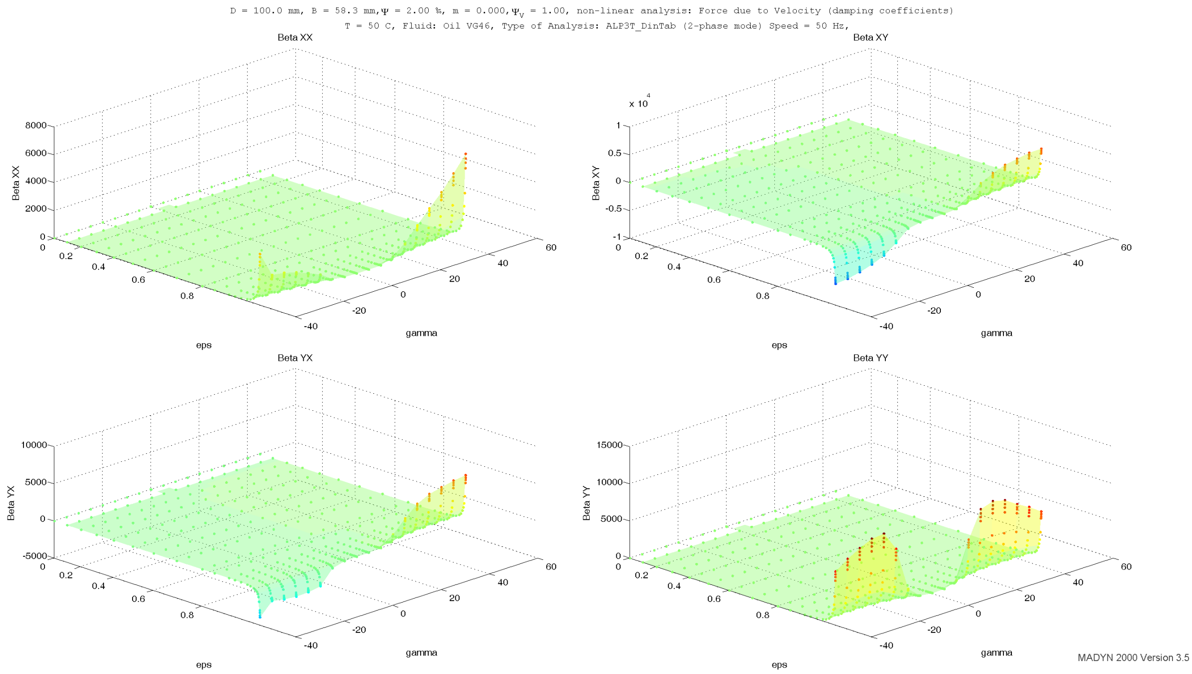


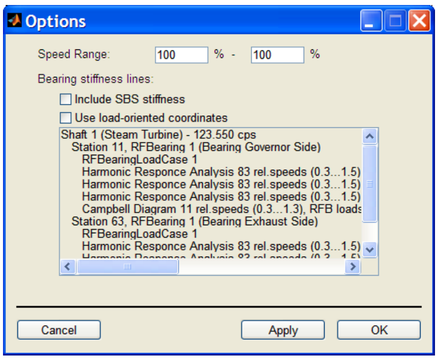
Figure 7.3: Plot of the damping coefficients as a function of the journal position

8. Stiffness Lines of Fluid Film Bearings in the Undamped Critical Speed Map

The lines of the speed dependent stiffnesses of fluid film bearings can be drawn into the critical speed map. This presentation can be deceiving, since the real critical speeds do not correspond to the intersections of these lines with the critical speed lines for various reasons:

- The bearing dampings are neglected.
- No bearing cross couplings are considered.
- The bearings in the critical speed map are equal.
- …

Nevertheless this possibility is offered, since it is required according to some specifications. The GUI for the selection of stiffness lines opened from the “Options” item of the MADYN menu of the Critical Speed Map window is shown in figure 8.1.



Figur 8.1: GUI to select bearing stiffnesses to be drawn in the Critical Speed Map

The GUI in figure 8.1 allows selecting bearings and their stiffness lines from various sources: Directly from the bearing analysis for the load case defined there or from any MADYN 2000 analysis such as a Campbell diagram or a Harmonic Response analysis with the corresponding bearing loads. Moreover check boxes allow the consideration of the bearing supports (the support stiffnesses are then added in series to the direct fluid film bearing coefficients) and to specify a load oriented coordinate system instead of the general 2-3- system for the direct stiffnesses. The latter can make sense in case of gear bearings, when the bearing load direction can be quite different from the 2- or 3-direction.

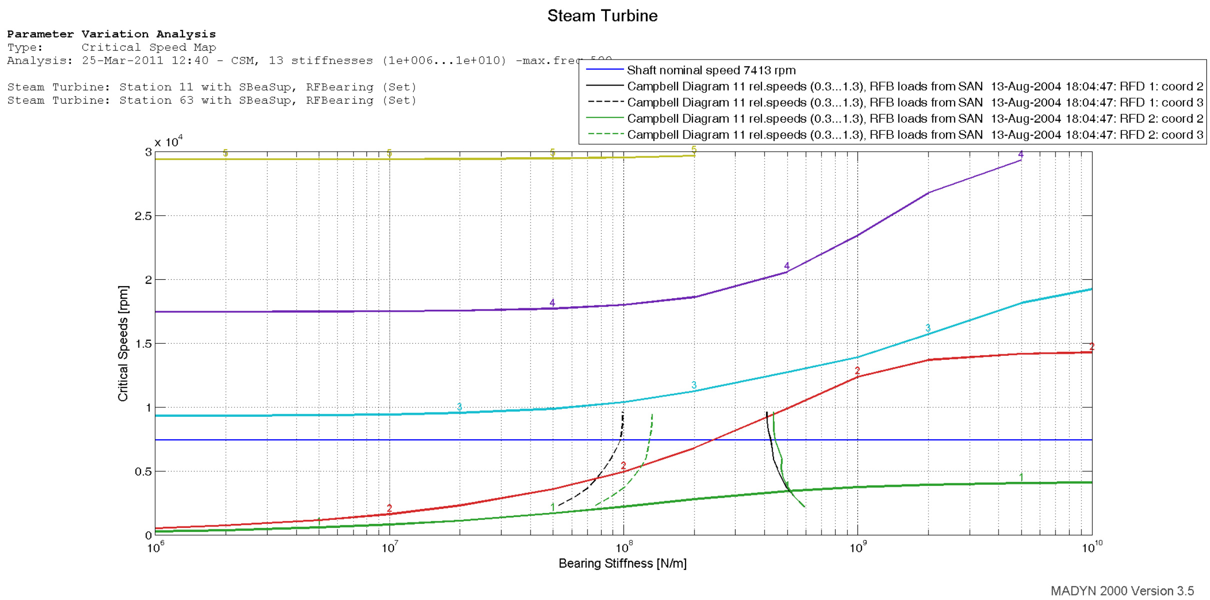


Figure 8.2: Critical speed map with fluid film bearing stiffnesses from a Campbell diagram

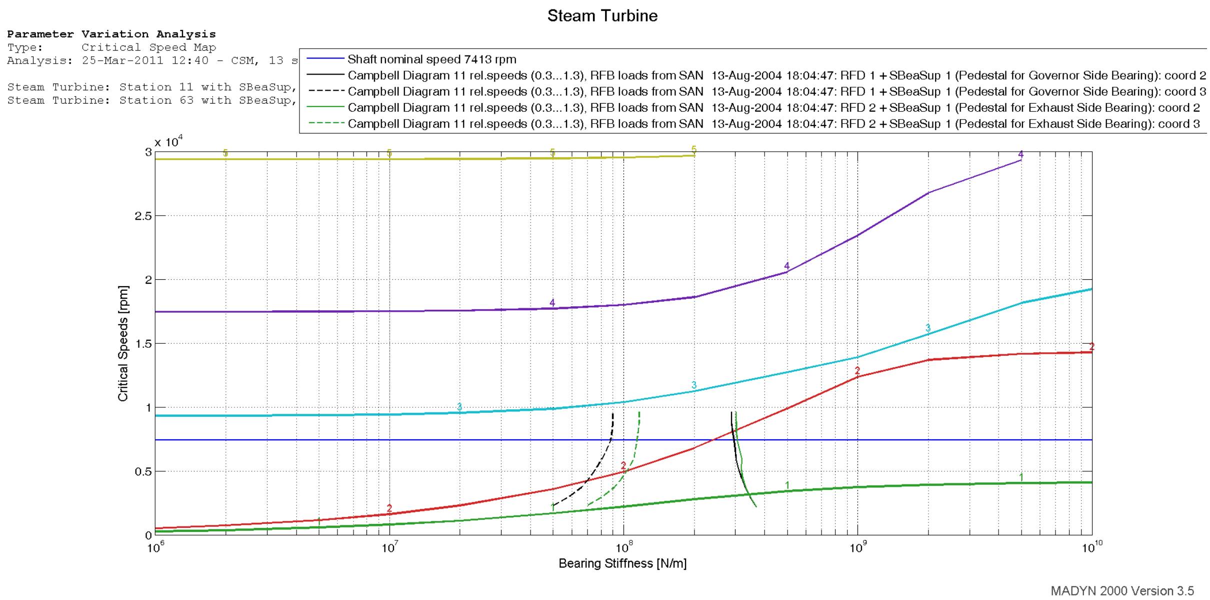


Figure 8.3: Critical speed map with fluid film bearing stiffnesses from a Campbell diagram including the support stiffness

9. The Rest Mode Method in Transient Response Analysis

The check box “Rest Mode Method” in the transient analysis GUI (see figure 9.1) allows applying this method in a transient analysis. In this method the negligence of higher modes in the lower frequency range is compensated by adding the difference of the static response of the complete unreduced system and the modally reduced system to the response.

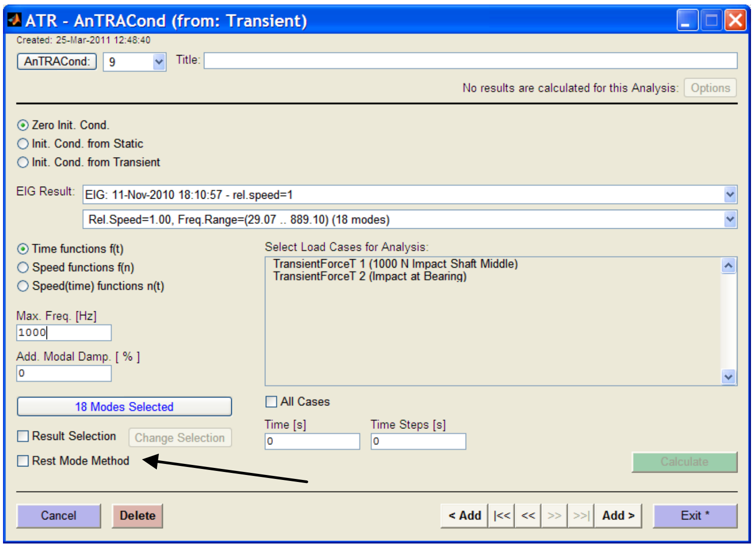


Figure 9.1: Transient analysis GUI with check box to apply the “Rest Mode Method”

The results of the transient response of a bearing and support force to a rectangular force function directly applied at the bearing (station 11) can be seen in figure 9.2 without rest modes and 9.3 including rest modes. It can be seen that in figure 9.3 the support force and bearing force after a short while are equal and approach 1000N, which is the magnitude of the force step. This result is correct. The result in 9.2 is not correct. There is no reason for the large difference between the support force and the bearing force. Such a difference could be explained by the inertia of the support, which, however, is negligible after the decay of the oscillation.

This example has been constructed to cause a big error due to neglected higher modes. Higher modes usually have a large deflection at the bearing and play an important role for the bearing forces, especially if a force is directly applied at the bearing. If in the same example the force would be applied in the middle of the rotor, the error would be much smaller.

It should be mentioned, that the bearing in this example has no damping force. It is a spring damper bearing without damping. The damping in the response is due to modal damping. The influence of the neglected modes can be very well compensated in such a case. Unfortunately this does not work as well for bearings with damping, because the influence of neglected modes then is not purely static.

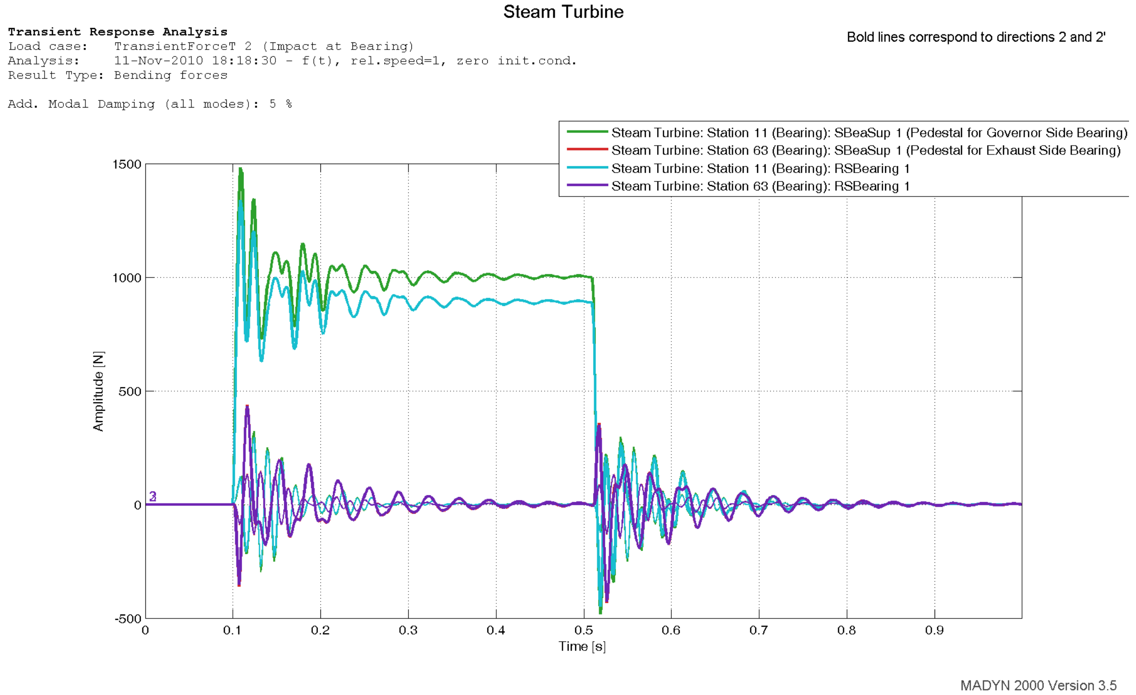


Figure 9.2: Transient response of the bearing force and support force to a rectangular force function directly applied at the bearing (station 11)

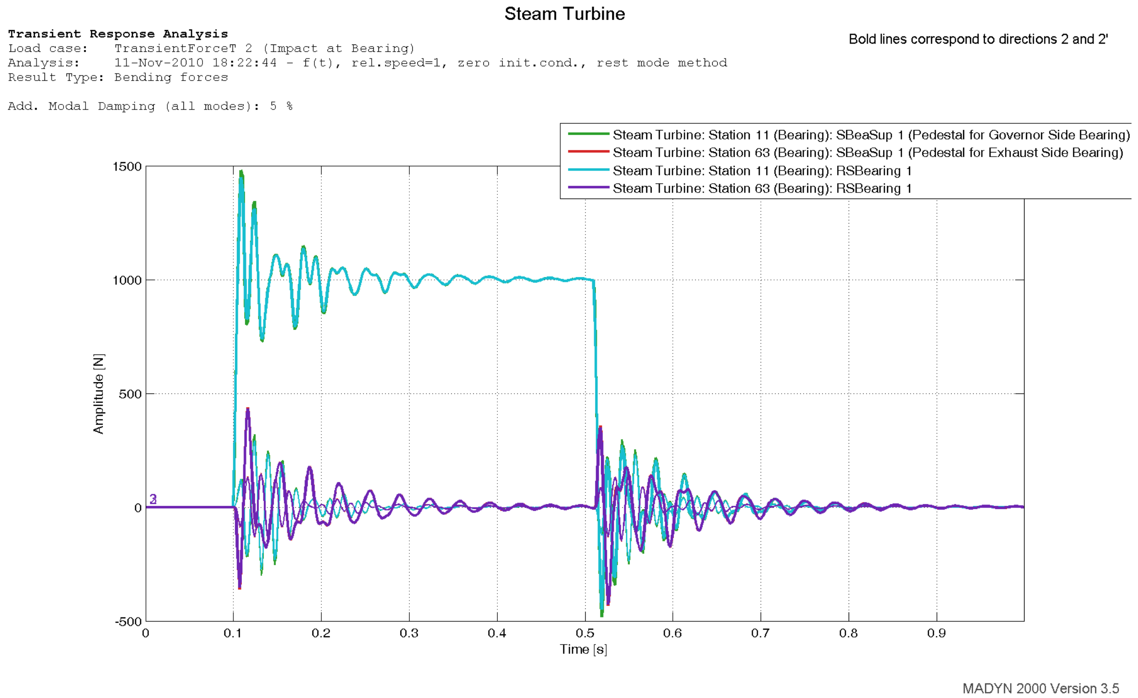


Figure 9.3: Same transient response as in figure 9.2 with rest mode method

10. New icons in some Result Plot Windows

Apart from the icons for the processing of time histories from transient analyses, which are explained in figure 2.1, further icons were introduced in some result plot windows.

Legends in some cases require a lot of space and can partly hide the actual results. They can be eliminated by clicking on the legends icon of the result plot (see figure 10.1).

Shapes can be plotted by clicking on the icon for shape plots (see figure 10.1). Two perpendicular lines appear after the click, which can be used to mark a speed and frequency. A left mouse click then plots the shapes next to the selected speed and frequency, a right mouse click all shapes at the selected speed.

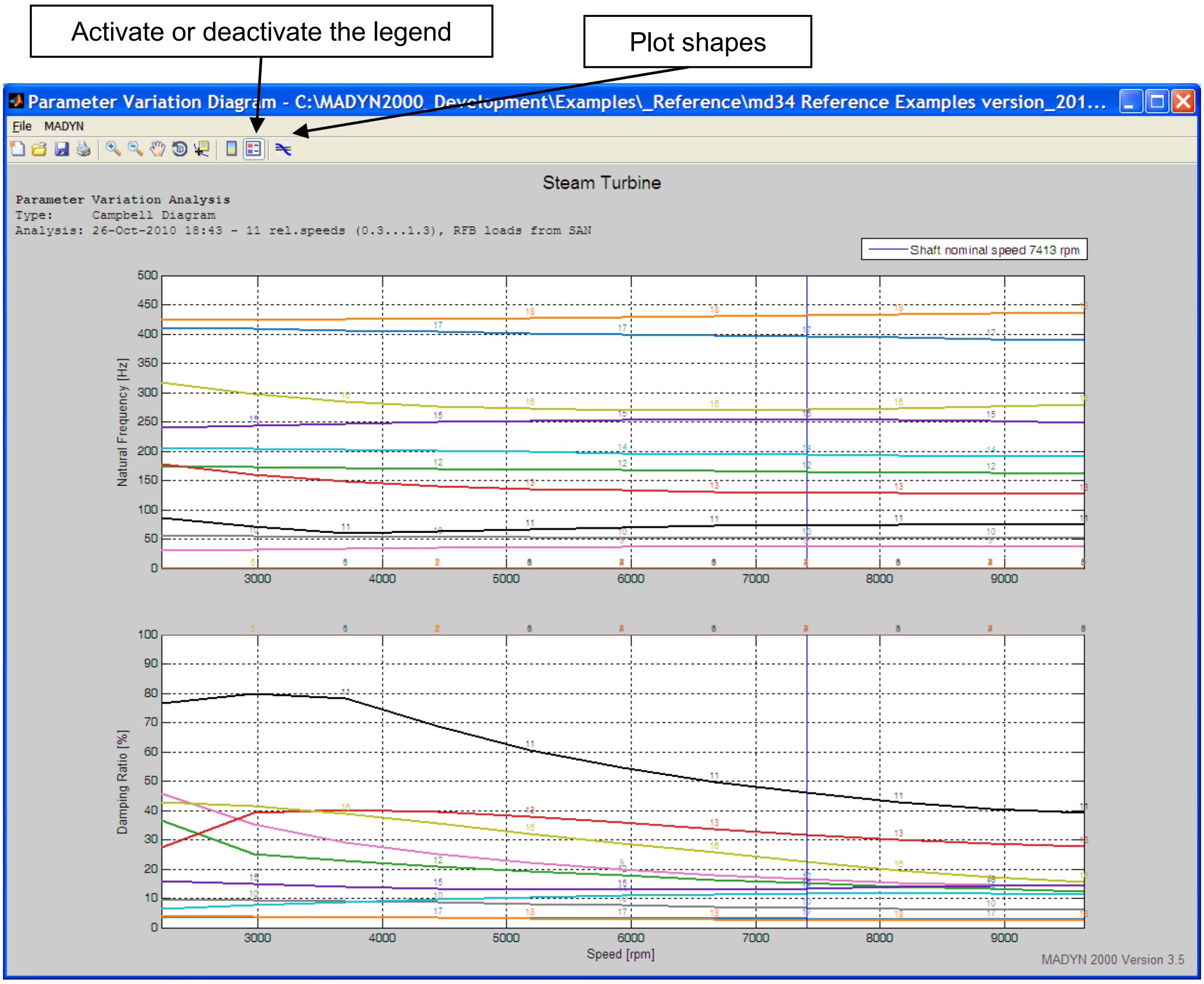


Figure 10.1: Explanation of new icons for plots for the example of Campbell diagrams