MADYN 2000 Version 4.1

The following new features and improvements were introduced in version 4.1:

1. Alignment Optimization
2. General Parameter Variation
3. Configurable Plots
4. Dynamic Bearing Support (DBS) Improvements
5. Fluid Film / Floating Ring Bearing (RFB / FRB) Improvements
6. Rolling Element Bearing (REB) Improvements
7. Import of Frequency and Speed Dependant Bearing Characteristics
8. Fluids with Offset
9. Set Boundary Conditions by General Spring GSP

Table of content for detailed description of features:

1. Alignment Optimization

The “Rigid Alignment Analysis” has been introduced as new analysis type in static analysis (see figure 1.1). It is a robust and quick analysis to find an alignment for a shaft train with minimum bending moments and shear forces at the couplings. In the ideal case they are zero. This facilitates erecting shaft trains with several shafts and rigid connections as they are common in power generation. The analysis assumes rigid bearings.

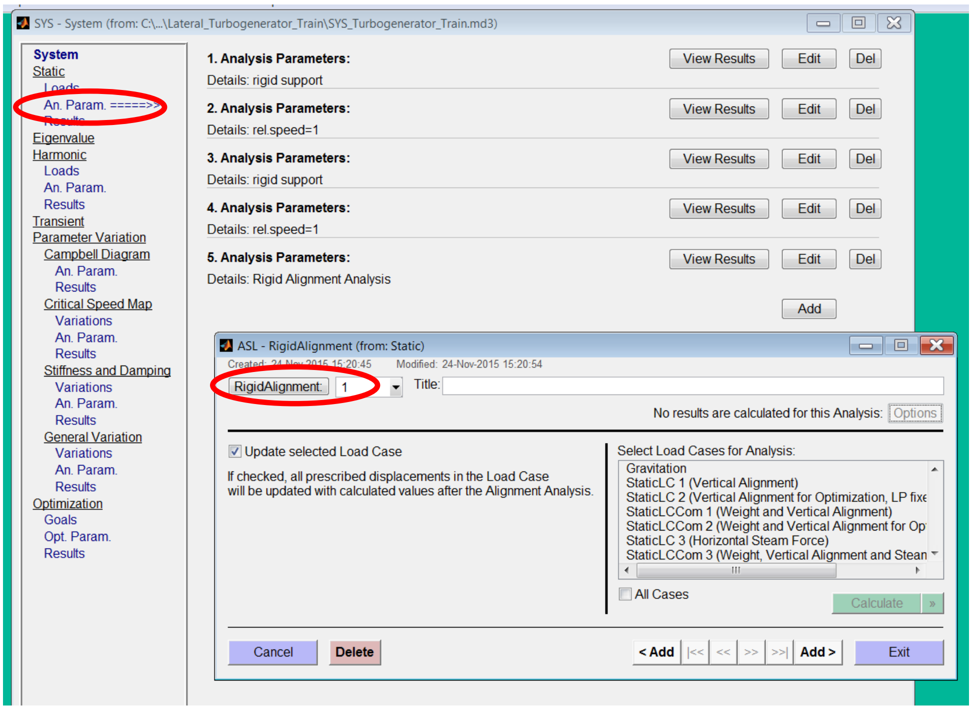

Fig. 1.1: Analysis GUI for the “Rigid Alignment Analysis”

A static load case combination consisting of a weight load and a displacement load has to be selected in the analysis GUI. The displacement load defines which supports are shifted to find the optimal solution. In case the check box “Update selected Load Case” is active, the results of the load case will be overwritten by the results of the alignment analysis. A suited load is shown in figure 1.2.

The algorithm to find the solution is based on a matrix of influence numbers (coupling bending moments and shear forces per alignment change at each bearing). Unknowns are the bearing displacements. The number of independent equations may be smaller than the unknowns (too may supports, which are shifted, for too few couplings). In this case a solution is still found by automatically setting the displacements of some supports to zero. However, the solution then is not unique. The user is informed by a warning about this fact. If the solution is practically not feasible a static load case with less bearing displacements has to be created and selected. On the other side the number of independent equations may be larger than the unknown displacements (too few supports, which are shifted, for too many couplings). In this case a least square solution for the coupling forces is found. Hereby the algorithm in a first trial always tries to find a solution with zero bending moments and least square coupling shear forces. If this is not possible, then a least square solution also for bending moments is found. The bending moments are prioritised for a solution with zero, because in most practical configurations such a solution exists, whereas in many configurations zero shear forces are not achievable (e.g. if a coupling acts as a shaft support). Coupling forces, which are not affected by the alignment (e.g. couplings at overhang shafts) are automatically eliminated from the system of equations.

For the system shown in figure 1.2 there are 4 displacements and 4 couplings. The result of the optimal alignment is shown in figure 1.3.

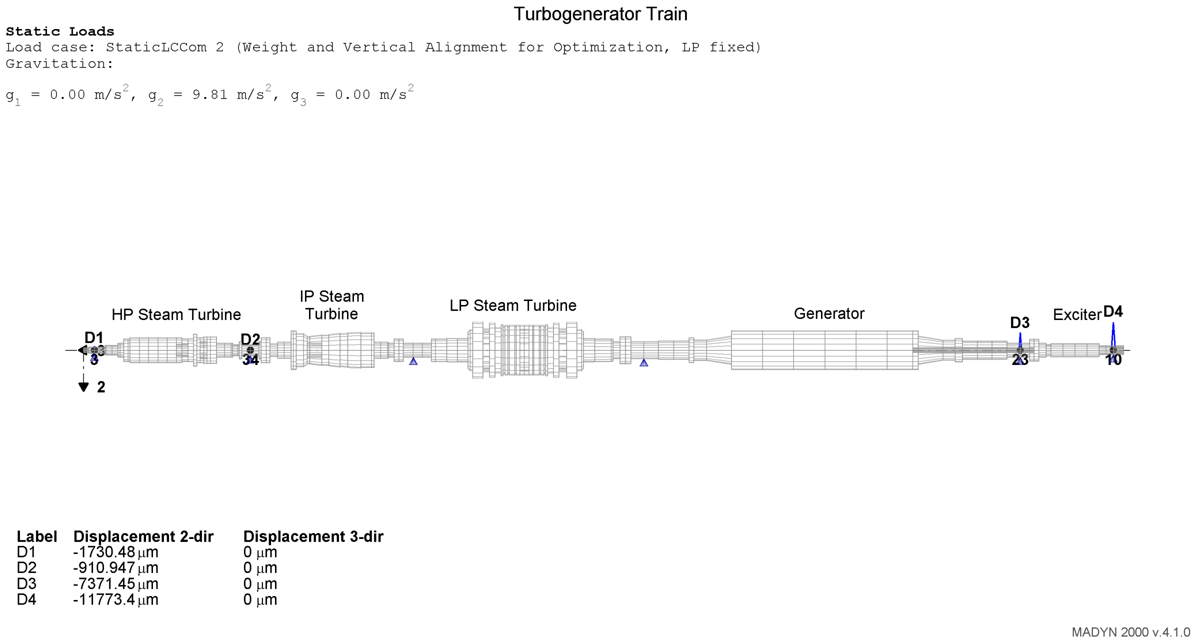

Fig. 1.2: Suited static load case for alignment optimization

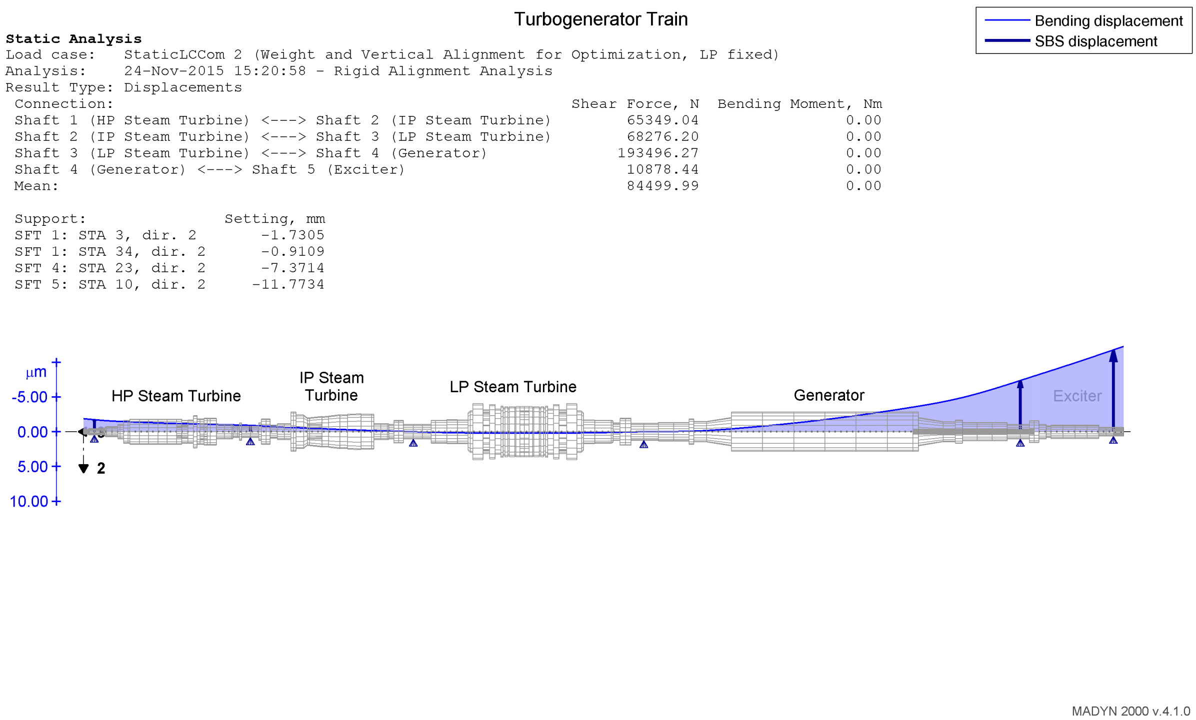

Fig. 1.3: Optimal alignment for the case in figure 1.2.

If the load case in figure 1.2 would have one displacement more, than the solution for the optimal alignment would not be unique (5 displacements, 4 couplings).

In previous versions a similar feature was already available under “Optimization” using an optimization algorithm. This feature is still available and can be used in case the deflection of the shaft journal in the bearing should be considered to find an optimal alignment.

2. General Parameter Variation

The “General Parameter Variation” is an eigenvalue analysis with the variation of a parameter of the system. Properties of one or several arbitrary objects (e.g. section diameter, bearing diameter …) can be varied by one set of factors. Parameters for the variation are added by the button “Add Variation” in the “General Variation” GUI. The button opens a window with an edit field to paste the property by its address (see figure 2.1).

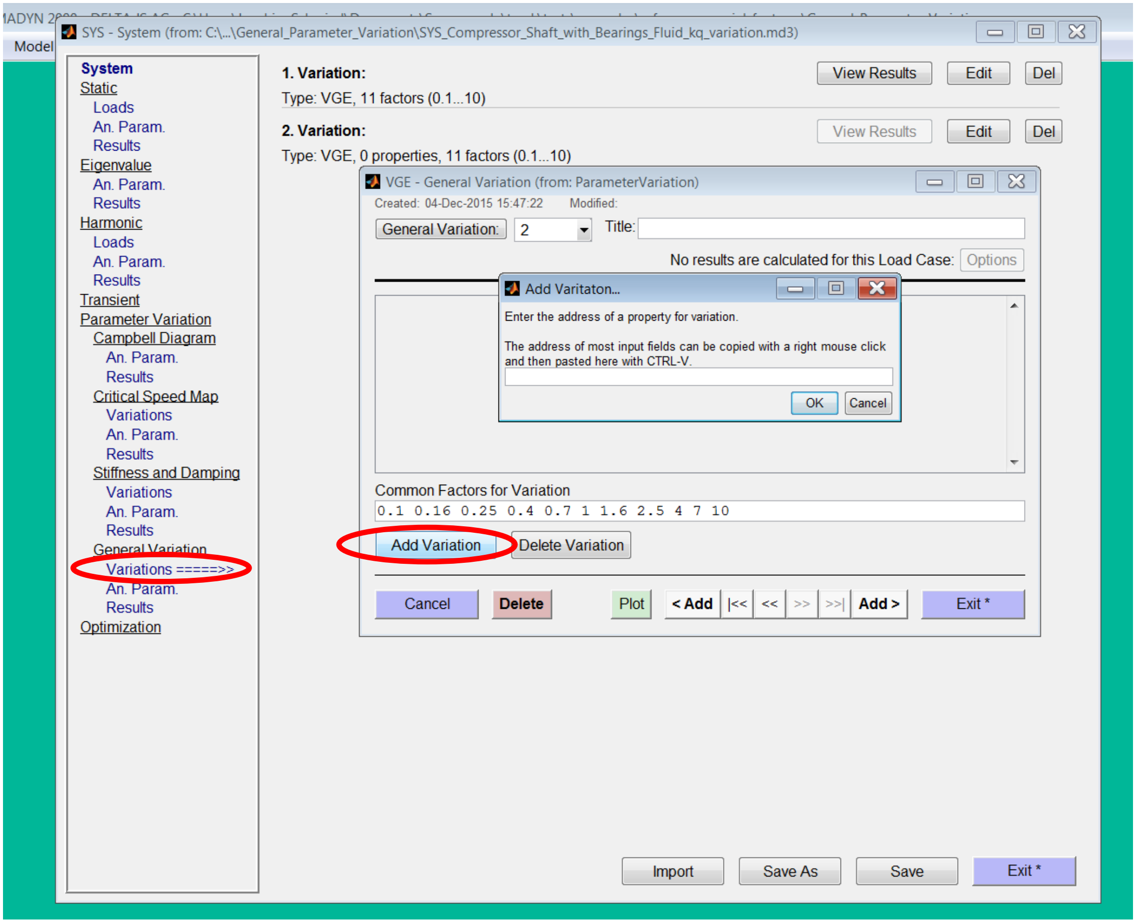

Fig. 2.1: GUI to define a general parameter variation

The address is received by the respective edit field in the object GUI with a right mouse click. To copy the address of a fluid coefficient for example, the fluid GUI has to be opened and a right mouse click in the edit field will copy the address (see figure 2.2). The property is pasted in the edit field of the variation GUI by the key combination “ctrl V” (see figure 2.1).

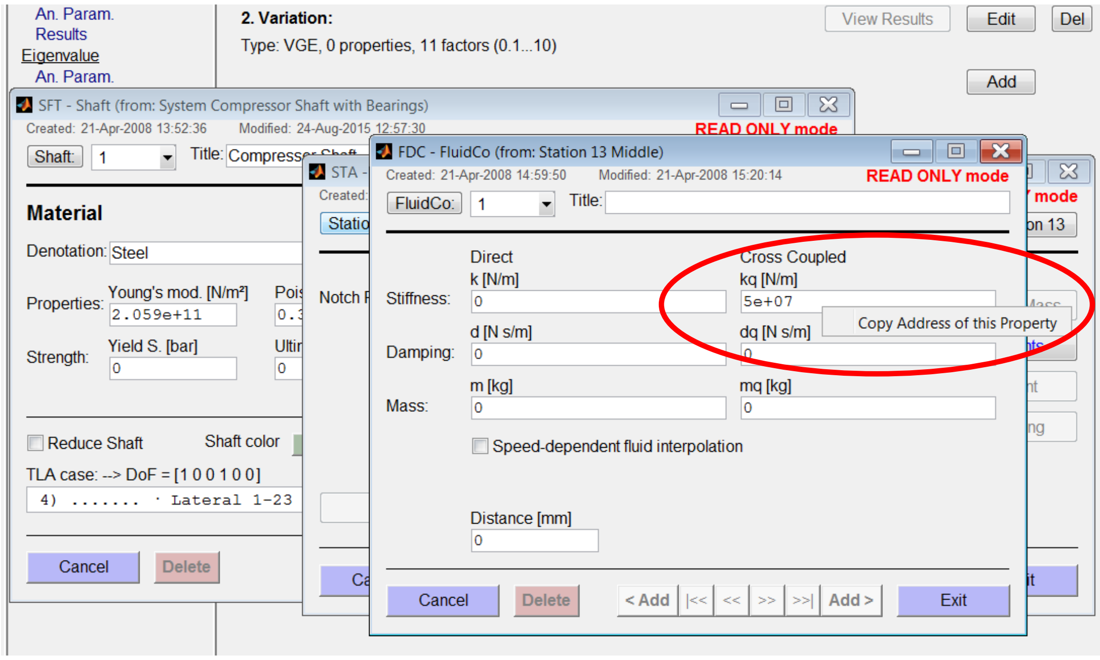

Fig. 2.2: Copying the address of the fluid coefficient k_q.

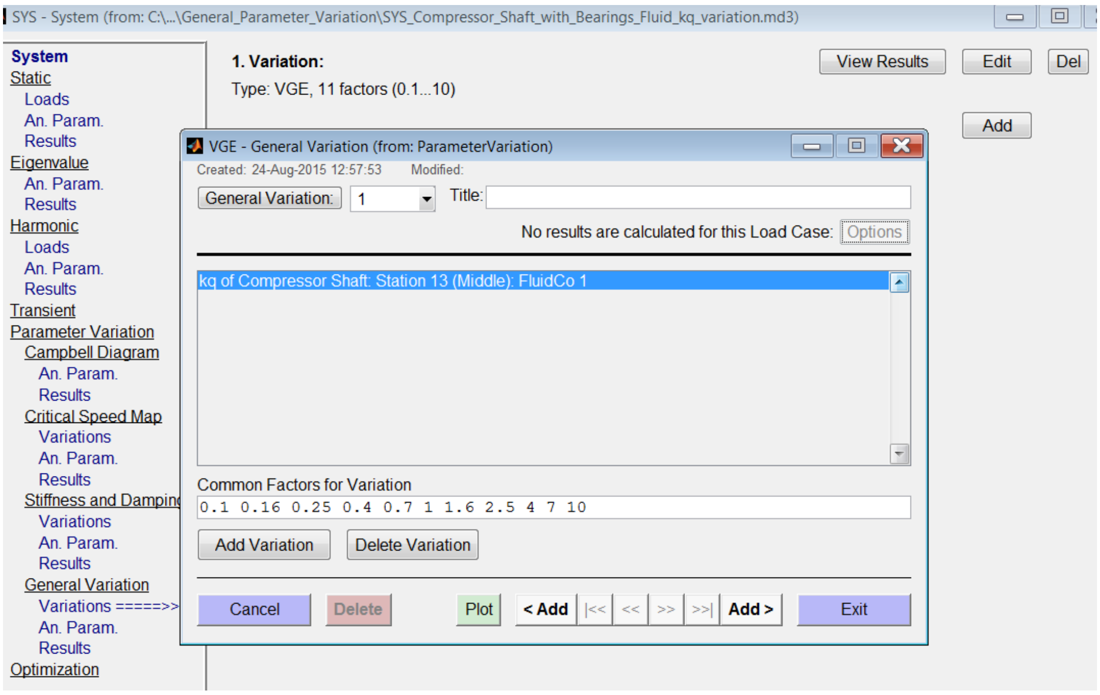

Fig. 2.3: General parameter variation GUI with selected parameters

After the address is copied it appears in a list of varied parameters (see figure 2.3). Several parameters can be added. The factors for the variation are defined in the edit field “Common Factors for Variation”.

Analysis parameters are defined in a similar way as for the stiffness and damping variation of bearings (VSD). The result of a variation of the fluid cross coupling coefficient can be seen in figure 2.4.

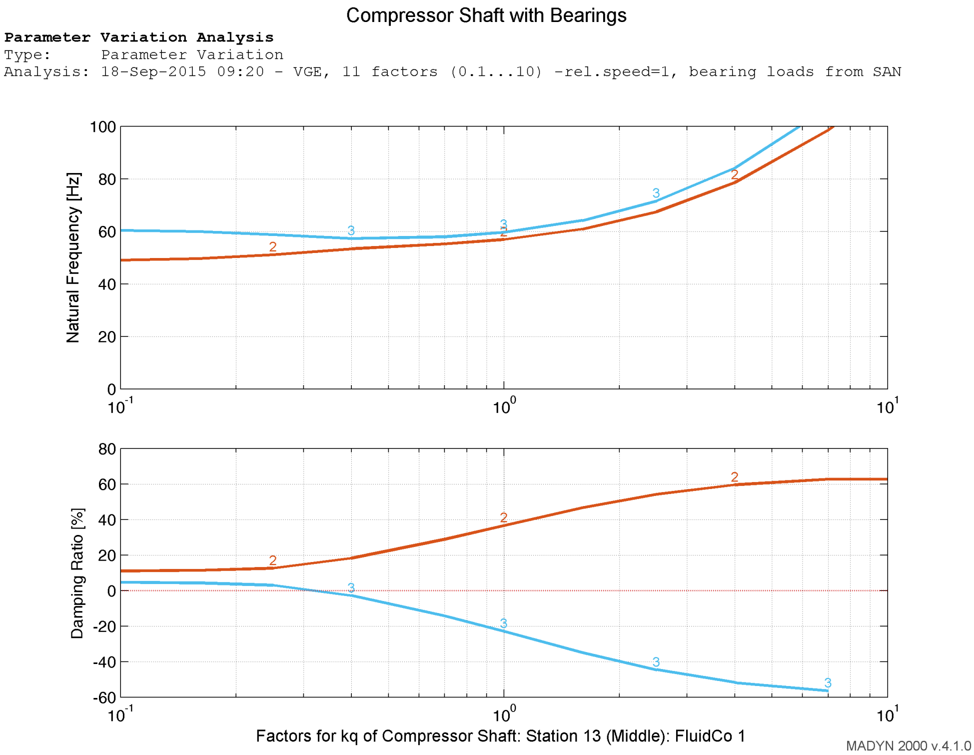

Fig. 2.4: Diagram of the eigenvalues for the variation of a fluid cross coupling coefficient

The cross coupling variation as it is required for level I stability analysis according to the API standard 617 can be carried out with the help of the general parameter variation.

3. Configurable Plots

Configurable plots can be created for the following diagrams and orbits:

- Diagrams for eigenvalues
- Diagrams for parameter variation
- Diagrams for harmonic response analyses (apart from magnetic bearing sensitivity)
- Diagrams (time history plots) for transient response
- Orbits for harmonic and transient response

The settings of configurable plots are stored. The plots can therefore be easily recreated. This feature is a first step to the creation of complex automated reports.

Configurable plots are created from the menu item “Create new Plots”. The menu appears when clicking on the plot button in the system explorer (see figure 3.1) or in the GUI to select results of analyses and load cases (see figure 3.2).

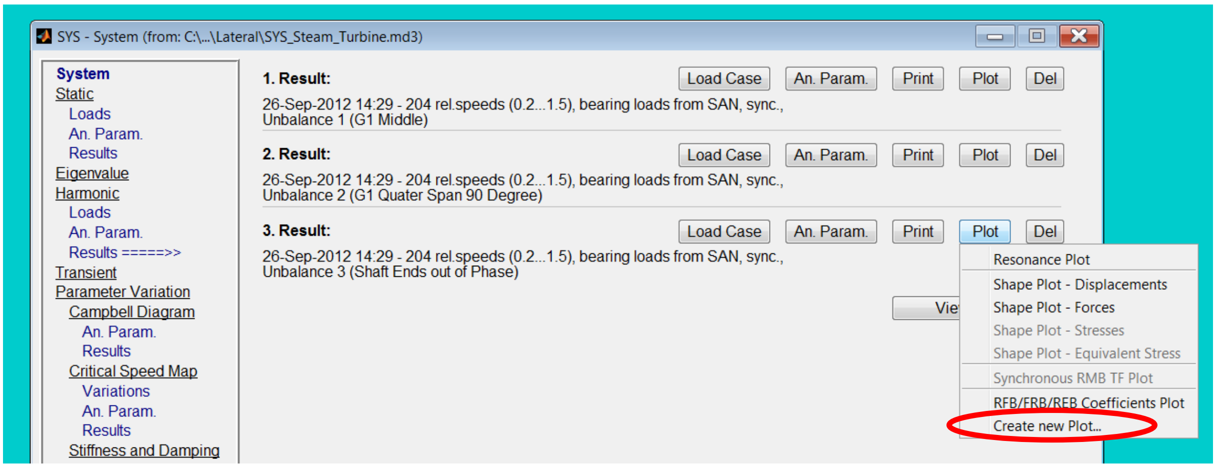

Fig. 3.1: Menu with item to create configurable plots from plot button in system explorer

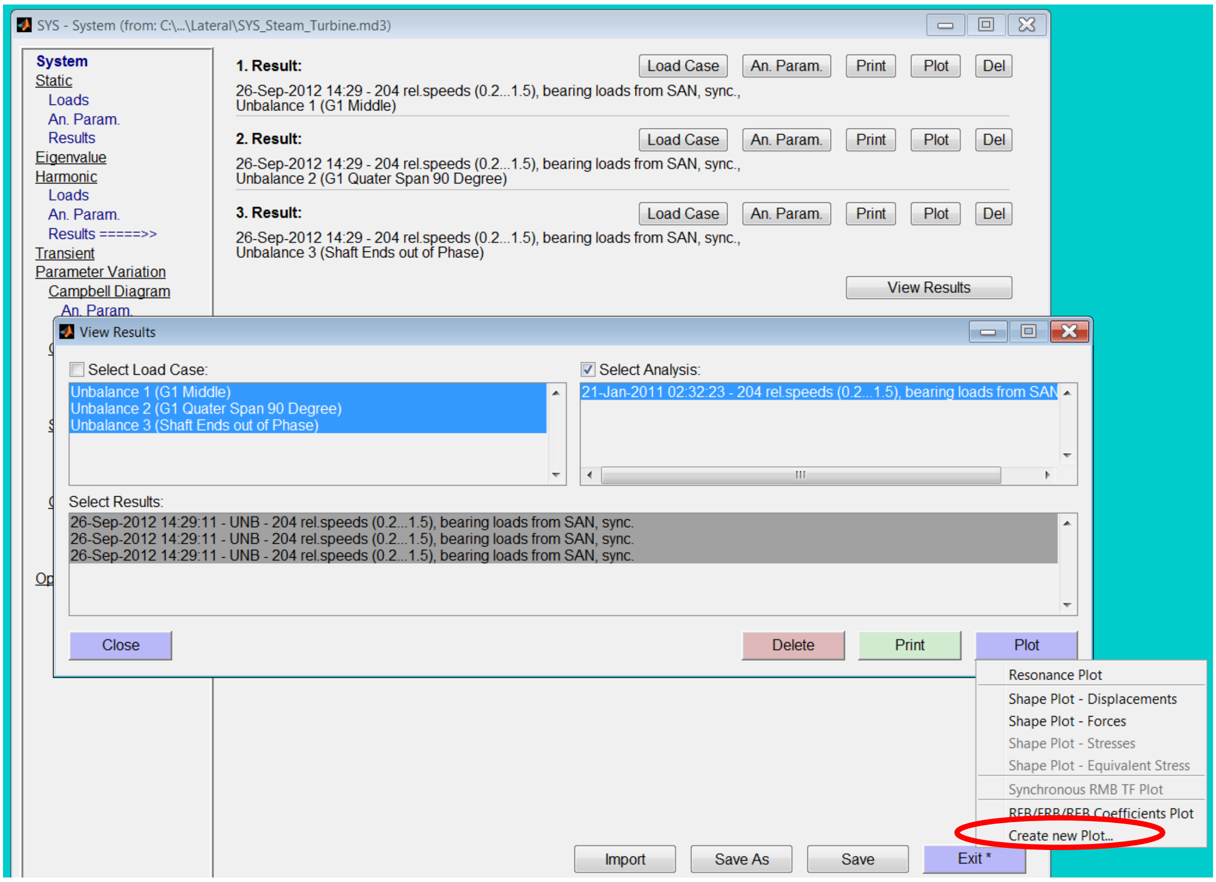

Fig. 3.2: Menu with item to create configurable plots from plot button in load / analysis selection GUI

In both cases the configuration GUI is opened (see figure 3.3).

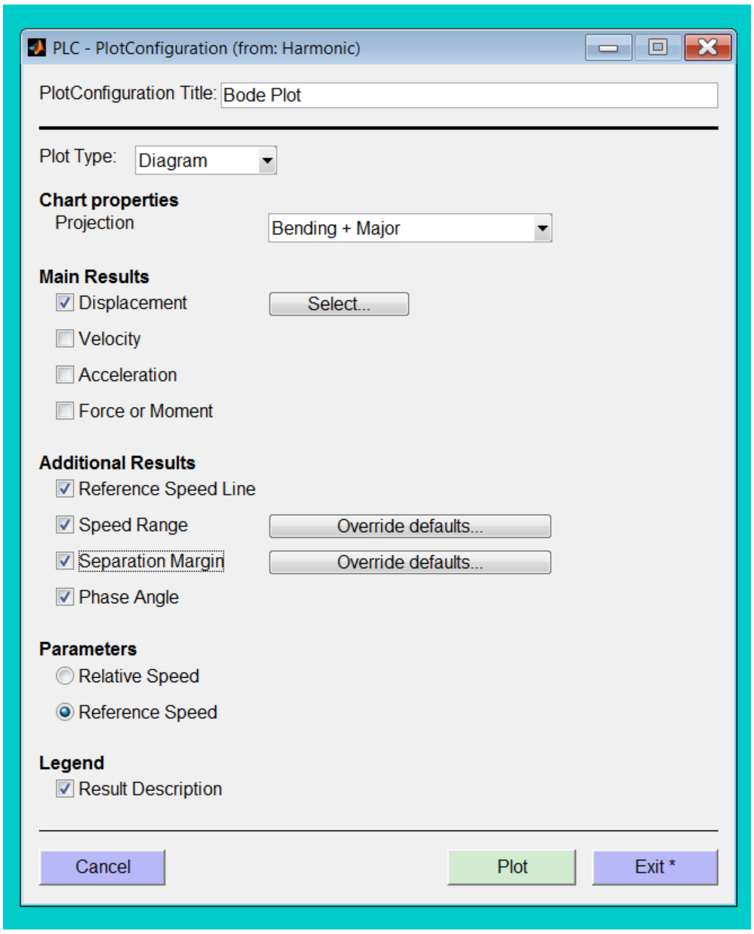

Fig. 3.3: GUI to configure plots

The GUI allows to define the type of plot (diagram or orbit), to select the result and to set further configurations. Available configurations depend on the type of analysis for which the plot shall apply. For the Bode plot of an unbalance response analysis for example the “Speed Range” and “Separation Margin” can be defined (whereas in the normal standard plot only the speed range is plotted). Once the plot is opened, further configurations can be set in the plot window. Setting for axes can be adjusted by a right mouse click on the axes title, which opens a corresponding window (see figure 3.4).

For plots with a parameter, which does not appear on axes such as speeds in case of an orbit plot, a scroll bar and edit fields to define a range for the parameter can be activated (see figure 3.5).

All configurations defined in the GUI and the plot window are saved under a name corresponding to the title. For further plotting, e.g. after model changes, the configured plot can be called from a menu item corresponding to the title (see figure 3.6). This item will directly open the plot window. The configuration window can be invoked from the MADYN menu (see figure 3.4) in the plot window for any changes. Configurations can be copied and pasted as other objects with a right mouse click in the GUI.

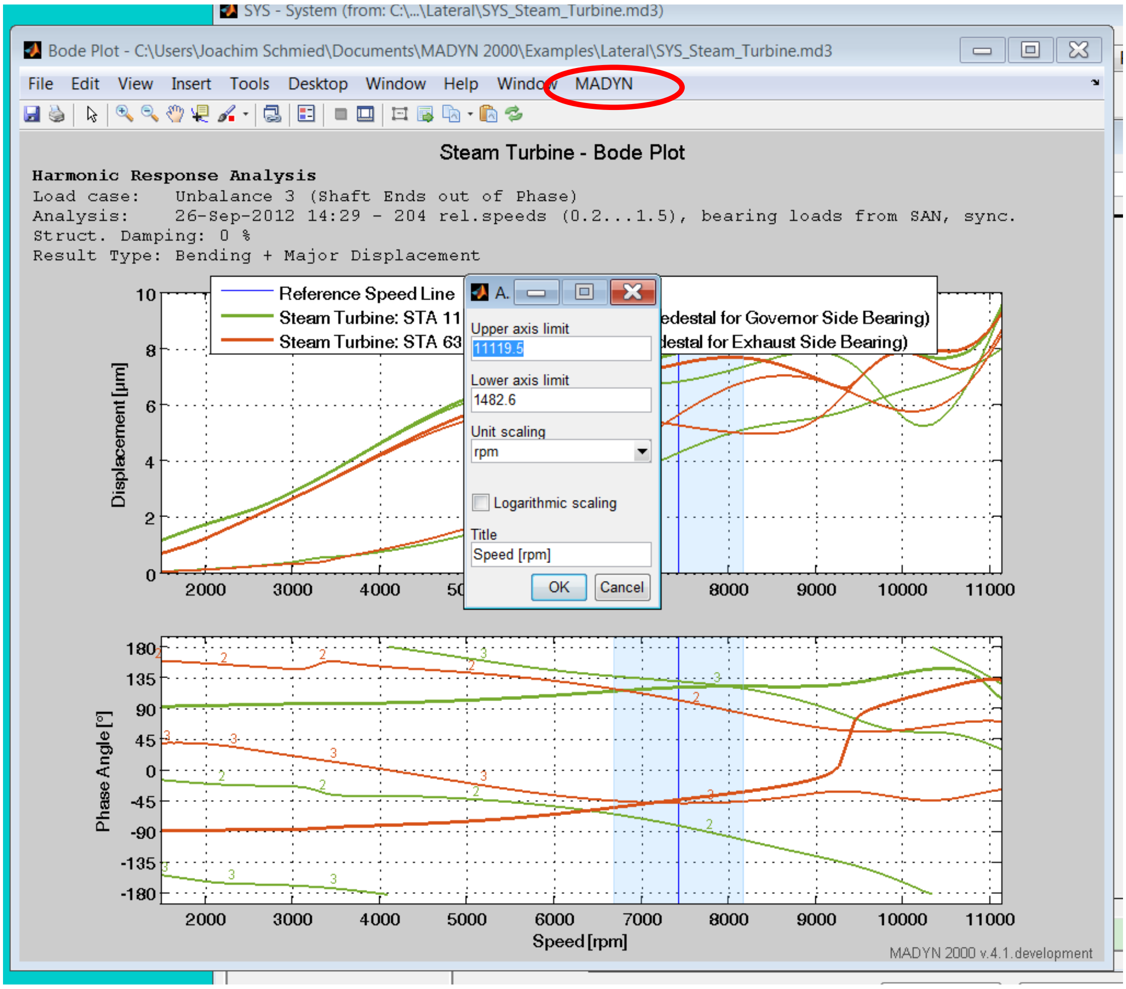

Fig. 3.4: Axes configuration and MADYN menu in plot window

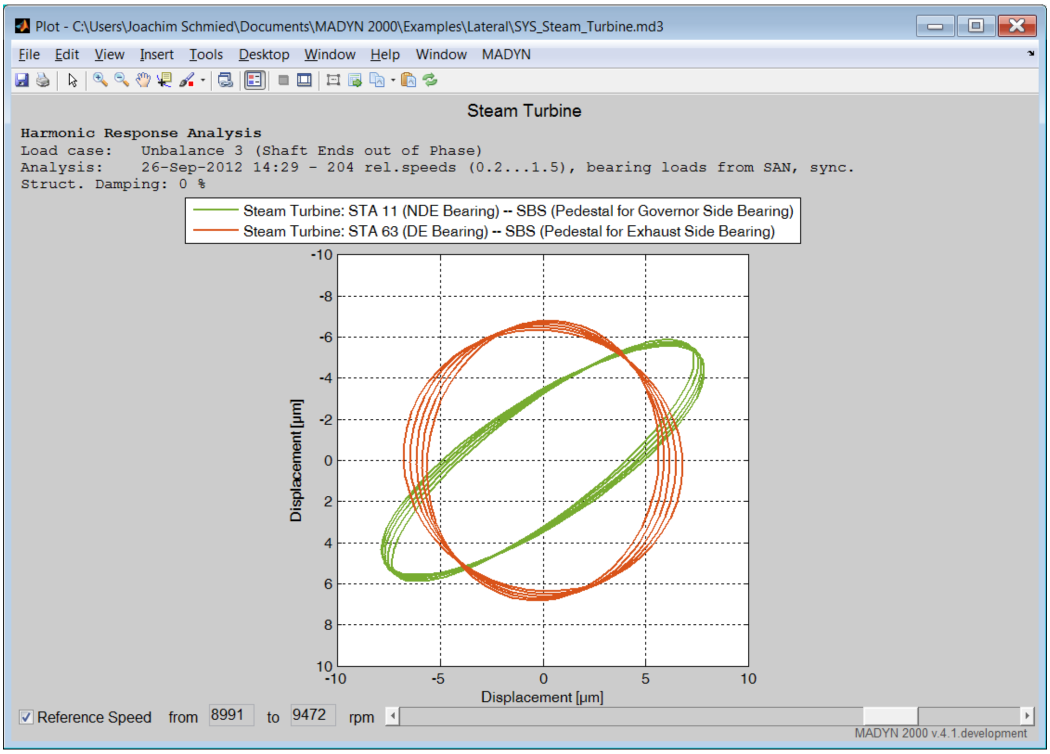

Fig. 3.5: Orbit plot with scroll bar to define parameter range

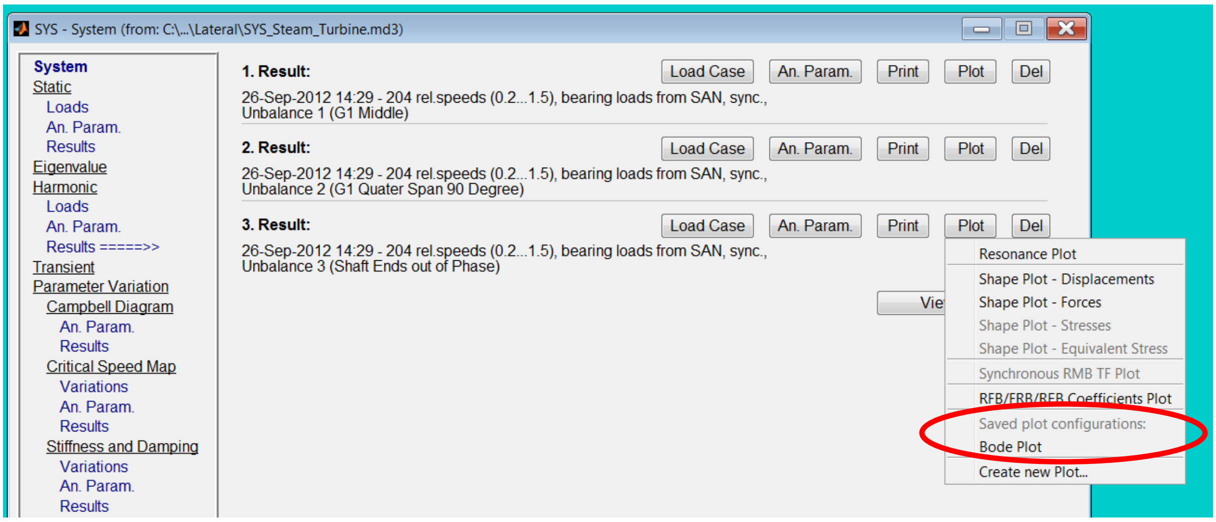

Fig.3.6: Menu item to call a configured plot

4. Dynamic Bearing Support (DBS) Improvements

4.1 State Space Reduction

The state space form of “Dynamic Bearing Supports” is needed for eigenvalue analyses and Campbell diagrams. Version 4.1 offers a feature to reduce the states.

The state space matrices can either be directly imported, which is the preferred method to model the supporting structure, if the state space matrices are gained from a physical model (see for example http://www.delta-js.ch/cms/upload/pdf/english/technical-papers/SIRM2013_Berlin_Alstom_ABS-235.pdf). Finite element programs such as ANSYS provide ways to export state space matrices, which can readily be imported to MADYN 2000. In this case a state space reduction is not necessary.

However, such models are not always available and transfer functions in table form (TFU) can also be gained from other sources, e.g. measurements. For this reason the path via the polynomial form is an additional useful feature. The state space system created from such polynomials in general contains multiple equal poles, due to the fact, that the same resonance can be seen at several supports. This can be avoided by reducing the states. A suited order for the reduced system normally is two times the number of different natural frequencies (resonances) of the DBS system.

The DBS GUI with the controls to reduce the states and define the reduced order can be seen in figure 4.1. The eigenvalues of the state space system with the original order of 36 and the reduced order of 14 can be seen in the print in figure 4.2, which is newly available in version 4.1.

The plots of the transfer functions are shown in all available forms:

Original table,
adapted polynomial,
reduced state-space.

As in previous versions the plot for the transfer functions of a single support can be created with a right mouse click in the field for the corresponding support (see figure 4.3). An overview of all transfer functions in the form of amplitude plots can be created with the plot button (see figure 4.4).

All shown GUIs and plots in this chapter are from the demo example “Compressor with Dynamic Bearing Support”. The demo examples are distributed with the installation package.

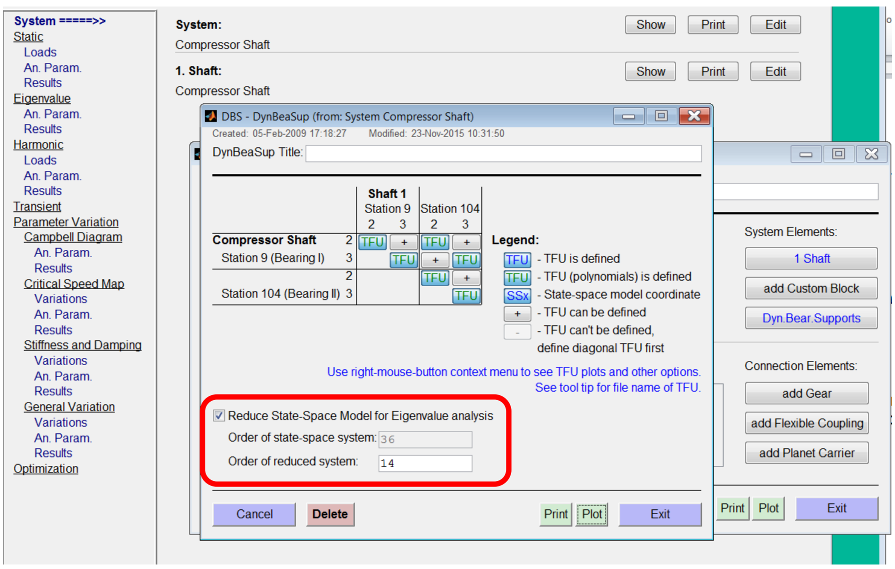

Fig. 4.1: DBS GUI with new check box for the state space reduction and an edit filed to define the order

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DynBeaSup - Print Preview

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Dynamic Bearing Support:

  Polynomial Natural Frequencies, reduced State-Space, for combined system:
   Frequency [Hz]     Damping Ratio [%]
      57.832             1.00
      57.850             1.06
      78.700             1.00
     239.325             1.00
     242.889             1.00
     286.154             1.62
     299.886             1.03

  Polynomial Natural Frequencies, from Poles, for combined system:
   Frequency [Hz]     Damping Ratio [%]
      57.832             1.00
      57.832             1.00
      57.832             1.00
      57.834             1.01
      78.700             1.00
      78.701             1.00
      78.701             1.00
      78.741             1.02
     239.325             0.99
     239.325             0.99
     239.325             1.00
     239.326             1.01
     242.889             1.00
     242.889             1.00
     242.889             1.00
     243.371             0.86
     286.362             1.60
     299.886             1.03
```

Fig. 4.2: Print of the eigenvalues of the DBS state space system, reduced and original order

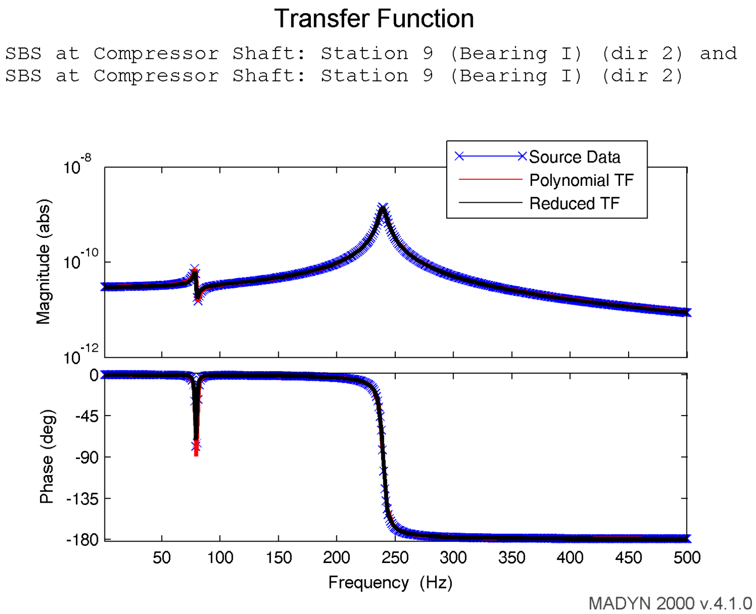


Fig. 4.3: Transfer function plot for a single support for all available forms

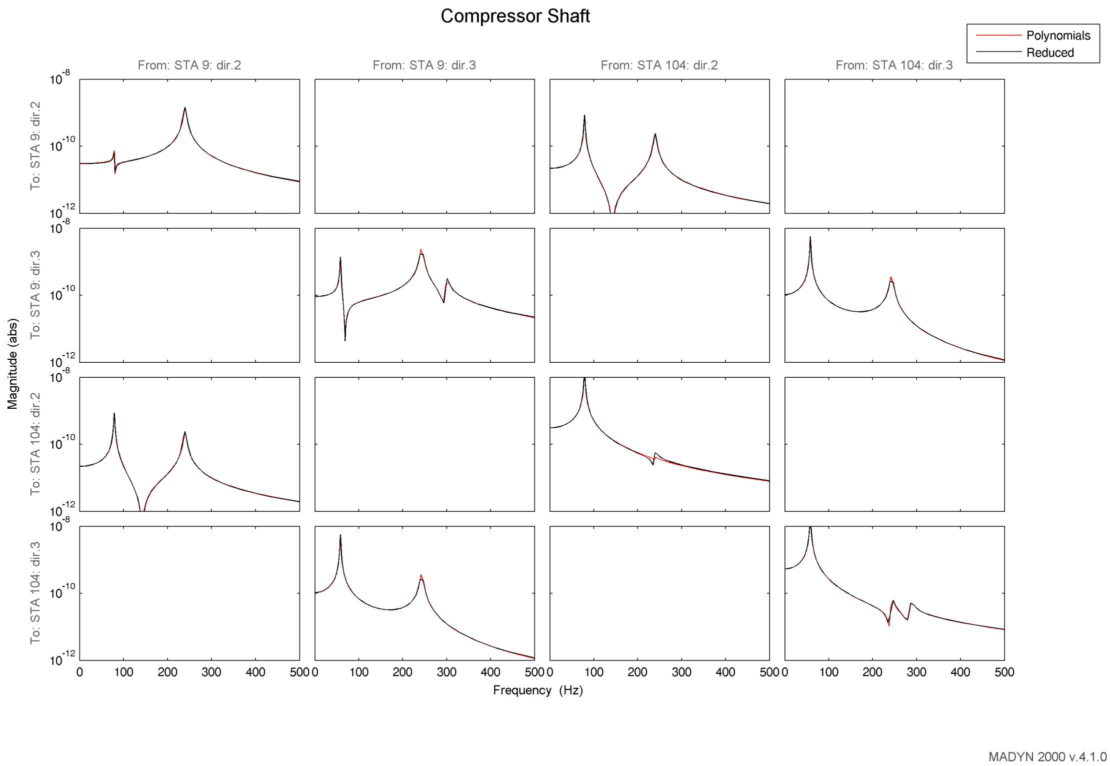


Fig. 4.4: Transfer function plot of the complete support system

4.2 Nonlinear Fluid Film Bearings and DBS

DBS can now also be used in nonlinear transient analyses. They are used, if the underlying eigenvalue analysis or Campbell diagram of a transient analysis has considered the DBS.

5. Fluid Film / Floating Ring Bearing (RFB / FRB) Improvements

5.1 Stand Alone Squeeze Film Damper

A squeeze film damper is now available[1]. It can be combined with other bearings such as rolling element bearings REB or fluid film bearings RFB via shaft in shaft connections. The combination of a fluid film bearing with a squeeze film damper can also be modelled as a floating ring bearing with zero ring speed. Linear as well as nonlinear characteristics can be considered.

The GUI for the squeeze film damper can be seen in figure 5.1. The geometry can be defined in the same way as for a normal bearing. The check box “Calculate as Squeeze Film Damper” defines the treatment as squeeze film damper. The following characteristics are then calculated:

- Damping coefficients for the centred position as linear characteristics (see figure 5.2)
- A field of dimensionless damping coefficients β_{ik}^{+} and β_{ik}^{-}, as a function of the journal position defined by the dimensionless eccentricity ε and the angle γ as non-linear characteristics (see figure 5.3). The β_{ik}^{+} coefficients hereby apply for a positive radial velocity and the β_{ik}^{-} coefficients for a negative radial velocity.

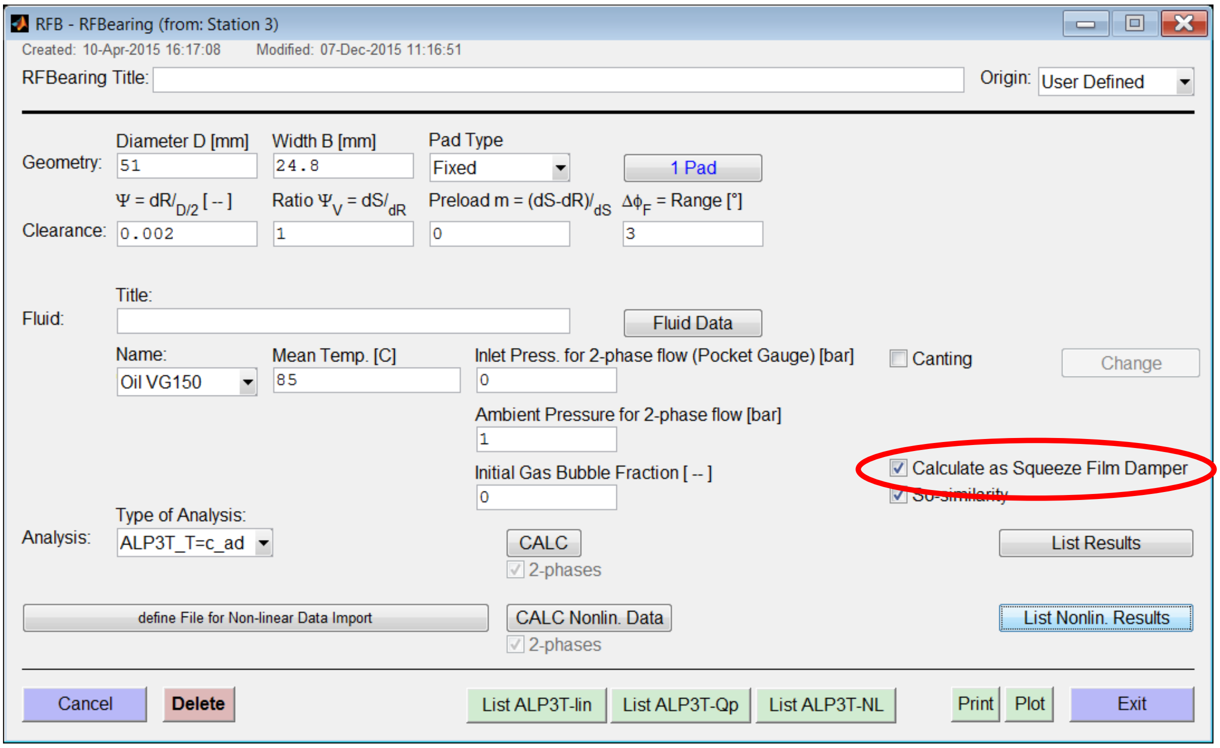
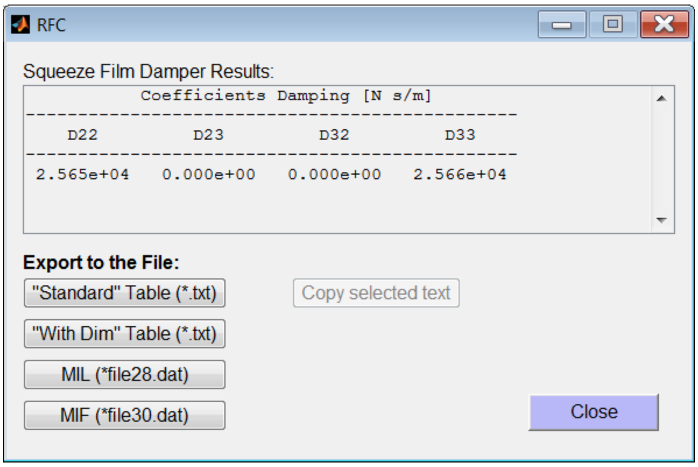


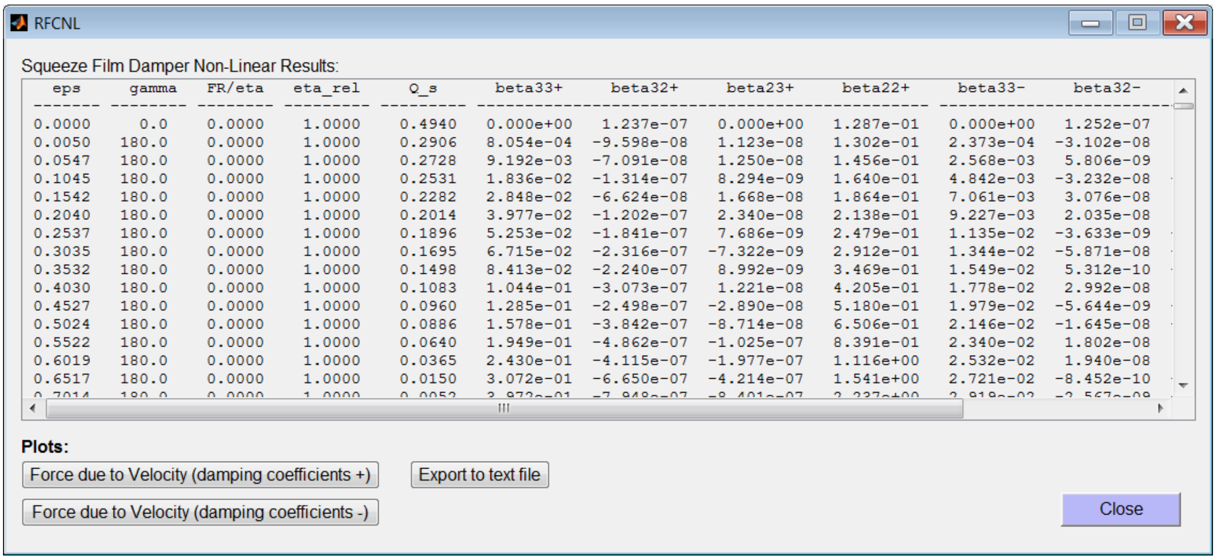
Fig. 5.1: GUI for the squeeze film damper

[1] In version 4.0 the squeeze film damper had to be modelled as a standard bearing with imported dimensionless coefficients. The dimensionless coefficients were available from the outer film of a floating ring bearing with zero ring speed.



D22	D23	D32	D33
2.565e+04	0.000e+00	0.000e+00	2.566e+04

Fig. 5.2: Linear characteristics of a squeeze film damper (window available from "List Results")



eps	gamma	FR/eta	eta_rel	Q_s	beta33+	beta32+	beta23+	beta22+	beta33-	beta32-
0.0000	0.0	0.0000	1.0000	0.4940	0.000e+00	1.237e-07	0.000e+00	1.287e-01	0.000e+00	1.252e-07
0.0050	180.0	0.0000	1.0000	0.2906	8.054e-04	-9.598e-08	1.123e-08	1.302e-01	2.373e-04	-3.102e-08
0.0547	180.0	0.0000	1.0000	0.2728	9.192e-03	-7.091e-08	1.250e-08	1.456e-01	2.568e-03	5.806e-09
0.1045	180.0	0.0000	1.0000	0.2531	1.836e-02	-1.314e-07	8.294e-09	1.640e-01	4.842e-03	-3.232e-08
0.1542	180.0	0.0000	1.0000	0.2282	2.848e-02	-6.624e-08	1.668e-08	1.864e-01	7.061e-03	3.076e-08
0.2040	180.0	0.0000	1.0000	0.2014	3.977e-02	-1.202e-07	2.340e-08	2.138e-01	9.227e-03	2.035e-08
0.2537	180.0	0.0000	1.0000	0.1896	5.253e-02	-1.841e-07	7.686e-09	2.479e-01	1.135e-02	-3.633e-09
0.3035	180.0	0.0000	1.0000	0.1695	6.715e-02	-2.316e-07	-7.322e-09	2.912e-01	1.344e-02	-5.871e-08
0.3532	180.0	0.0000	1.0000	0.1498	8.413e-02	-2.240e-07	8.992e-09	3.469e-01	1.549e-02	5.312e-10
0.4030	180.0	0.0000	1.0000	0.1083	1.044e-01	-3.073e-07	1.221e-08	4.205e-01	1.778e-02	2.992e-08
0.4527	180.0	0.0000	1.0000	0.0960	1.285e-01	-2.498e-07	-2.890e-08	5.180e-01	1.979e-02	-5.644e-09
0.5024	180.0	0.0000	1.0000	0.0886	1.578e-01	-3.842e-07	-8.714e-08	6.506e-01	2.146e-02	-1.645e-08
0.5522	180.0	0.0000	1.0000	0.0640	1.949e-01	-4.862e-07	-1.025e-07	8.391e-01	2.340e-02	1.802e-08
0.6019	180.0	0.0000	1.0000	0.0365	2.430e-01	-4.115e-07	-1.977e-07	1.116e+00	2.532e-02	1.940e-08
0.6517	180.0	0.0000	1.0000	0.0150	3.072e-01	-6.650e-07	-4.214e-07	1.541e+00	2.721e-02	-8.452e-10

Fig. 5.3: Non-linear characteristics of a squeeze film damper (window available from "List Nonlin. Results")

5.2 Features for Hydrostatic Pockets

Hydrostatic pockets are the area between the end angle of the pads and the start angle of the next pad. For fixed pad bearings the width of the pocket can be defined relative to the bearing width. The pocket width of a pad applies to the whole area between pads before the pad (see figure 5.4). In this area the hydrostatic pressure is applied.

The hydrostatic pressure is also applied at infinitely narrow hydrostatic pockets, i.e. in the case that the end angle of a previous pad and the start angle of the next pad are equal (e.g. the 1st lower pad ends and 60° and the 2nd pad starts at the same angle 60° → the circumferential length of the pocket is zero). The area with hydrostatic pocket is only completely closed by setting its width to zero (see figure 5.5). The bearing clearance plot for a closed hydrostatic pocket as defined in figure 5.5 is seen in figure 5.6.

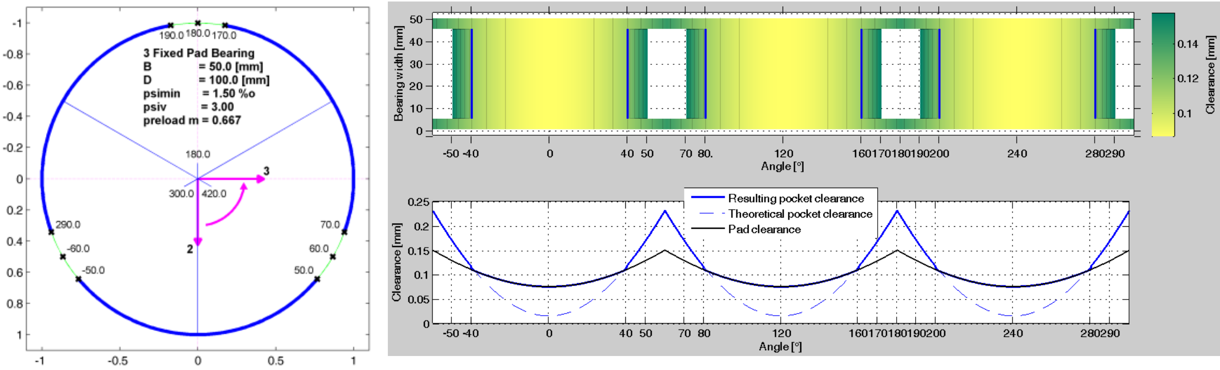


Fig. 5.4: Hydrostatic pockets between 50° to 70°, 170° to 190° and 290° to -50°

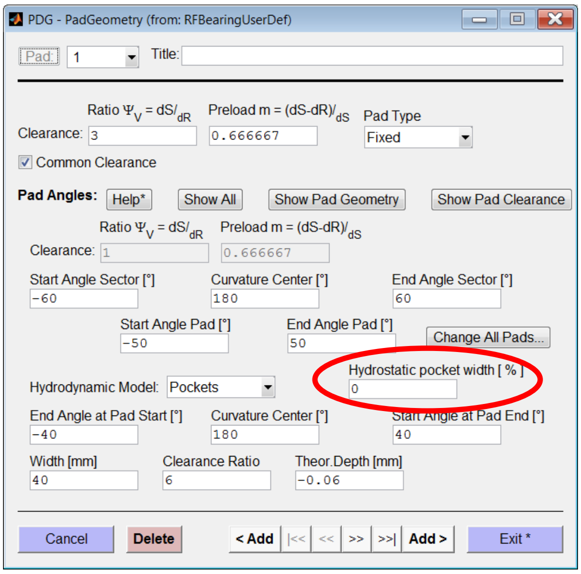


Fig. 5.5: Closing the hydrostatic pocket before the 1st pad be setting the width to zero

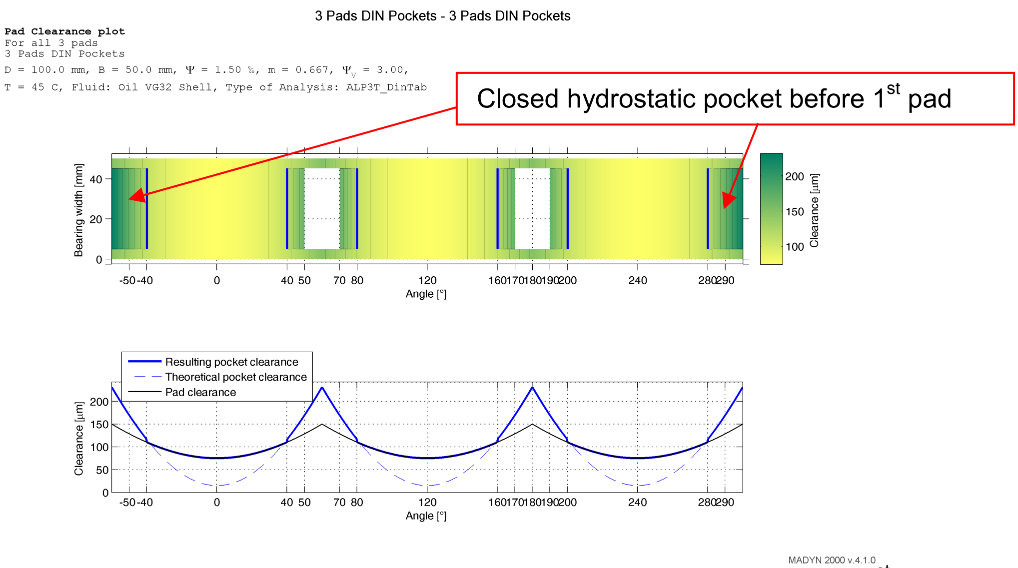


Fig. 5.6: Bearing clearance plot with closed hydrostatic pocket before the 1st pad

Moreover the hydrostatic pocket widths so far were not considered in the DIN bearing analysis, which is in accordance to the standard DIN 31 657 assuming a width according to the bearing width. In version 4.1 the correct pocket width is considered. For a pocket width smaller than the bearing width the analysis now deviates from the original DIN analysis. Narrower widths than the bearing width result in slightly higher mean bearing temperatures.

5.3 Non-Linear Characteristics

The ε,γ fields for the journal position to calculate the nonlinear characteristics have been extended to values closer to the bearing stator wall. This further enhances the robustness of transient analyses with non-linear fluid film bearings.

5.4 Non-Linear Static Analysis with Fluid Film Bearings

Static analyses with fluid film bearings considering the oil film thickness (i.e. the Gümbel curve from the results of the bearing analysis) require an iteration, which has been improved for the case with SBS. This improvement reduces the necessary number of iterations, especially in extreme cases, e.g. in case of two very close fluid film bearings as in the example shown below.

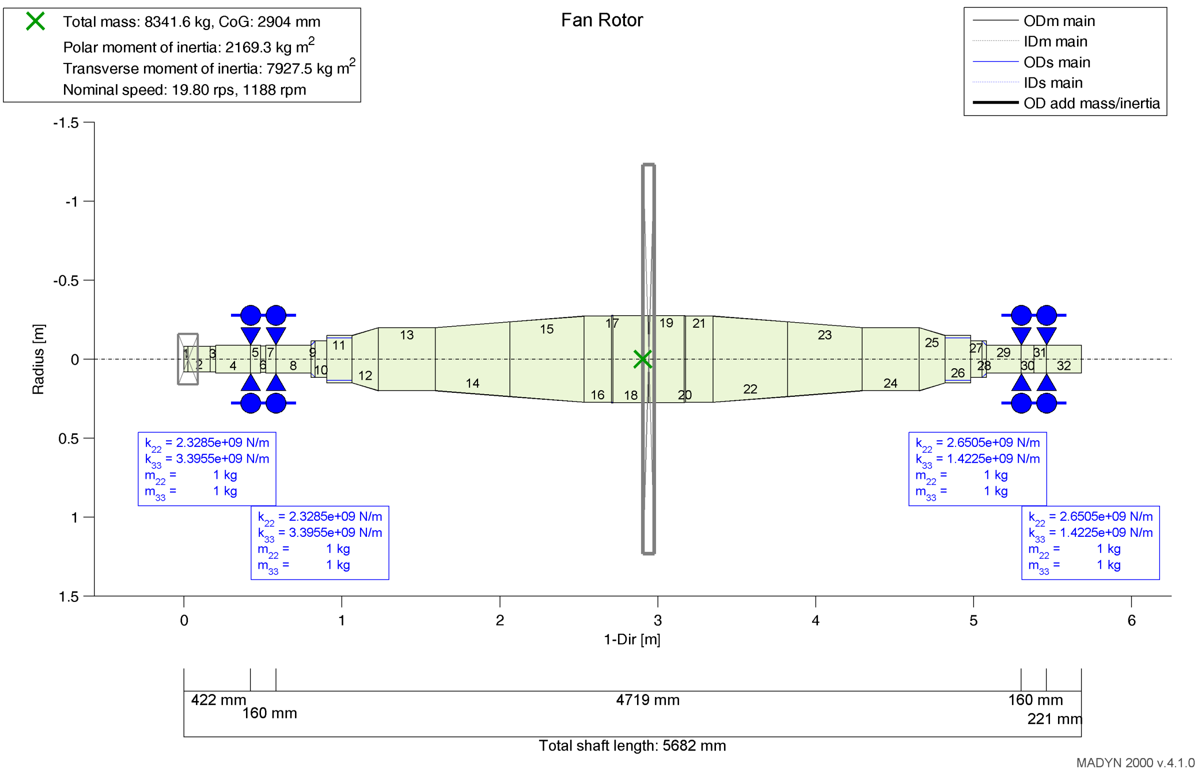


Fig. 5.7: Example of a sensitive fluid film bearing arrangement regarding static analysis

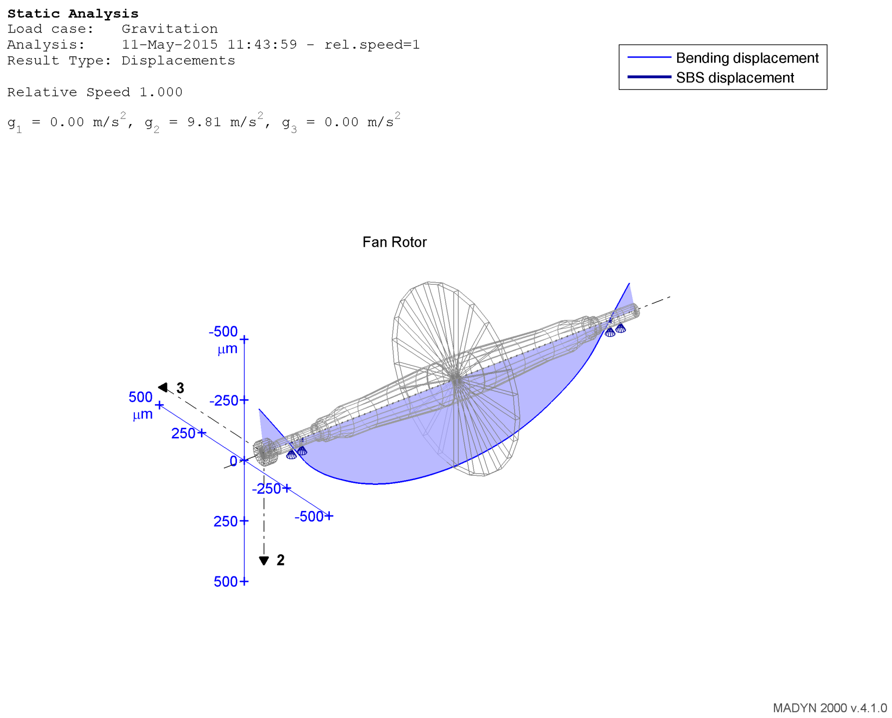


Fig. 5.8: Static deformation under weight of the sensitive example in figure 5.7

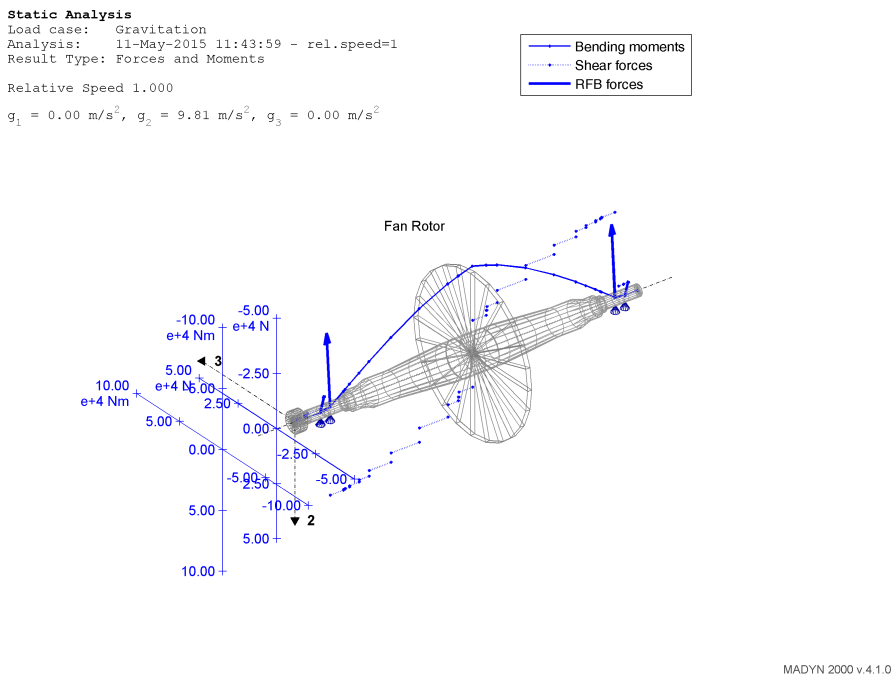


Fig. 5.9: Static forces due to weight of the sensitive example in figure 5.7

6. Rolling Element Bearing (REB) Improvements

In version 4.0, which is the first version with rolling element bearings (REB) some restrictions applied, which are eliminated in version 4.1 thanks to a consistent and better implementation.

Combination of REB and SBS/DBS: In previous versions only the radial bearing stiffnesses could be considered and the axial direction could not be taken into account at all for this combination. In version 4.1 the full 5x5 stiffness matrix is considered including the rotational stiffnesses about the radial 2- and 3-axes, the axial direction and all couplings between axes.

REB arrangement with 2 axially fixed bearings in one shaft: Such an arrangement in practice can cause problems, because it is over-constrained. Thermal shaft expansion for example can cause unnecessary stress in the system. Nevertheless such arrangements are used in some applications. In the previous version static analyses of such systems were numerically sensitive and required many iterations with a low relaxation factor. They were not recommended, i.e. a warning appeared. In the current release the iteration of the static analysis was improved and such arrangements should not cause a problem anymore.

7. Import of Frequency and Speed Dependant Bearing Characteristics

Tilting pad bearings are load and speed dependent as all fluid film bearings, but in addition can be frequency dependent i.e. non-synchronous characteristics are different from the synchronous properties. In MADYN 2000 this behaviour can be considered by a full model of the tilting pad bearing, which yields speed and load dependent state space matrices A,B,C,D.

Other objects such as certain seals or other bearings such as foil bearings may also be frequency dependent. Although their properties cannot be calculated within MADYN 2000, it is possible to import speed and load dependent state space matrices A,B,C,D from a MATLAB mat-file to generally describe such characteristics.

The file must contain the MATLAB structure ssmData with the field SSMTable:

ssmData.SSMTable

Further fields may be added to the structure ssmData in future.

SSMTable is a structure with dimension according to the number of speed and load combinations and has the following field:

SSMTable.Speed	the rotor speed in [Hz]
SSMTable.F2	force in 2-direction
SSMTable.F3	force in 3-direction
SSMTable.TFU	Field with the 3 fields A,B,C,D for the state space matrix.

A file containing only the structure SSMTable can be imported as well.

As for the normal imported dimensioned data (see chapter II.6.6) it is necessary, that all loads (combination of F2, F3) are defined for the same speeds.

The MAT-file can be imported from the RFB GUI for the bearing type “Import with Dimension” as “Nonsyn. Source File” (see figure 7.1).

Inputs to the bearing system are the shaft displacements and velocities in 2- and 3-direction at the bearing location, outputs are the bearing forces in 2- and 3-direction. This means, that the dimensions of the state space matrices must be as follows:

System Matrix A:	N x N with N according to the order of the system.
Controller matrix B:	N rows, 4 columns for 4 inputs.
Measurement matrix C:	2 rows for 2 outputs, N columns
Direct transition matrix D:	4 columns for 4 inputs and 2 rows for 2 outputs.

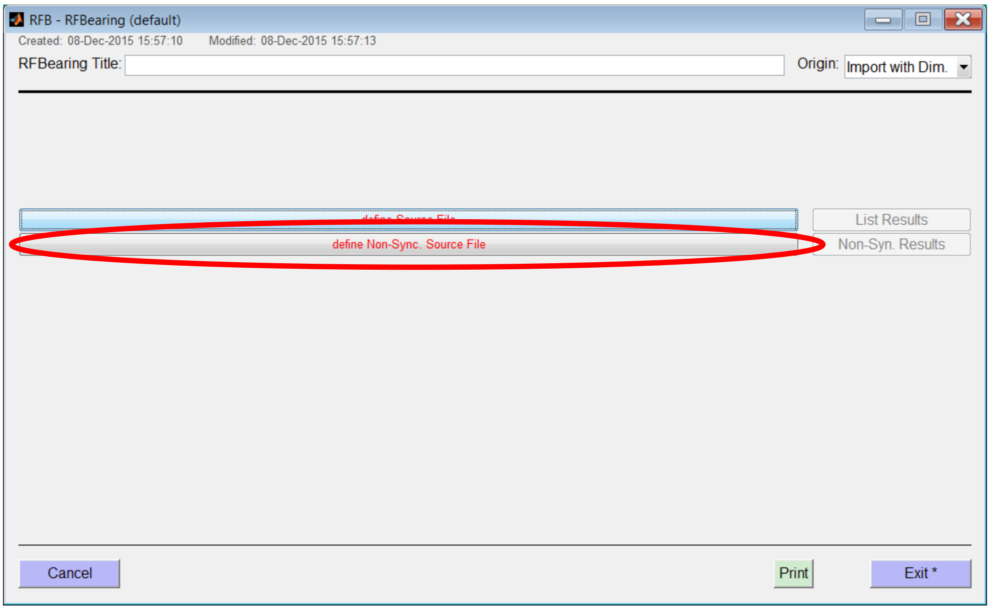


Fig. 7.1: GUI for imported dimensioned data with button to import non-synchronous bearing characteristics

8. Fluids with Offset

Labyrinth seals, which are modelled as seals, are often located at impeller shrouds with some distance between the impeller fixation and the labyrinth location. Especially for overhang impellers the exact location of a fluid plays an important role.

In order to simply create an accurate model of the seal in such cases, a distance to the location of fixation was introduce as additional parameter of a fluid. The GUI with the corresponding edit field can be seen in figure 8.1. The shaft model plot with the corresponding fluid is shown in figure 8.2.

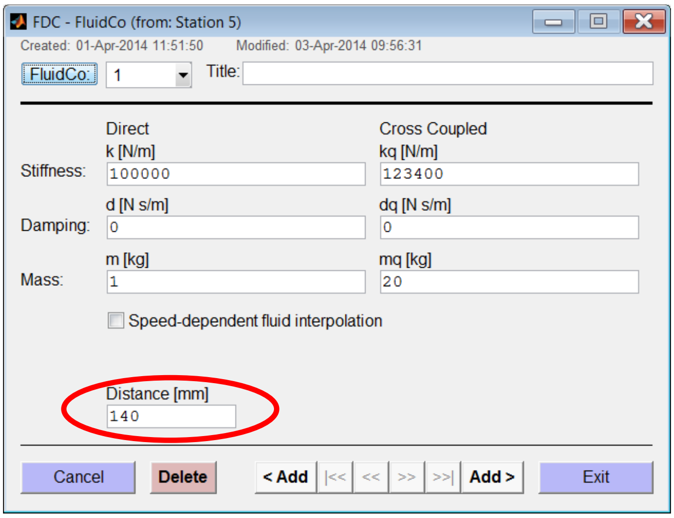


Fig. 8.1: GUI for fluids with the edit field to define a distance or offset

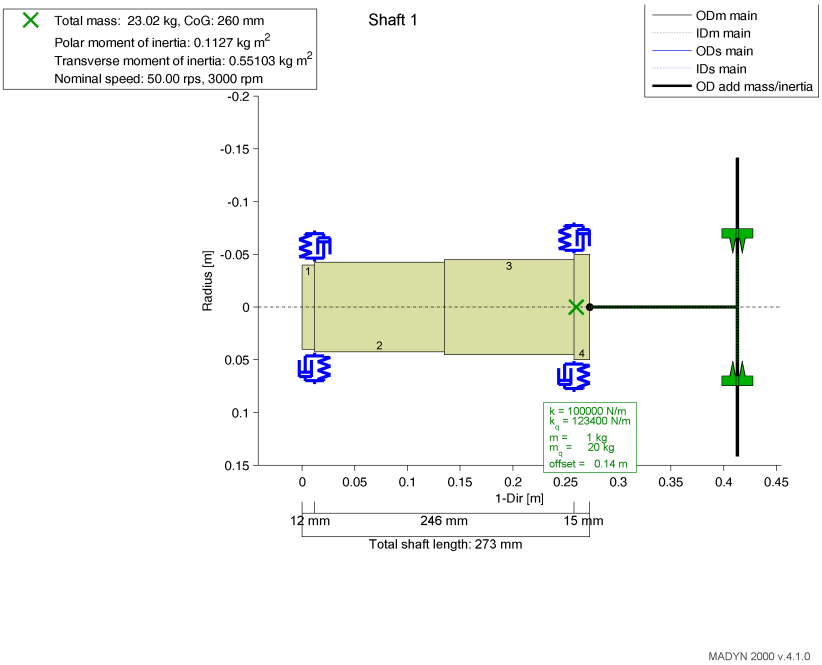


Fig. 8.2: Shaft plot of a simple shaft with an overhung impeller and a fluid with offset

9. Set Boundary Conditions by General Spring GSP

It is possible to set rigid constraints with a general spring. The GUI of a general spring is shown in figure 9.1. By introducing “Inf” as a stiffness (“inf” in MATLAB convention means infinite) the corresponding direction is set to rigid. In the example shown in the GUI the radial directions are rigid. Note, that it is not possible to set damping values or off diagonal elements to “inf”.

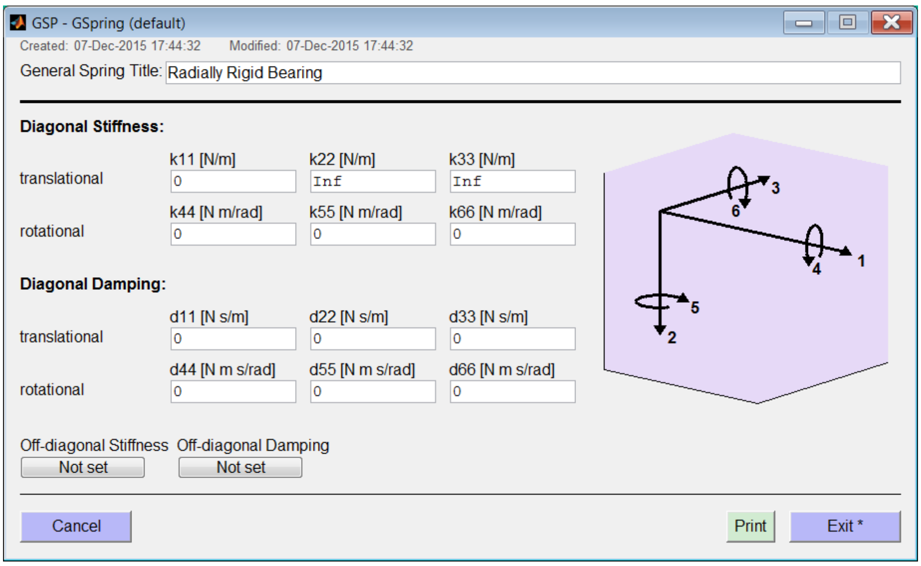


Fig. 9.1: GSP GUI with definition of a rigid radial support