DELTA JS AG

MADYN 2000
Software for Rotordynamics

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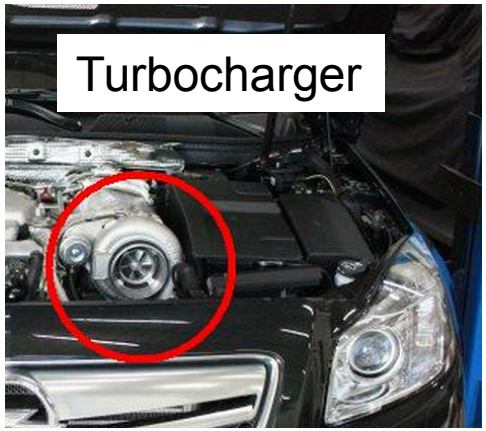
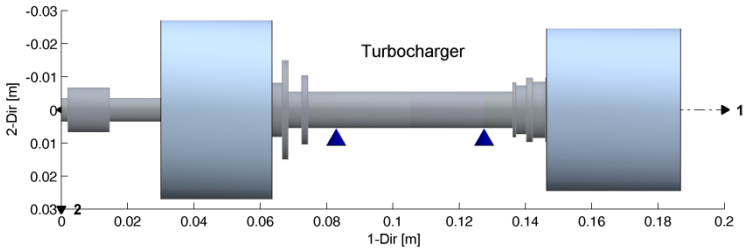
Content

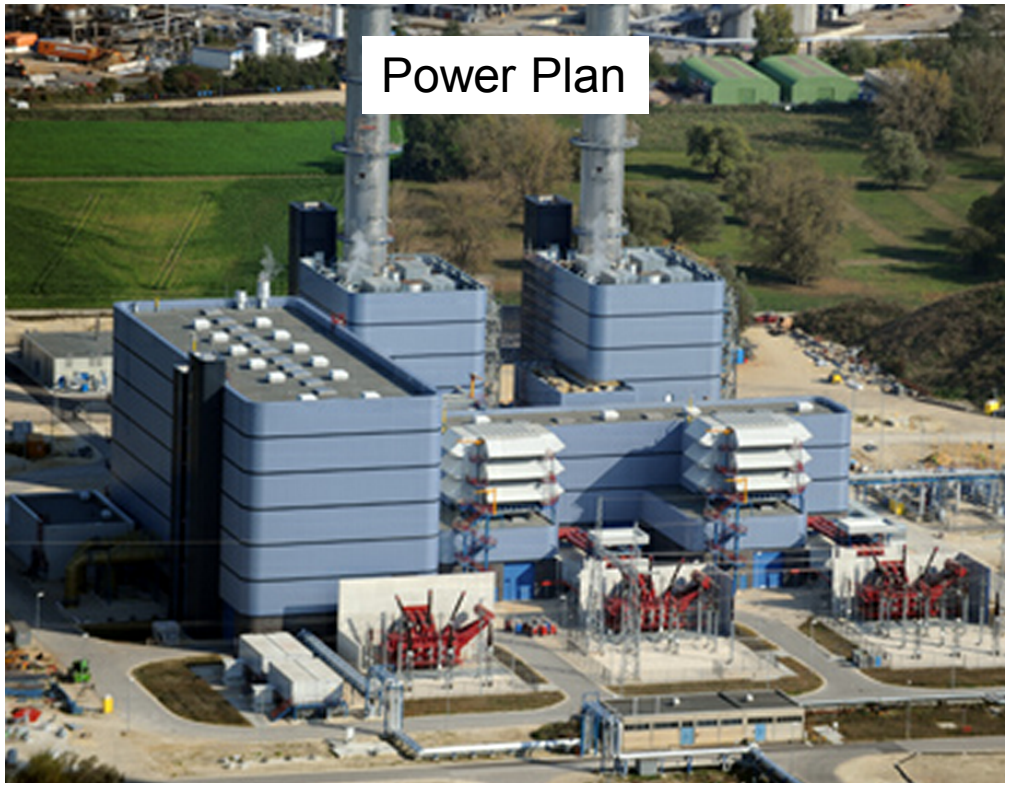
- General Introduction of MADYN 2000
  systems, analytical capabilities, available bearings
- Features for Magnetic Bearings in MADYN 2000
  controller design, assessment of controller robustness, assessment of the system behaviour
- Features for Back Up Bearings in MADYN 2000
- Conclusions

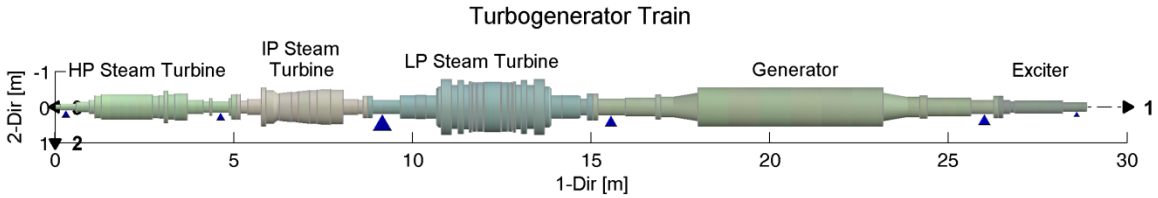
General Introduction to MADYN 2000

Systems





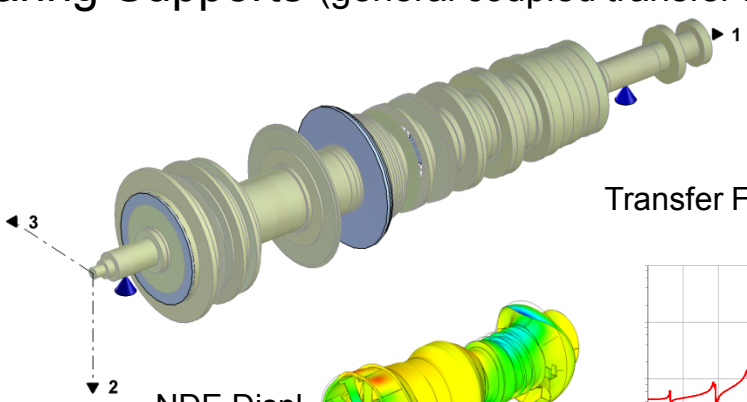


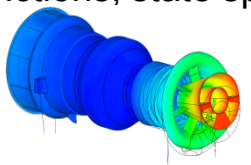


General Introduction to MADYN 2000

Systems with Bearing Supports

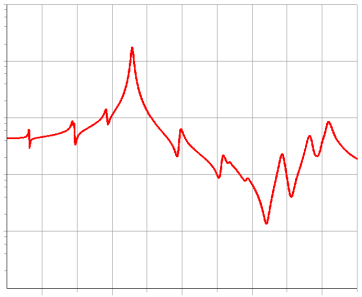
Dynamic Bearing Supports (general coupled transfer functions, state space matrices)

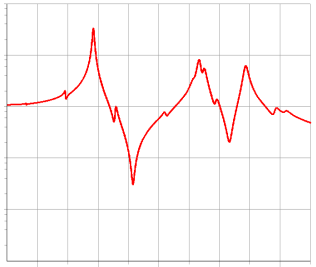


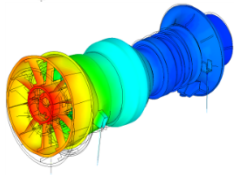


Transfer Function = $\frac{\text{DE Displ.}}{\text{DE Force}}$

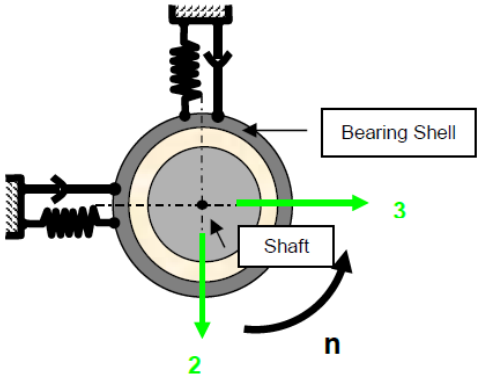
Transfer Function = $\frac{\text{NDE Displ.}}{\text{NDE Force}}$







Spring mass damper system
(suited in case of one uncoupled resonance)



Systems with Gear, Lateral Torsional Coupling

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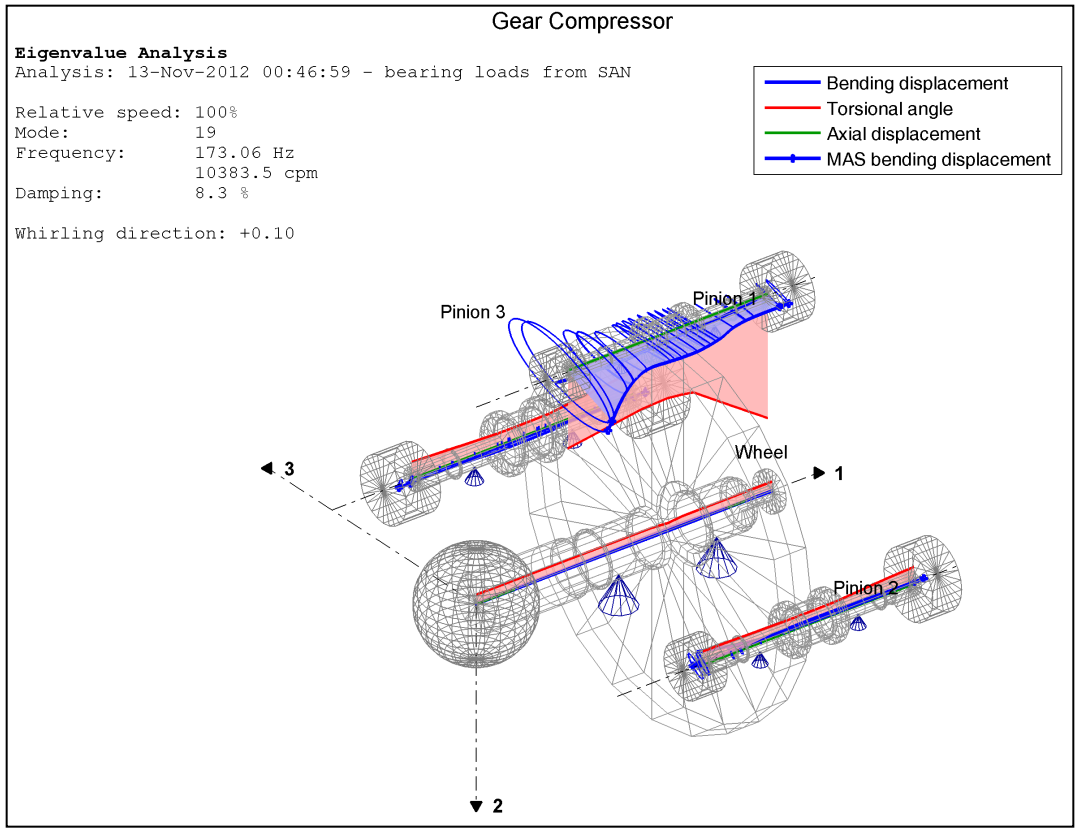
Coupled Lateral / Torsional Vibration Mode of a Gear Compressor



Coupled lateral torsional axial analysis of systems with gears

→ contribution of the radial bearing to torsional damping or excitation

→ new coupled modes may arise

General Introduction to MADYN 2000

Analytical Capabilities

Static analyses	SAN
Gravitation	.GRA
Gear load	.GEL
Static load cases	.SLC
Static load case combination	.SCO
Alignment sensitivity	.ASI

Eigenvalue analysis	EIG

Harmonic response analyses	HAR
Unbalance response	.UNB
Harmonic force response	.HAF
Harmonic base excitation	.BAS

Transient response analyses	TRA
Excitation f(t), response at constant speed	
Transient base acceleration	.TBA
Transient force	.TFT
Transient load case combination	.TCO

Nonlinear fluid bearings, couplings and other user defined nonlinearities can be considered.

Transient response analyses	TRA
Transient force f(n) for torsion	.TFN
Excitation n(t), response at variable speed	
Transient force n(t)	.TNF
Transient unbalance n(t) (e.g. run up)	.TNU
Transient load case combination n(t)	.TCN

Nonlinear fluid bearings, couplings and other user defined nonlinearities can be considered.

Parameter variation	PAR
Critical speed map	.CSM
Campbell diagram	.CDG
Variation of stiffness and damping[1]	.VSD
Variation of flexible coupling stiffness	.VFC

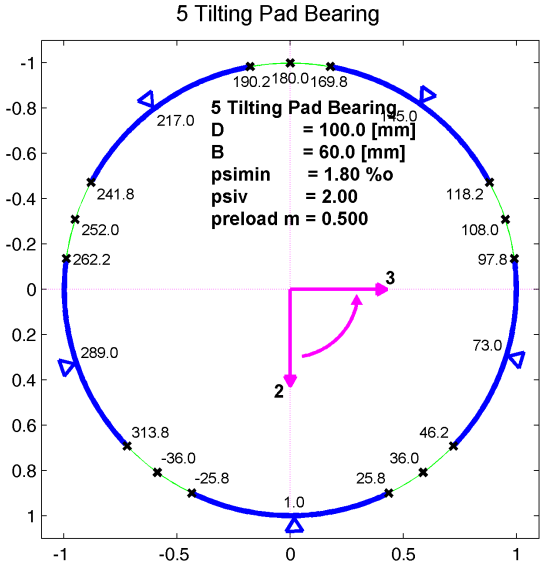
[1] Radial bearings and bearing supports, general springs

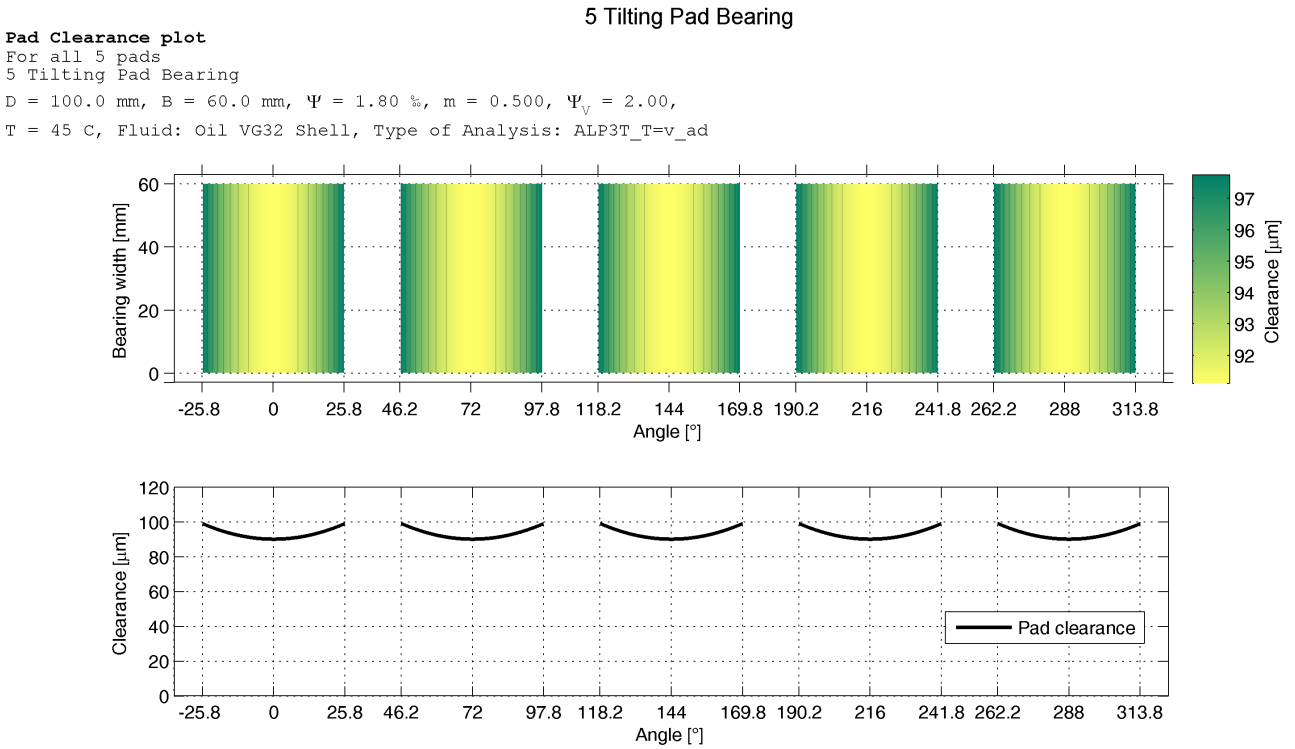
Optimization	OPT
Magnetic bearing controller optimization	
Alignment optimization	

General Introduction to MADYN 2000

Fluid Film Bearings: Geometry

e.g. 5 Tilting Pad Bearing





Fluid Film Bearings: Static Results, Coefficients

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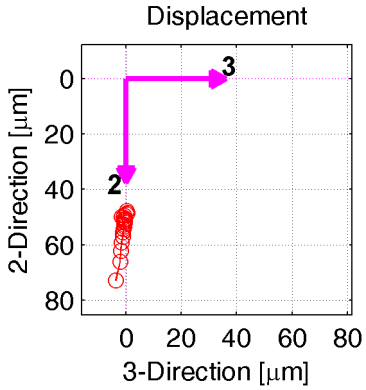
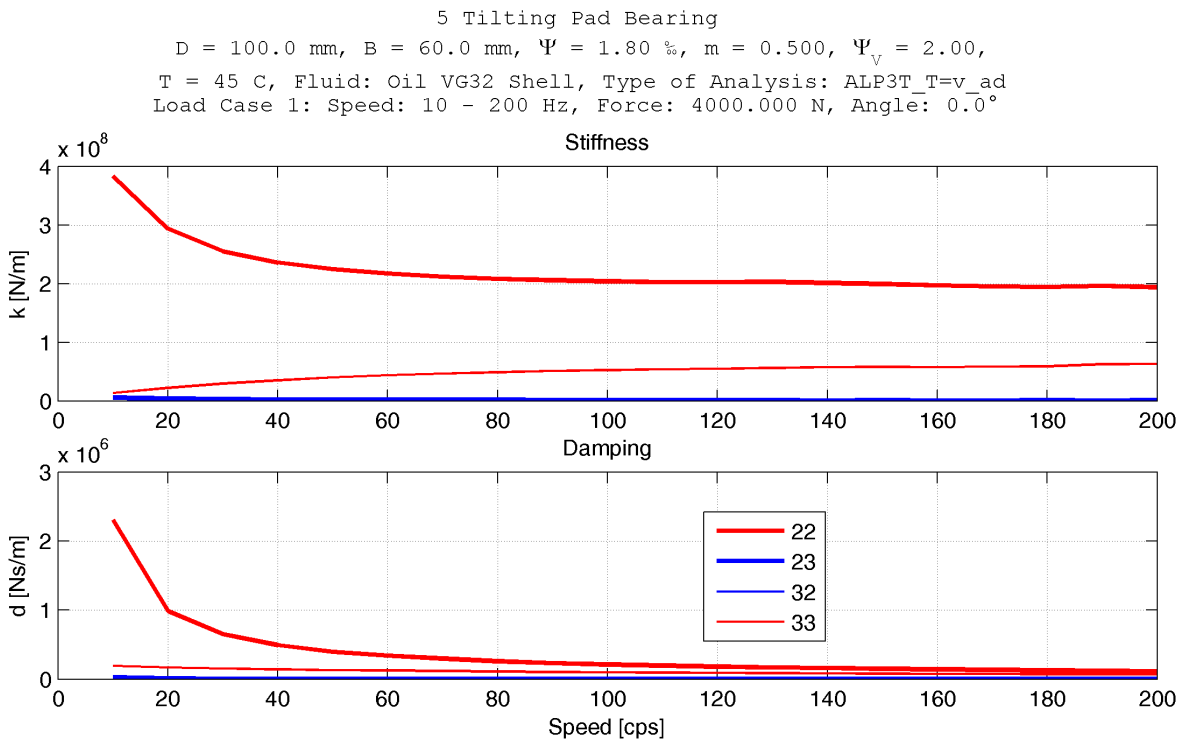
Load and Speed Dependent Stiffness and Damping Coefficients

Journal Position in the Bearing

F = 4000 N

n = 10 → 200 Hz





Non-synchronous load and speed dependent stiffness and damping coefficients can be considered as well.

General Introduction to MADYN 2000

Rolling Element Bearings

Load (and Speed*) Dependent Stiffness Matrix

(coupling of lateral displacements with rotations about radial axes and the axial displacement)

Induction Motor: Station 6 (Axially fixed REB)
Station 6, General Stiffness Matrix (speed 2990 rpm):

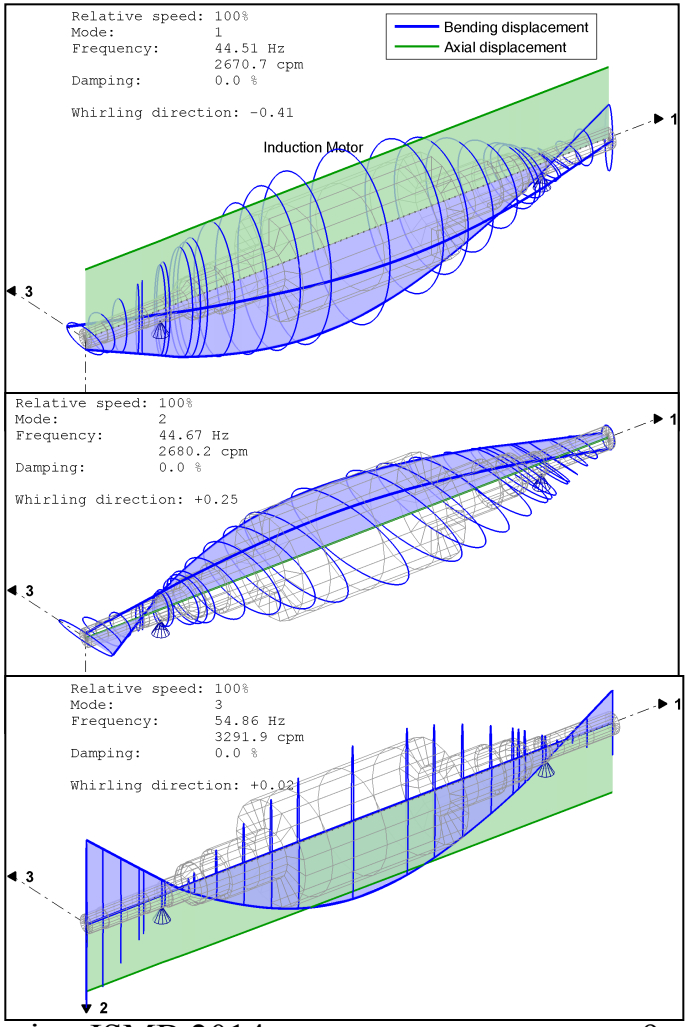
	k1	k2	k3	k4	k5	k6
	[1/m]	[1/m]	[1/m]	[1/rad]	[1/rad]	[1/rad]
[N]	2.4488e+08	2.0960e+08	0.0033	0	5.6889e-05	-6.8336e+06
[N]	2.0960e+08	4.4235e+08	-0.0036	0	1.3315e-04	-1.2136e+07
[N]	0.0011	-3.5048e-05	4.9984e+08	0	1.4758e+07	8.2548e-05
[N m]	0	0	0	0	0	0
[N m]	3.9192e-05	-8.6853e-06	1.4764e+07	0	4.8428e+05	2.6030e-06
[N m]	-6.8426e+06	-1.2138e+07	9.6776e-05	0	-3.7389e-06	3.9715e+05

Induction Motor: Station 24 (Axially loose REB)
Station 24, General Stiffness Matrix (speed 2990 rpm):

	k1	k2	k3	k4	k5	k6
	[1/m]	[1/m]	[1/m]	[1/rad]	[1/rad]	[1/rad]
[N]	0	0	0	0	0	0
[N]	0	4.6054e+08	5.7754e-04	0	-1.2687e-04	33781.2279
[N]	0	0.0036	1.1013e+08	0	-26768.1967	-1.7898e-04
[N m]	0	0	0	0	0	0
[N m]	0	-1.7533e-07	-6913.3925	0	7614.3257	-1.4381e-08
[N m]	0	-49277.7193	4.7171e-08	0	1.4752e-08	334.1555

* Speed dependence in case of consideration of centrifugal forces

Axial Lateral Coupled Natural Modes



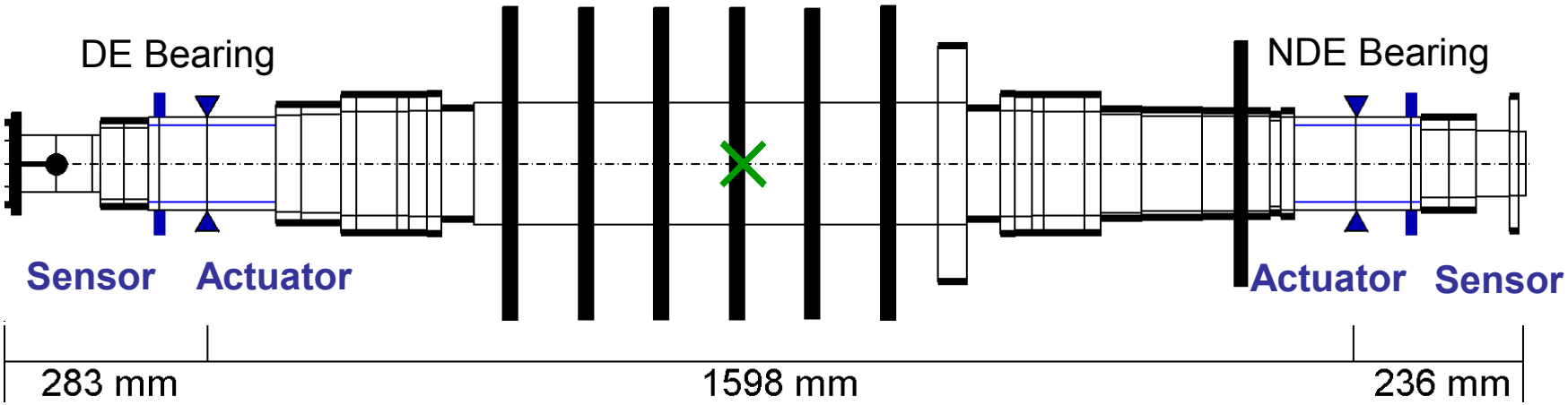
Magnetic Bearing Features in MADYN 2000

Example Rotor

Max. speed: 12’600 rpm (210 rps)

Total mass: 550 kg

Total length: 2’117 mm



Sensors and actuators are non-collocated, which is considered in all analyses.

Magnetic Bearing Features in MADYN 2000

Observability and Controllability

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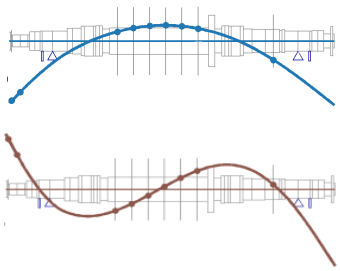
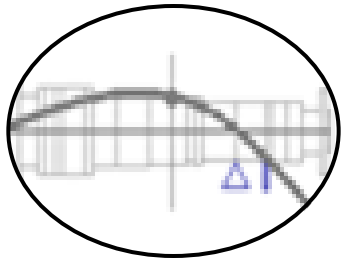
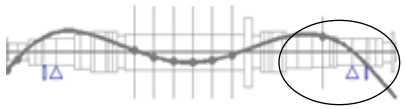
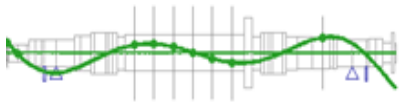


	Freq. [Hz]	DE Bearing Sensor	DE Bearing Actuator	NDE Bearing Sensor	NDE Bearing Actuator
1	0	80%	74%	79%	72%
2	1	100%	99%	96%	96%
3	1	94%	94%	99%	99%
4	9	74%	68%	85%	78%
5	133	46%	34%	70%	56%
6	140	47%	34%	70%	56%
7	260	**4%**	12%	52%	32%
8	286	**0%**	15%	51%	29%
9	470	33%	43%	29%	**1%**
10	505	32%	43%	27%	**1%**
11	728	49%	52%	**7%**	25%
12	764	53%	57%	**6%**	26%
13	1020	81%	71%	12%	43%
14	1095	81%	71%	16%	47%
15	1386	72%	42%	31%	56%
16	1481	75%	45%	35%	58%
17	1741	50%	10%	45%	59%
18	1842	53%	13%	49%	60%

210 rps







Insensitive frequency ranges for phase roll-off

Magnetic Bearing Features in MADYN 2000

GUI for Magnetic Bearing and Controller Building Blocks

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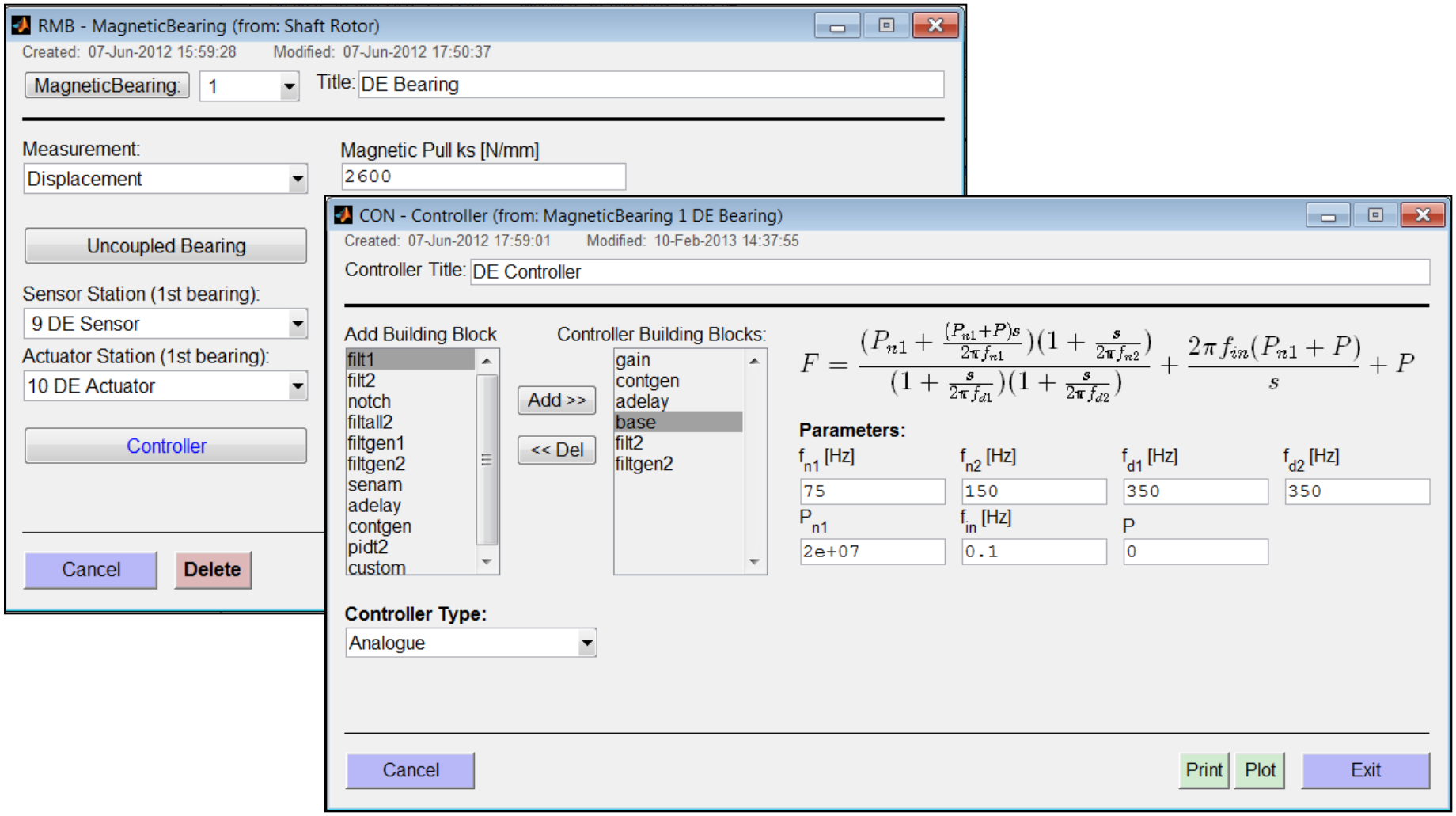

Magnetic Bearing Features in MADYN 2000

Natural Modes with MB Transfer Function

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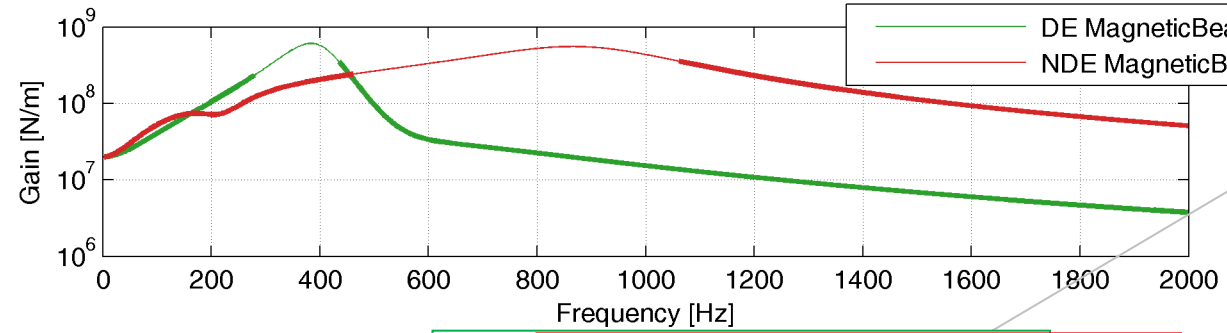
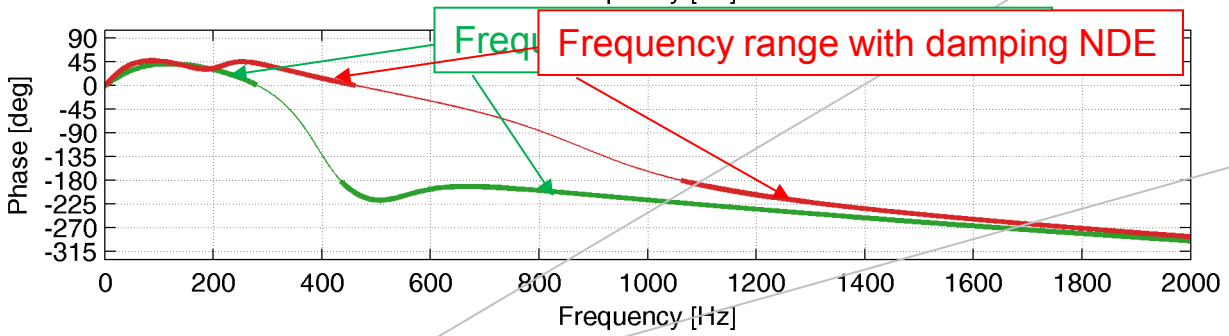
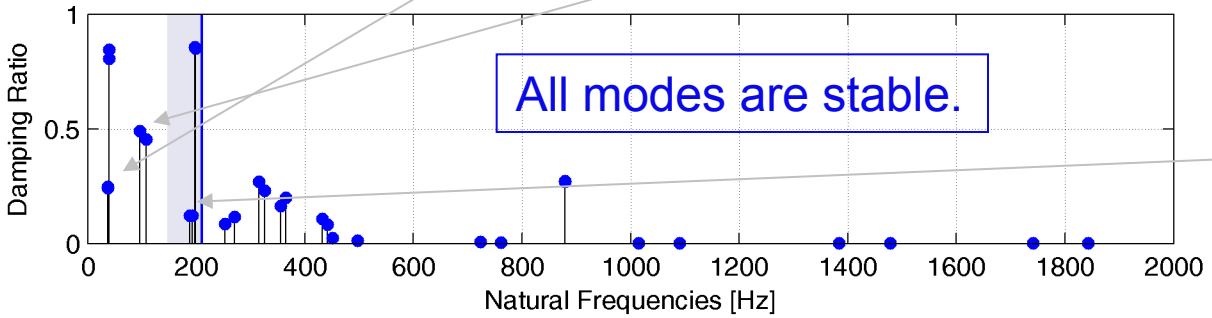
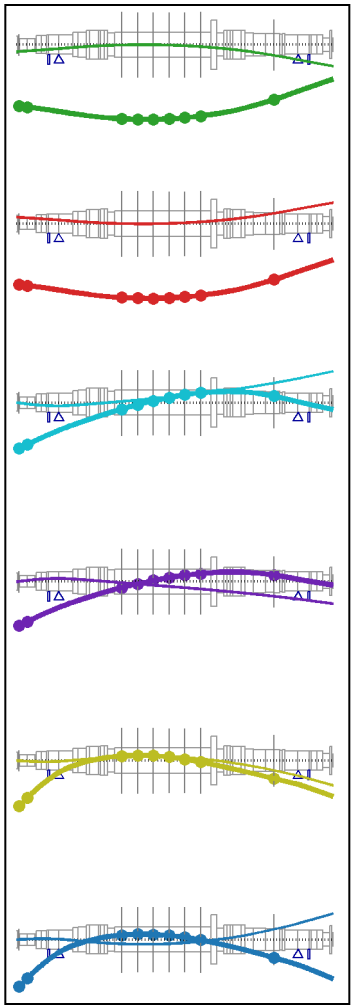


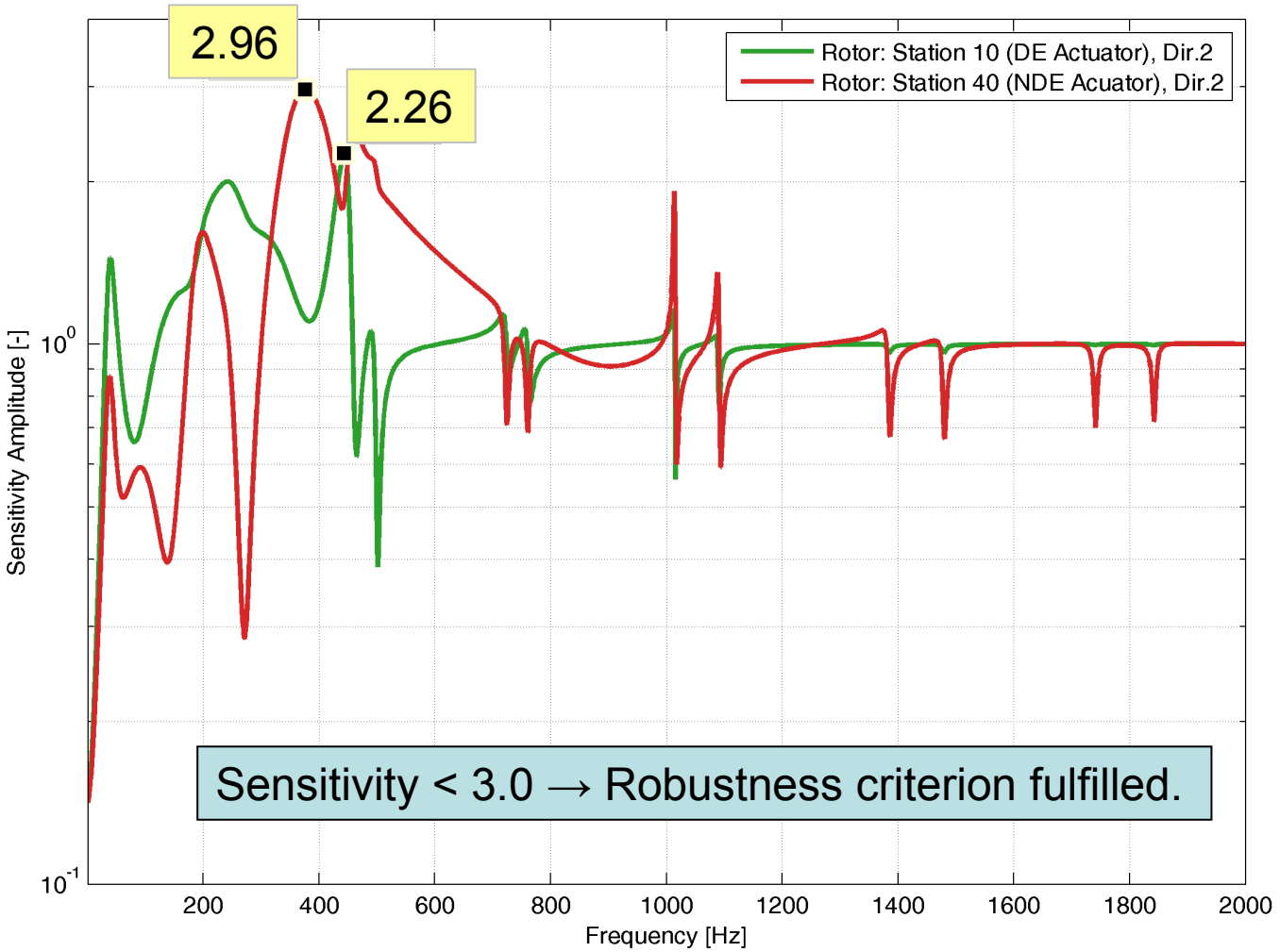






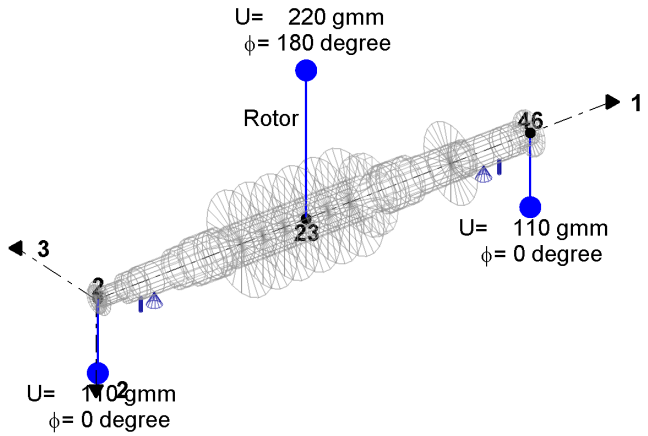
Magnetic Bearing Features in MADYN 2000

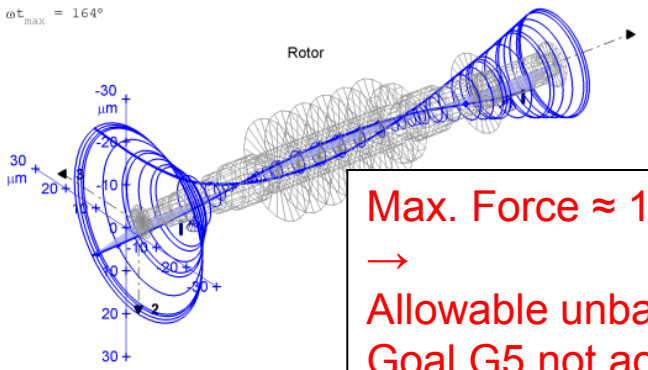
MB Sensitivity at Max. Speed



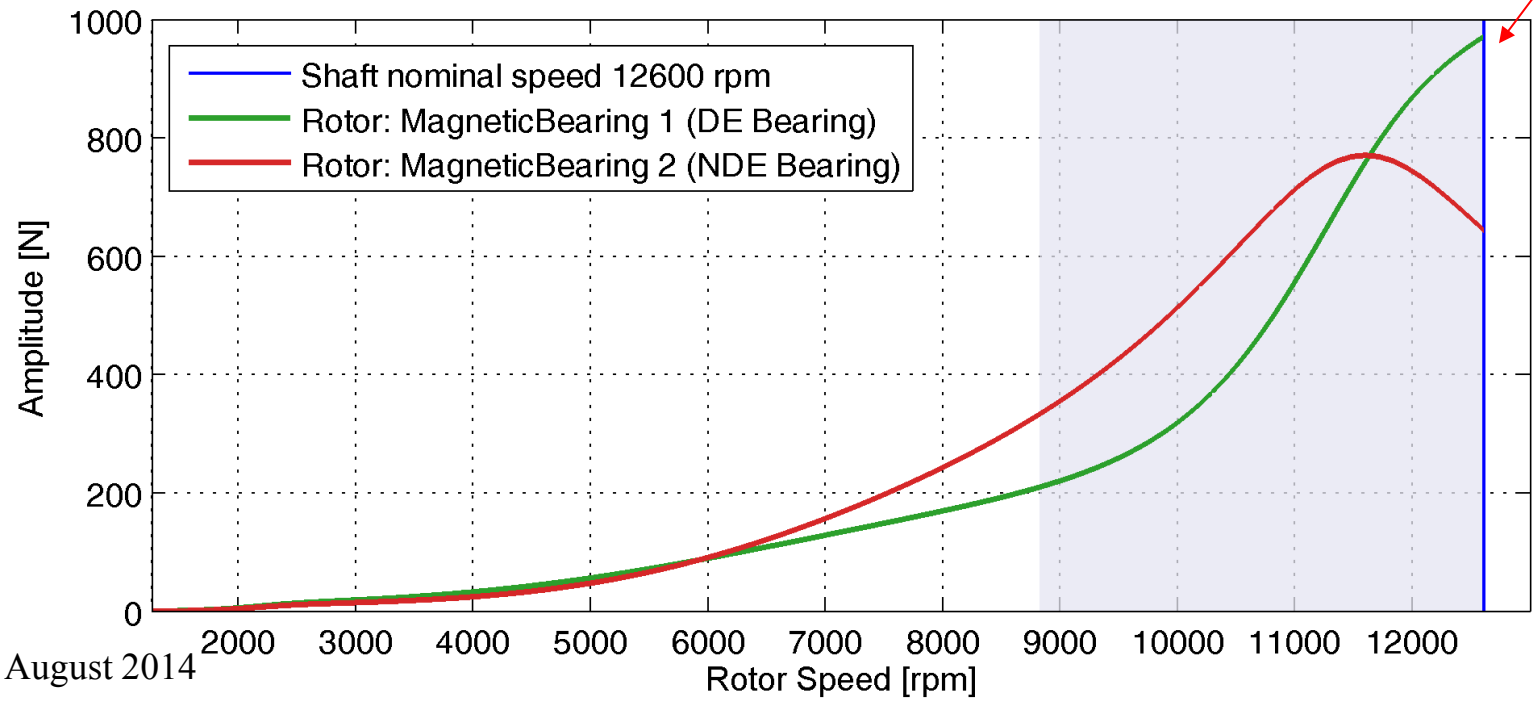
Magnetic Bearing Features in MADYN 2000

Unbalance Response



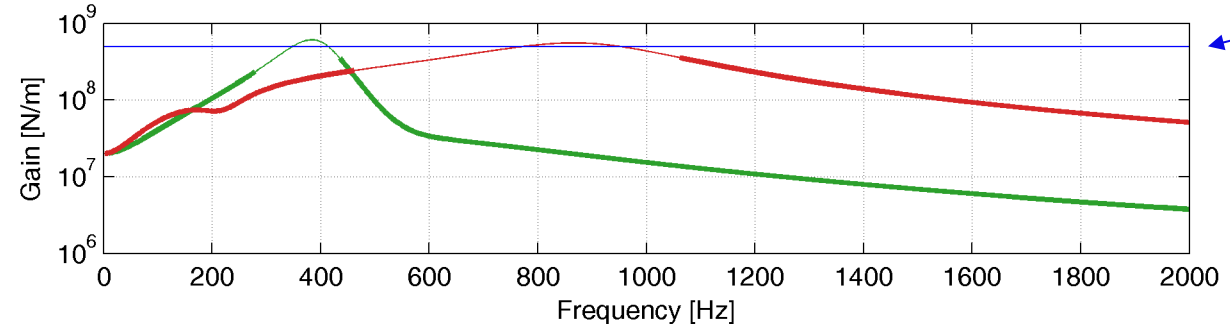


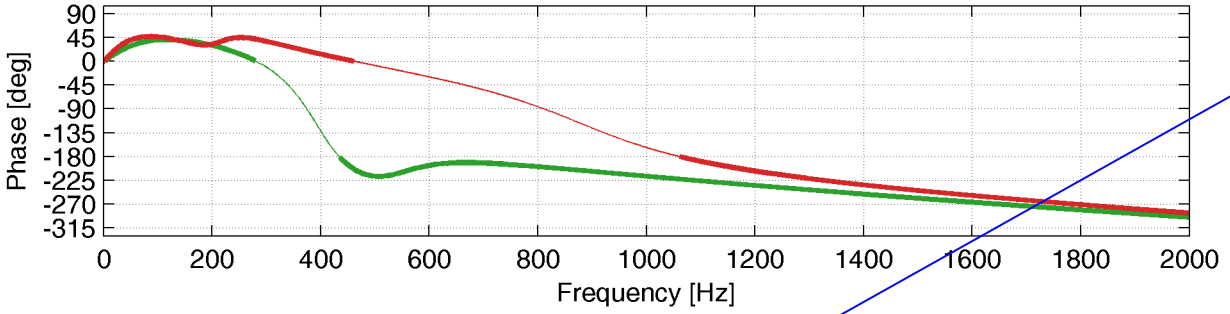
Max. Force ≈ 1'000 N
→
Allowable unbalance G3.
Goal G5 not achieved.

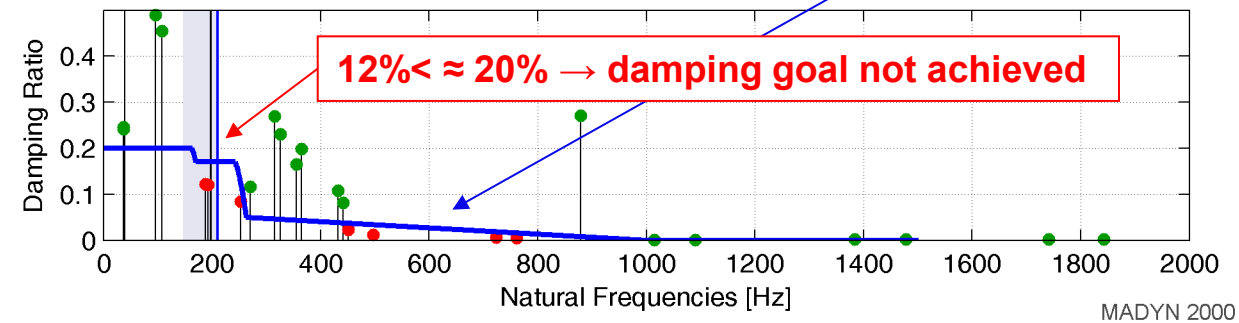


Magnetic Bearing Features in MADYN 2000

Controller Optimization Goals







MADYN 2000 v.3.7.4

Gain goal

+

Damping goal function

+

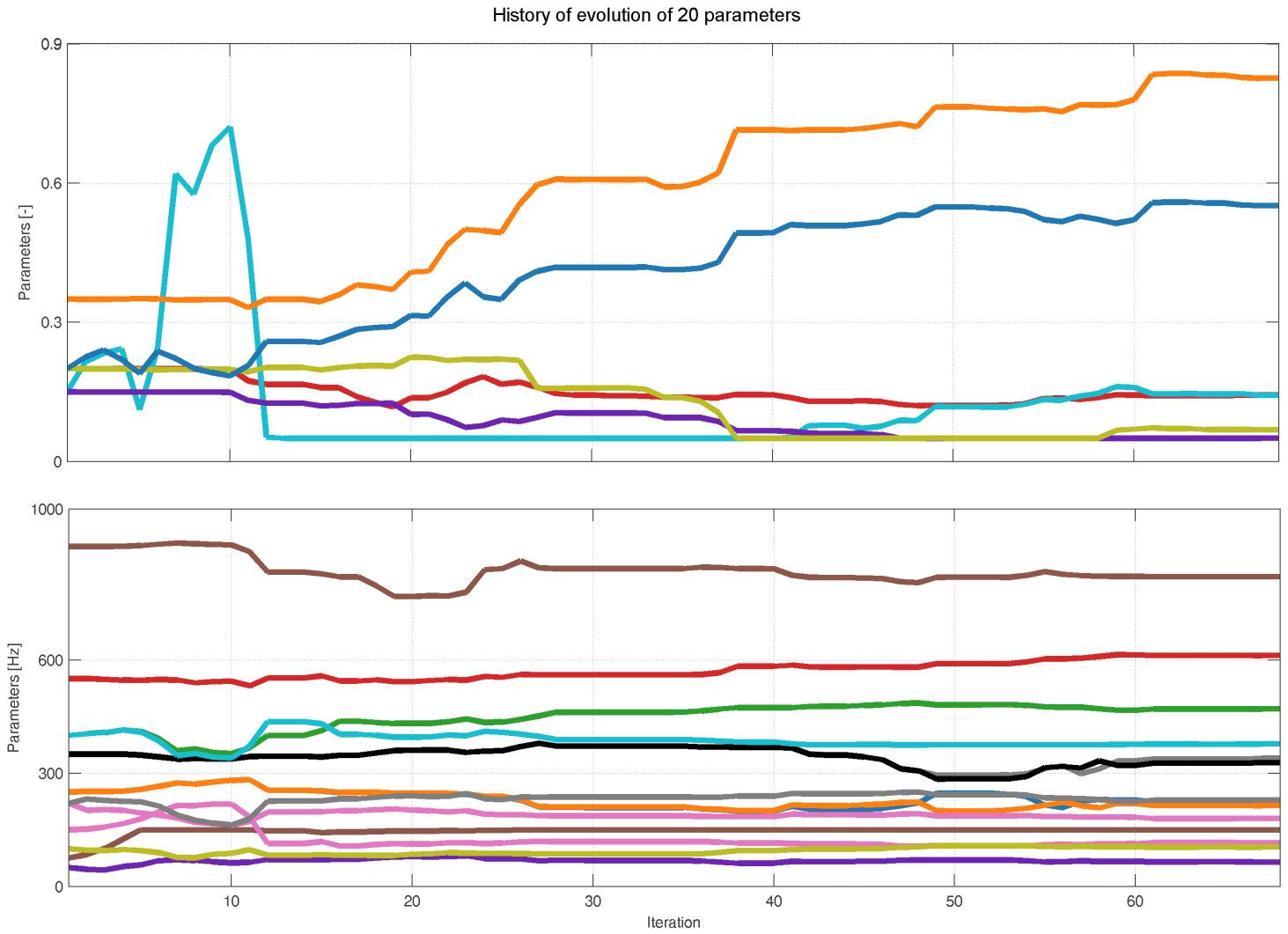
Force goal

=

Goal Combination

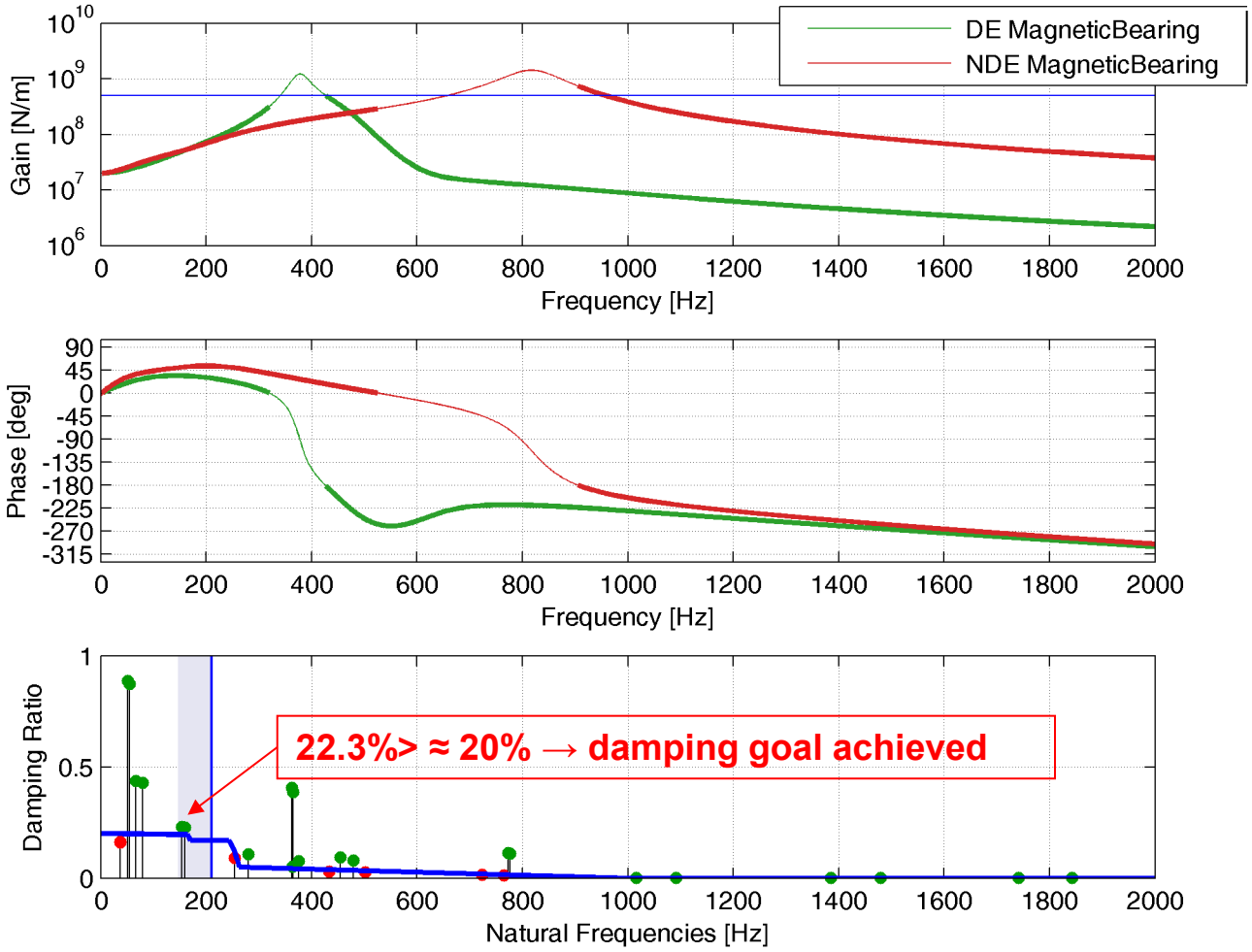
Magnetic Bearing Features in MADYN 2000

Parameter History of Optimization



Magnetic Bearing Features in MADYN 2000

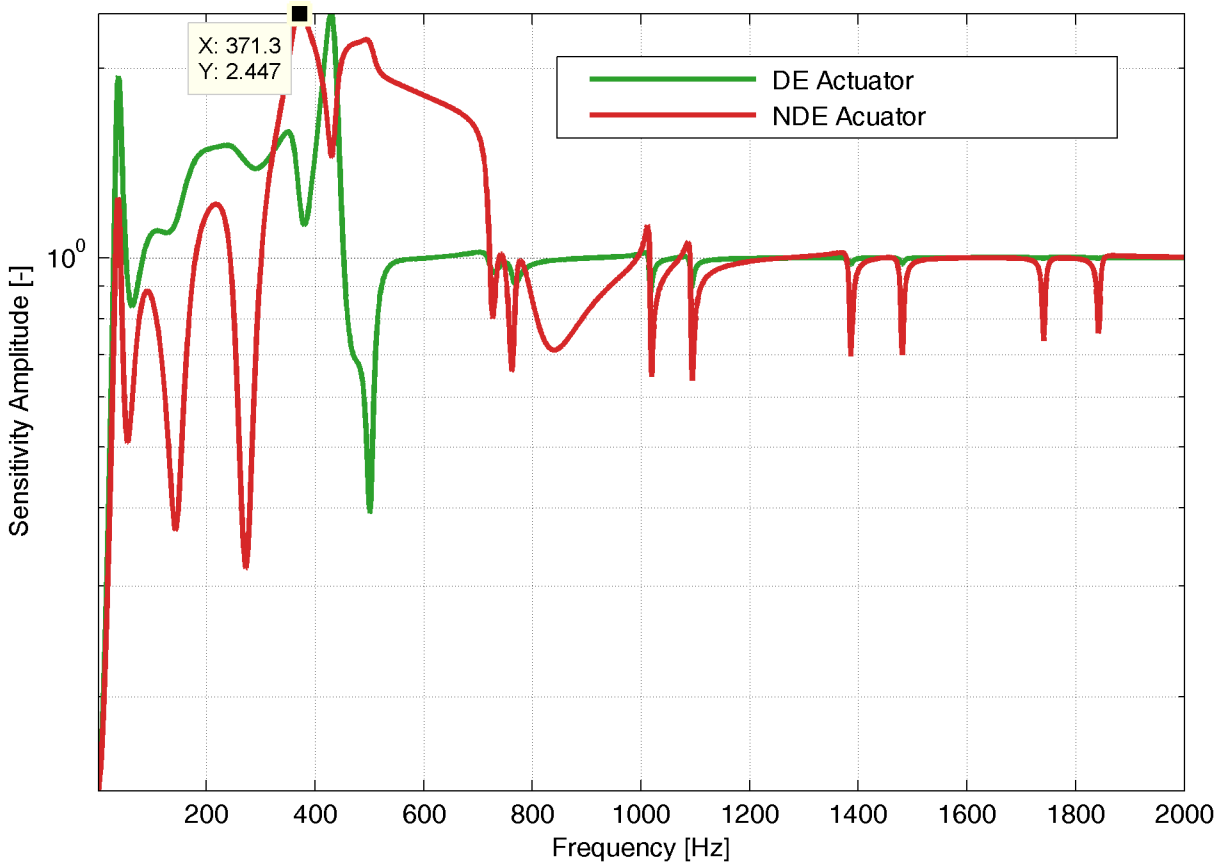
Eigenvalues at Max. Speed after Optimization



Magnetic Bearing Features in MADYN 2000

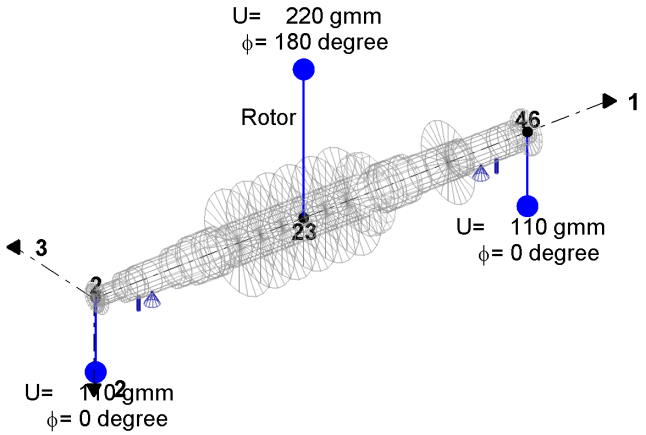
Sensitivity at Max. Speed after Optimization

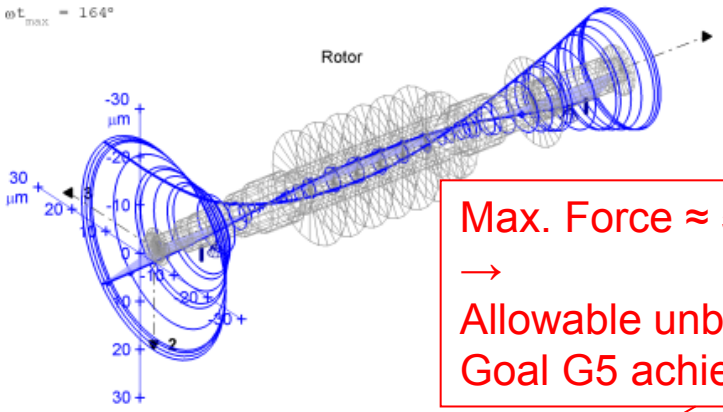
Sensitivity improved 2.956 → 2.447



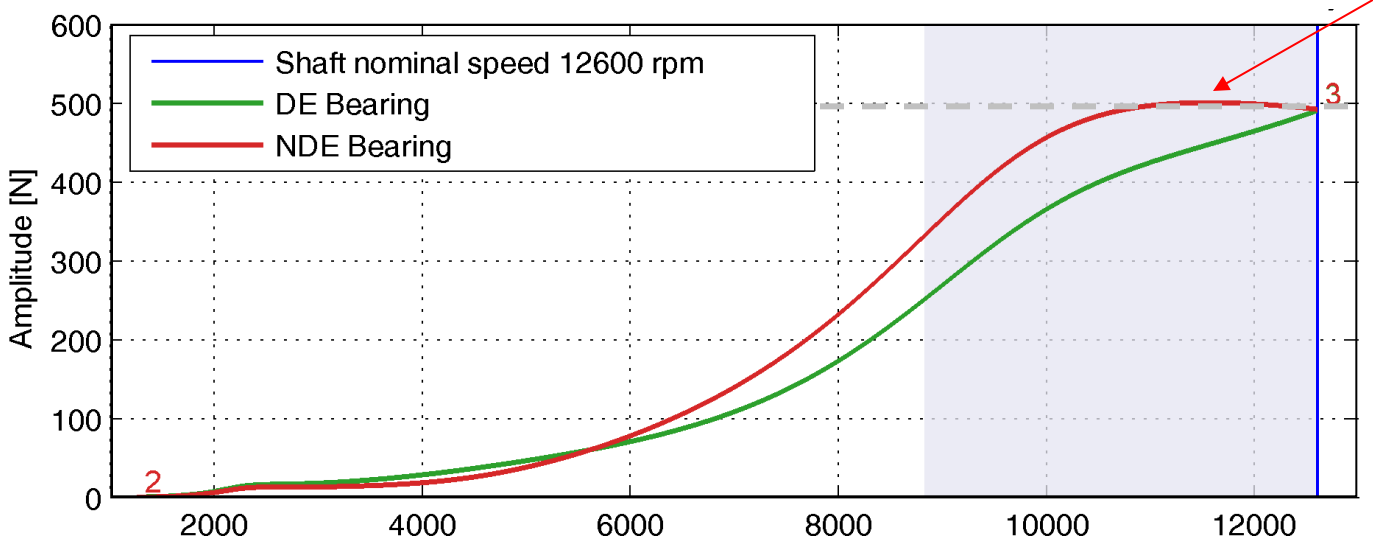
Magnetic Bearing Features in MADYN 2000

Unbalance Response after Optimization



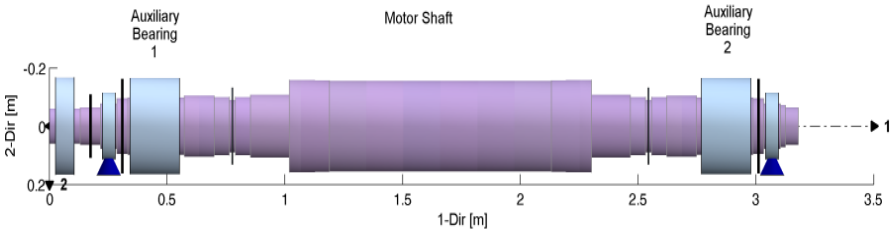


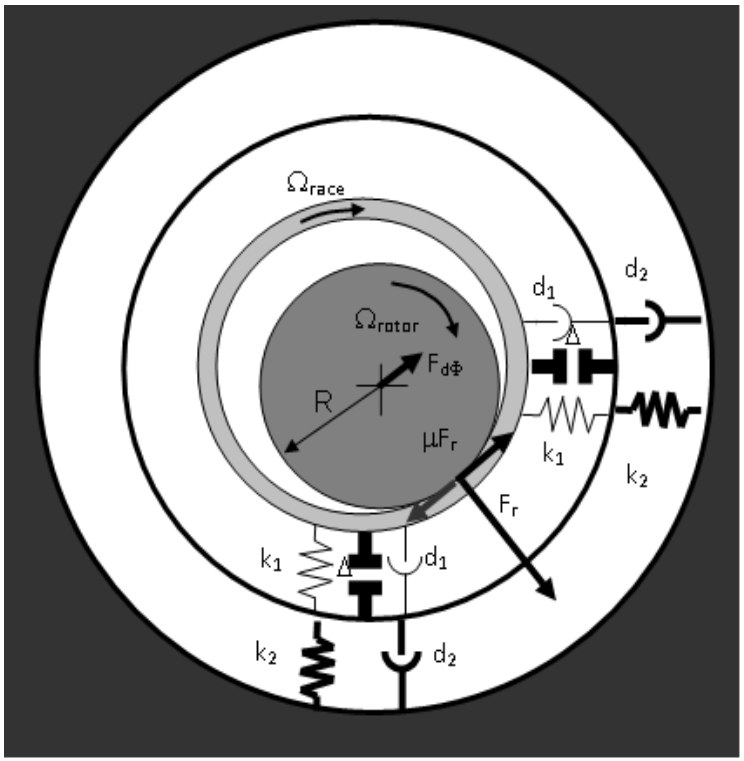
Max. Force ≈ 500 N
→
Allowable unbalance G6.
Goal G5 achieved.

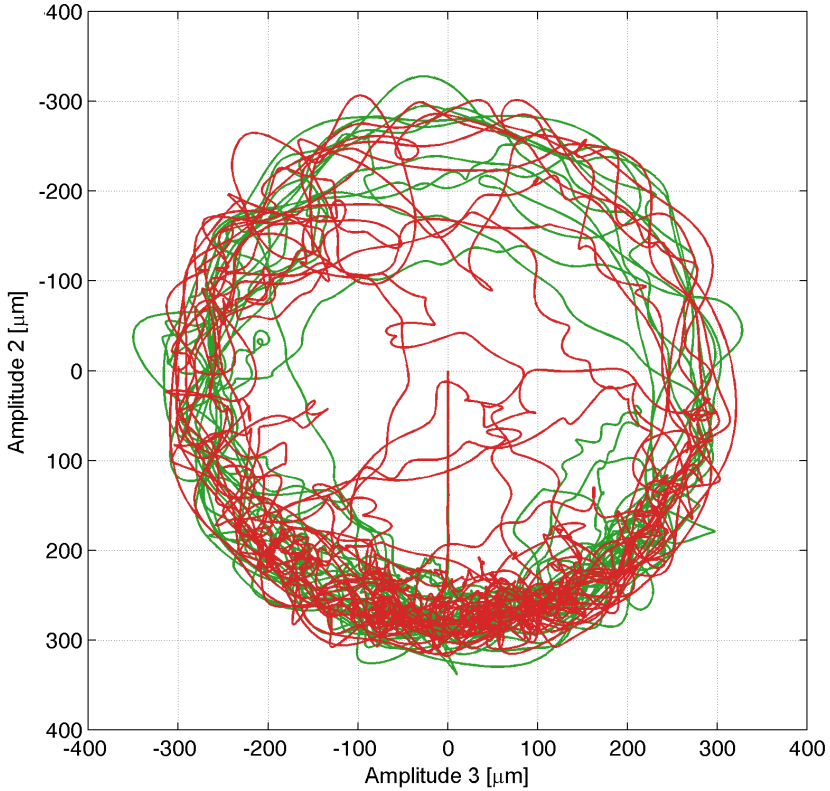


Features for Back Up Bearings in MADYN 2000

Simulation of a Drop







Conclusions

- MADYN 2000 is a general, proven simulation tool for rotordynamics.
- MADYN 2000 can handle all types of bearings (fluid film bearings, rolling element bearings, magnetic bearings).
- MADYN 2000 offers special, practically proven features for magnetic bearings.
- MADYN 2000 allows simulating drop analyses into back up bearings.
- For the spreading of magnetic bearings in the industry, it is important, that a general proven tool is available.

Conclusions

Beginning of the relation MADYN and MBs

MOPICO 1990, first hermetically sealed oil free compressor