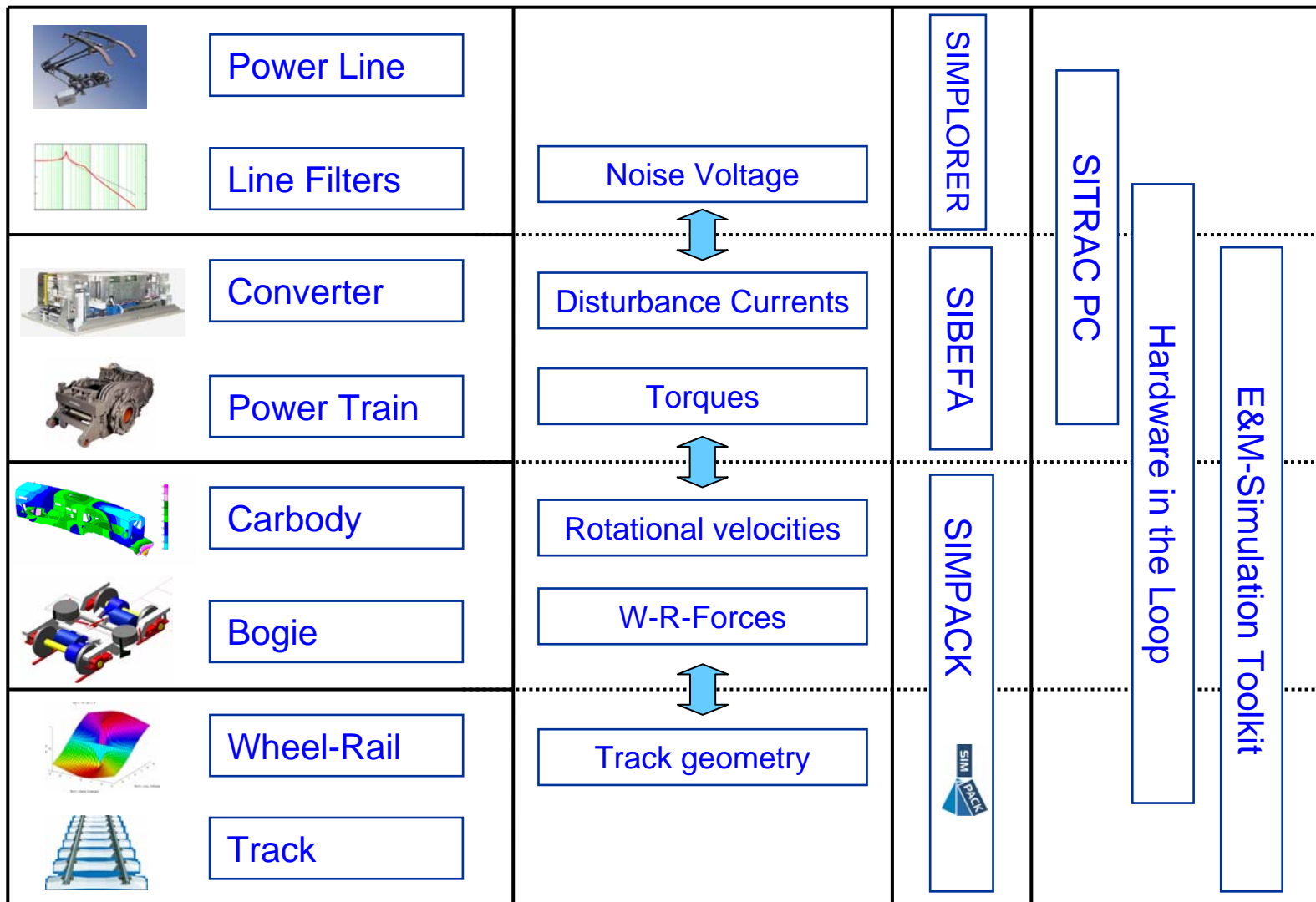


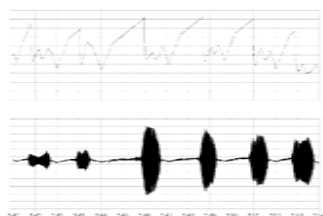
Linear Analysis of Railway Vehicle as Mechatronic System

Dr. Heinz-Peter Kotz
TS BG EN

Separated worlds ... and how to reunify them

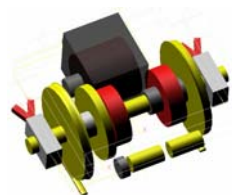


The Simulation Toolkit



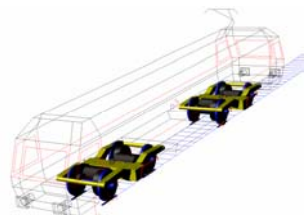
Focus

Analysis of Interaction Mechanics – Electrics – Software
 Methods: Co-Simulation & Linear System Analysis
 Established Software Platforms



Models

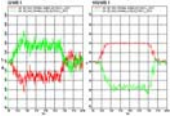
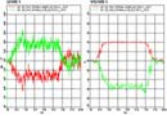
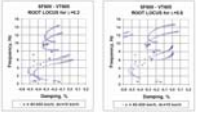
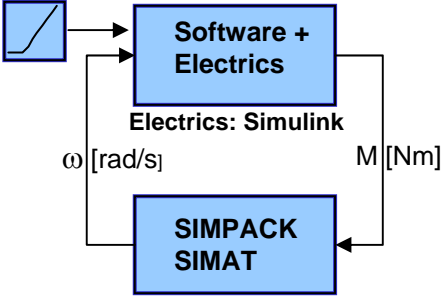
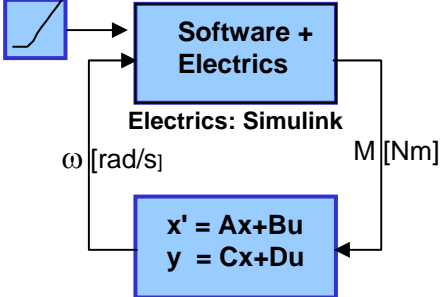
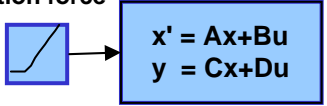
Mechanics: Drive train - Bogie - Vehicle
 Electrics: Converter – Induction motor – Tachometer dynamics
 Software: ASG – Slip control - GSS - dn/dt



Applications

Drive train vibrations
 Vehicle vibrations
 Shock-loads

Methods of Simulation

<p>Time-Integration Non-Linear-System</p> 	<p>Time-Integration Linear-System</p> 	<p>Linear System Analysis</p> 
<p>Traction force</p>  <p>Electrics: Simulink</p> <p>Mechanics: Co-Simulation SIMPACK</p>	<p>Traction force</p>  <p>Electrics: Simulink</p> <p>Mechanics: Co-Simulation SIMPACK</p>	<p>Traction force</p>  <p>Electrics & Mechanics: Linear System Matrices</p>
<p>Simulation of the entire system Electrics – Mechanics – Software including track geometry and track irregularities</p>	<p>Stand-alone-simulation in MATLAB</p>	<p>Fundamental insight into the behaviour of the linear system</p>
<p>Various applications: Shock Loads Torsional vibrations Vehicle vibrations</p>	<p>Used for verification of system-matrix-export</p>	<p>Implemented, validation and first applications</p>

The Linearisation Recipe

Automatisation



1. Synchronise

- Co-Simulation SIMPACK-MATLAB
- Synchronised state mechanics-electrics

2. Linearise

- Export of linear system matrices from SIMPACK
- Linearisation of complete system in MATLAB

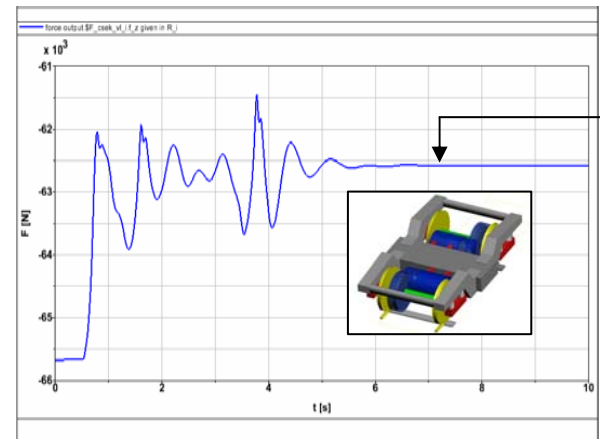
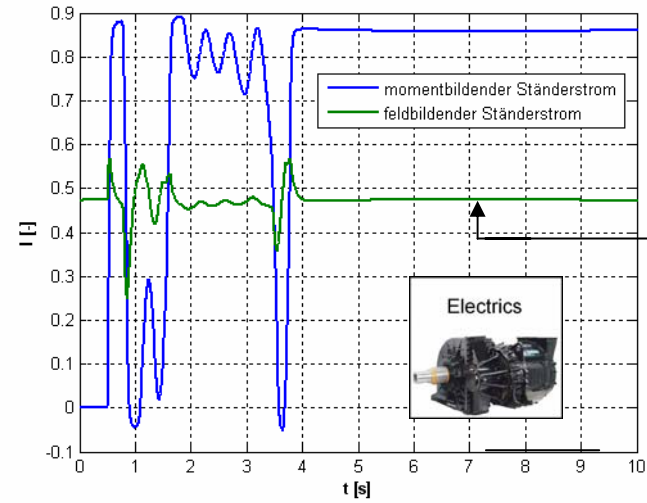
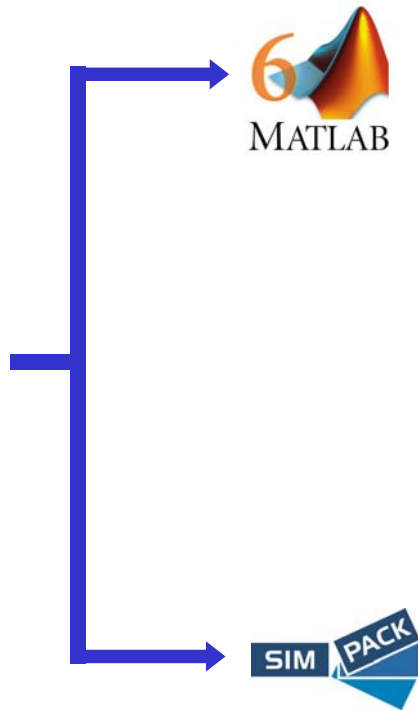
3. Visualise

- Root locii
- Visualise with SIMPACK



Synchronise

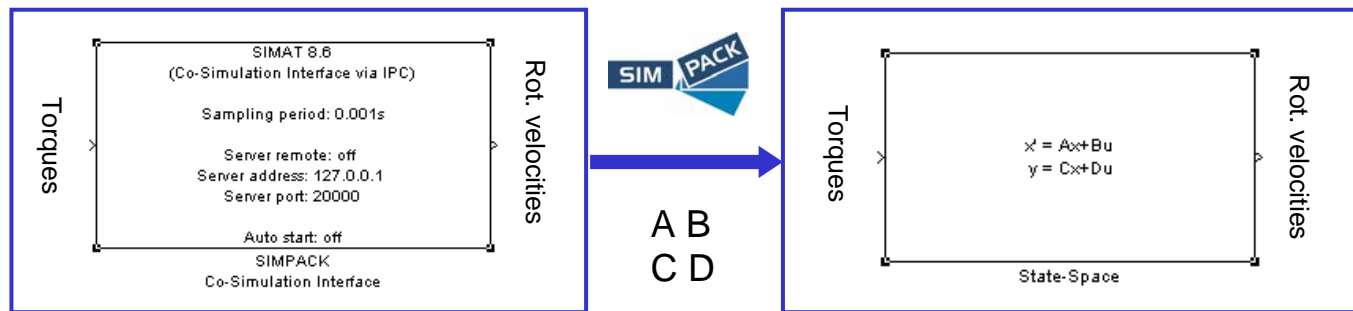
Co-Simulation
in time domain



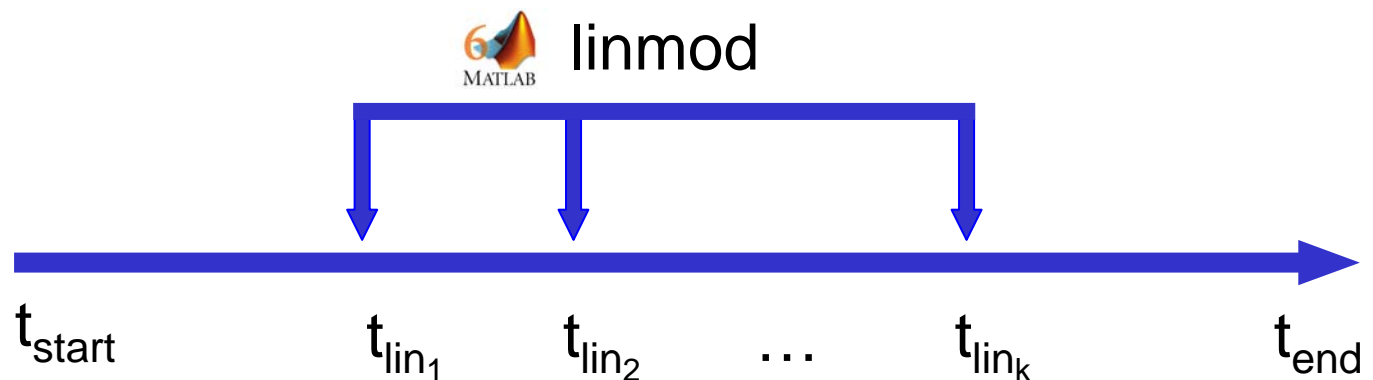
Synchronised state

Linearise

1. Exchange SIMAT – System Matrix Block



2. Linearise the complete system at given times



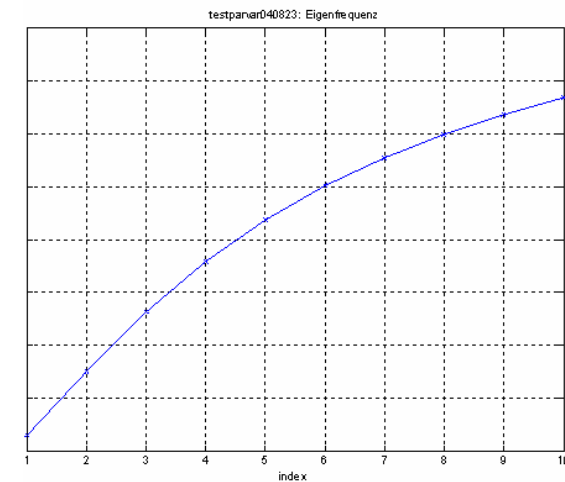
Visualise

Plot Eigenvalues

Ew	fmin	fmax	max(real)
1	0	0	-4263.0451
2	0	0	-3546.5929
3	0	0	-2748.8071
4	0	0	-1352.9142
5	0	0	-1351.9446
6	0	0	-883.8595
7	0	0	-875.64044
8	0	0	-655.65964
9	0	0	-665.56437
10	0	0	500
11	0	0	-481.28609
12	0	0	-333.33333
13	0	0	-200
14	0	0	-200
15	0	0	-196.34521
16	0	0	-111.17178
17	0	0	-100
18	0	0	-100
19	0	0	-74.25903
20	0	0	-50.024578
21	0	0	-49.371954
22	0	0	-21.421871

Select all

Ok Cancel



Generate SIMPACK aew-file

Auswahl Linearisierungspunkt(e)

Durchlauf 1, tlin = 1.0001
Durchlauf 1, tlin = 2
Durchlauf 2, tlin = 1.0001
Durchlauf 2, tlin = 2
Durchlauf 3, tlin = 1.0001
Durchlauf 3, tlin = 2
Durchlauf 4, tlin = 1.0001
Durchlauf 4, tlin = 2

Select all

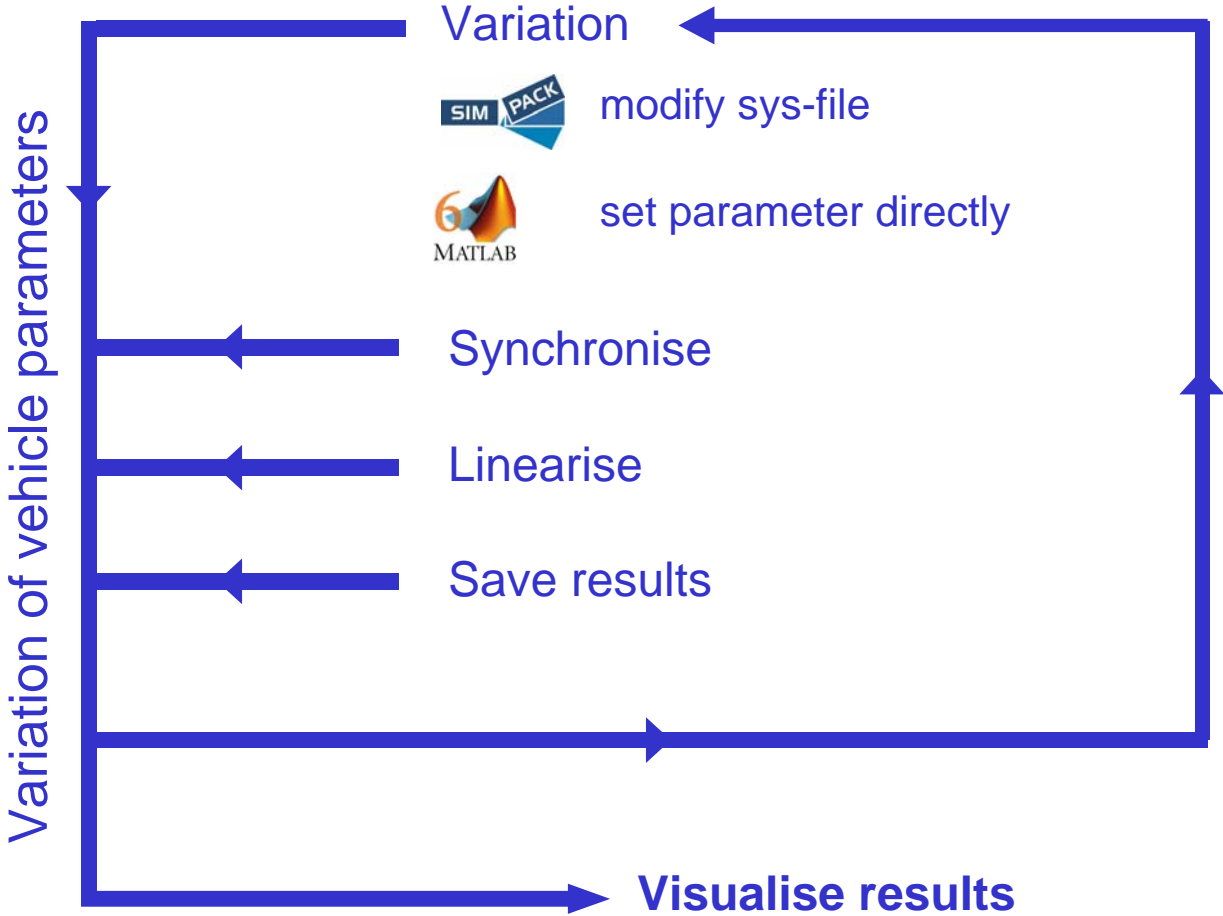
Ok quit

```

Editor - D:\Simulationsumgebung\v04.0.02\resource\aeawschreiben.m*
File Edit Text Cell Tools Debug Desktop Window Help
[Icons] Stack: Base
1 function [message]=main( S, xname, fmax, filename )
2 %aeawschreiben: Erzeugung von Simpack-aew-Dateien
3 %Aufruf:
4 % [message]=aeawschreiben( S, xname, fmax, [ filename ] )
5 % S: Datenstruktur mit Systemmatrizen/Eigenwerten/StateNames
6 % xname: Name des zu extrahierenden Subsystems oder Indizes der Eigenwerte,
7 %       Default: xname = [], entspricht 'Grundmodell_1fz/Mechanik/Mechanik Sim'
8 % fmax: Maximalfrequenz (Imaginaerteil/2/pi) der extrahierten Eigenwerte
9 % filename (optional): Pfad/Modellname (ohne Endung ".aew"); Wird kein
10 % Modellname vorgegeben, so erfolgt die Ausgabe auf stdout
main Ln 8 Col 30 OVR

```

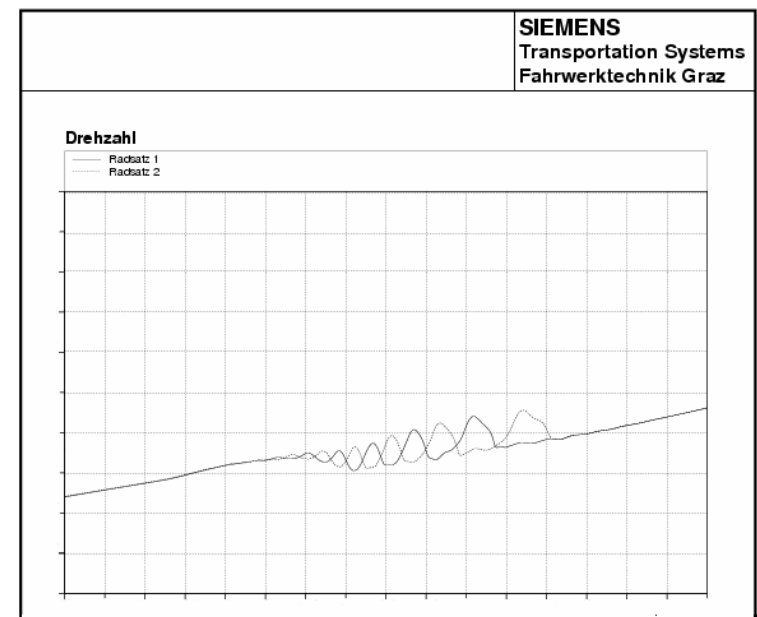
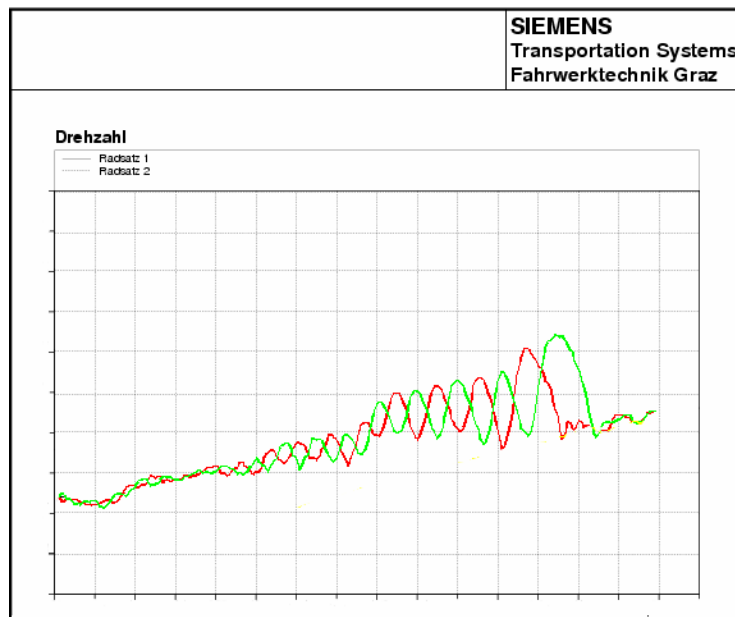
Automatisation



Example – Step 1

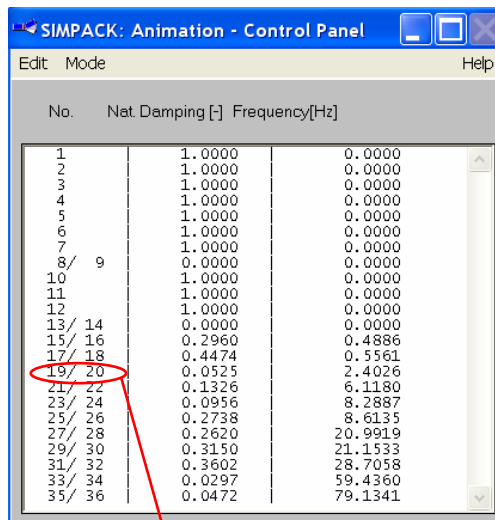
Vibration effect due to interaction
mechanics-electrics-software
is found on the real vehicle

Co-simulation in time domain
can reproduce the behaviour



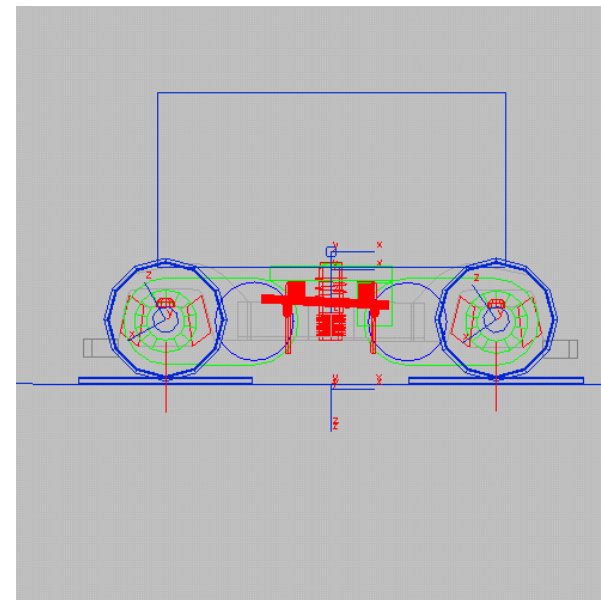
Example – Step 2

Linear analysis - mechanics only (without E&M-coupling)



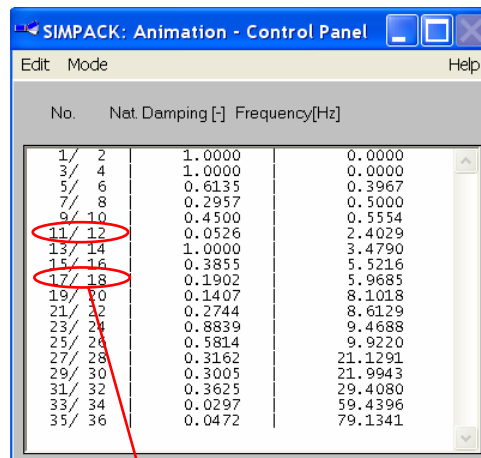
No.	Nat. Damping [-]	Frequency[Hz]
1	1.0000	0.0000
2	1.0000	0.0000
3	1.0000	0.0000
4	1.0000	0.0000
5	1.0000	0.0000
6	1.0000	0.0000
7	1.0000	0.0000
8/ 9	0.0000	0.0000
10	1.0000	0.0000
11	1.0000	0.0000
12	1.0000	0.0000
13/ 14	0.0000	0.0000
15/ 16	0.2960	0.4886
17/ 18	0.4474	0.5561
19/ 20	0.0525	2.4026
21/ 22	0.1326	6.1180
23/ 24	0.0956	8.2887
25/ 26	0.2738	8.6135
27/ 28	0.2620	20.9919
29/ 30	0.3150	21.1533
31/ 32	0.3602	28.7058
33/ 34	0.0297	59.4360
35/ 36	0.0472	79.1341

„Traditional“ mode shapes
from mechanics



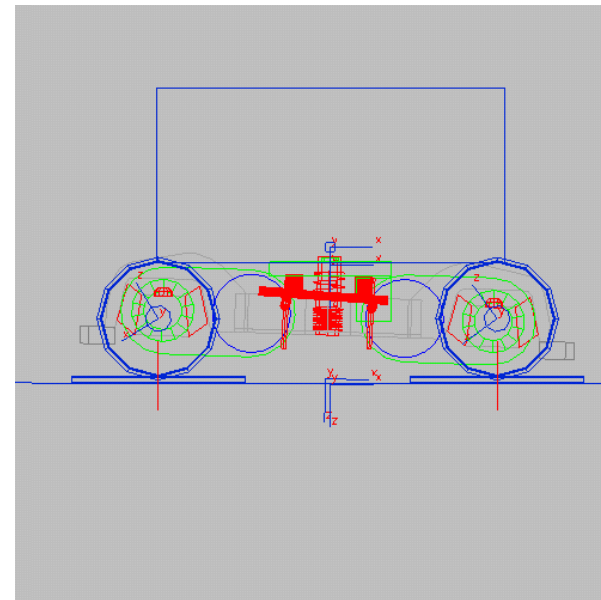
Example – Step 3

Linear analysis - complete system (with E&M-coupling)



No.	Nat. Damping [-]	Frequency [Hz]
1/ 2	1.0000	0.0000
3/ 4	1.0000	0.0000
5/ 6	0.6135	0.3967
7/ 8	0.2957	0.5000
9/ 10	0.4500	0.5554
11/ 12	0.0526	2.4029
13/ 14	1.0000	3.4790
15/ 16	0.3855	5.5216
17/ 18	0.1902	5.9685
19/ 20	0.1407	8.1018
21/ 22	0.2744	8.6129
23/ 24	0.8839	9.4688
25/ 26	0.5814	9.9220
27/ 28	0.3162	21.1291
29/ 30	0.3005	21.9943
31/ 32	0.3625	29.4080
33/ 34	0.0297	59.4396
35/ 36	0.0472	79.1341

Additional mode shapes
from interaction mechanics-electrics
with correct frequency are found



Summary

Intention

Apply methods of linear system analysis to models of railway vehicles as mechatronic system

Method

Find a synchronised state electrics-mechanics by co-simulation
Exchange SIMAT-block by system-matrix-block
Import system matrices from SIMPACK
Linearise the complete system in MATLAB
Visualise results in SIMPACK

Results

Method has been applied to sample models
Basic technical functionality is provided

Outlook

Validation and testing is in progress