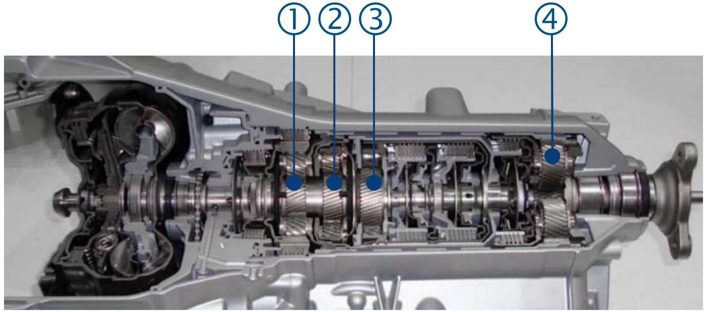
3DEXPERIENCE®

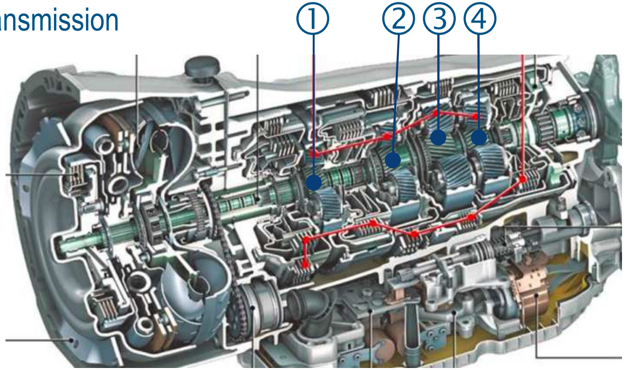
Planetary Gear System

Gear Whine (Transmission/Differential)

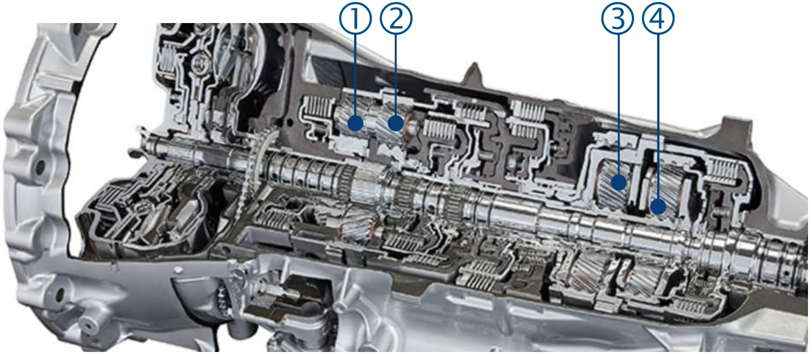
Planetary Gear Sets in Automatic Transmissions



ZF – **8** speed – Automatic Transmission
with **4** planetary gear sets

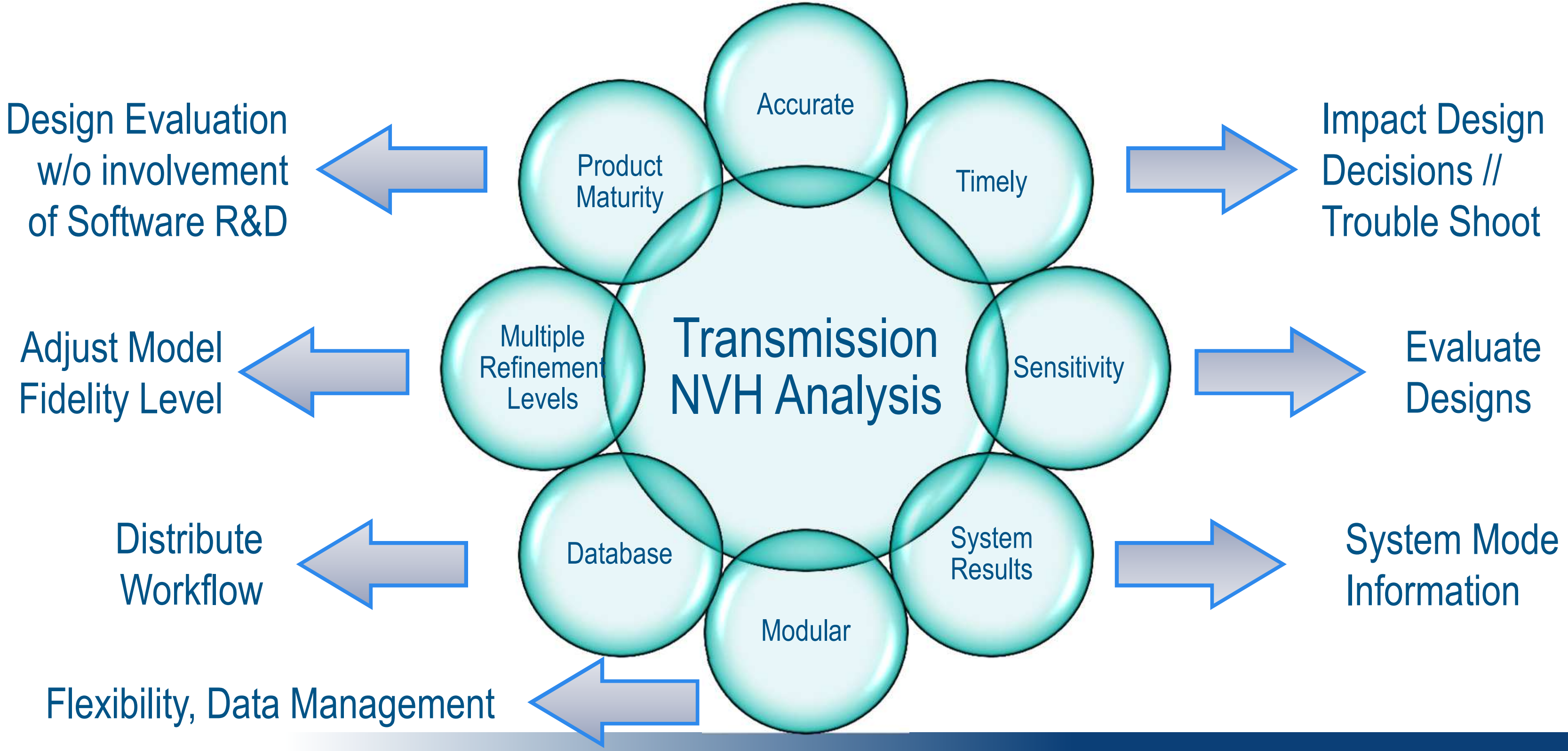


Mercedes – **9** speed – Automatic Transmission
with **4** planetary gear sets



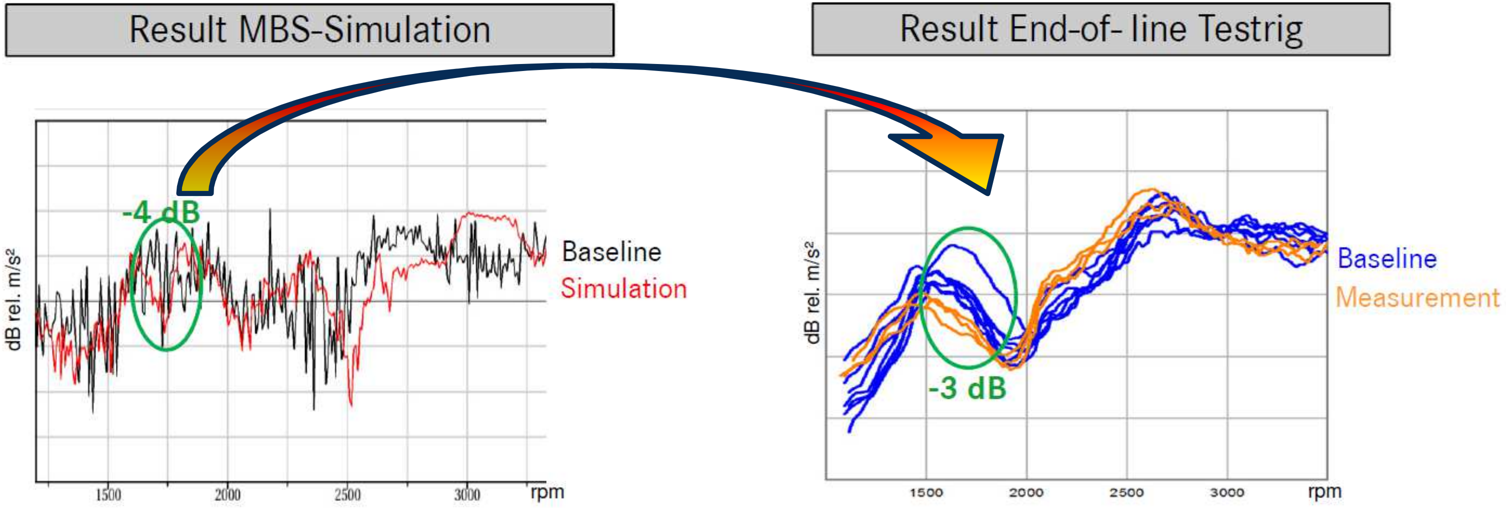
Toyota – **10** speed – Automatic Transmission
with **4** planetary gear sets

Demands on System Analysis Tool



Gear Whine Analysis at Mercedes-Benz

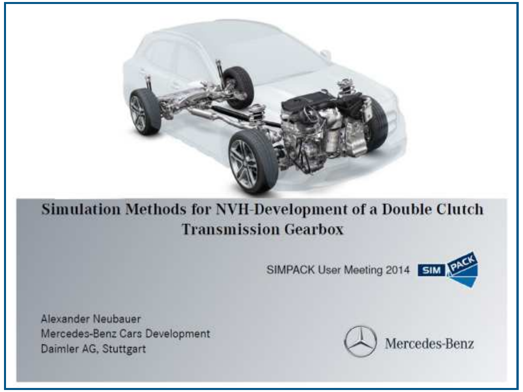
SIMPACK User Conference in Augsburg, October 2014

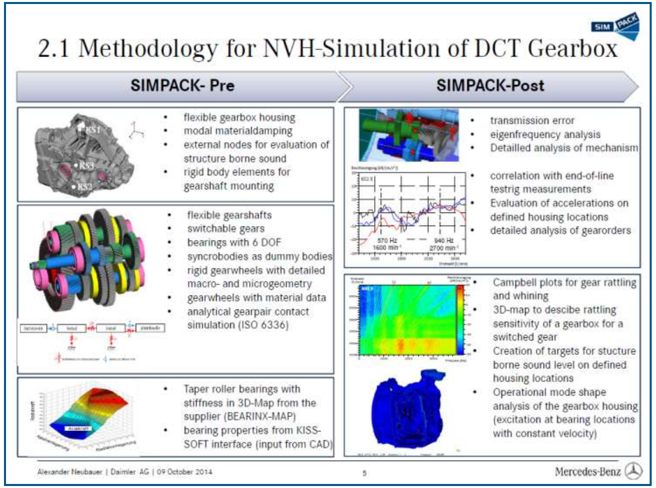


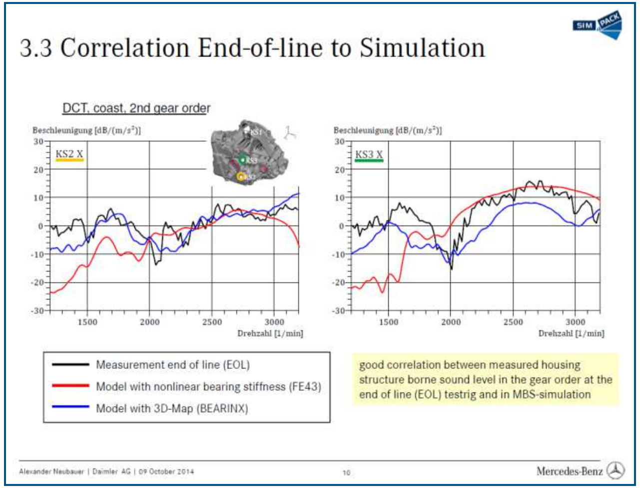
By using a system level approach, the SIMPACK customer was able to isolate the influencing factor of the gear whine problem in a specific speed range. The SIMPACK model was able to provide a design solution to reduce the impact of gear whine.

Gear Whine Example using SIMPACK

SIMPACK User Conference 2014: Mercedes-Benz



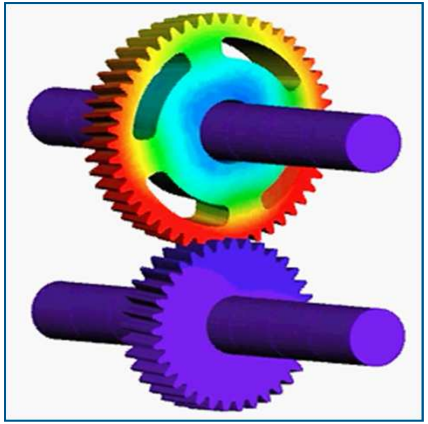




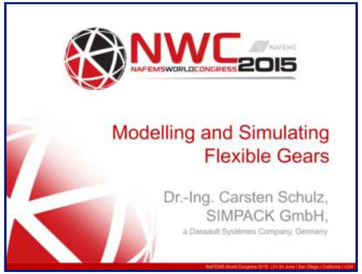
http://www.simpack.com/fileadmin/simpack/doc/usermeeting14/Day_2_Room-1/04_UM14_Daimler_Neubauer_Simu-NVH-Develop-Double-Clutch-Trans-Gearbox.pdf

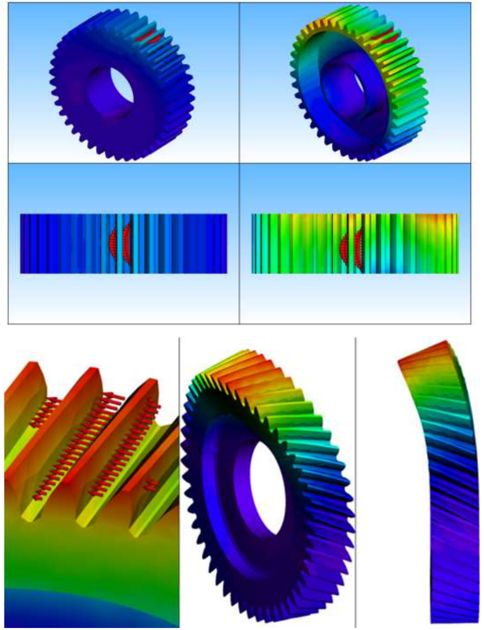
www.simpack.com → Downloads → User Meeting Presentations → Drivetrain → 

Flexible Gears under Dynamic Loading Conditions

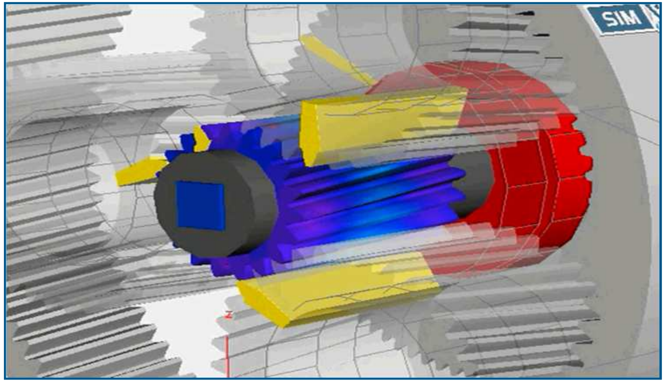


Non-standard gear design





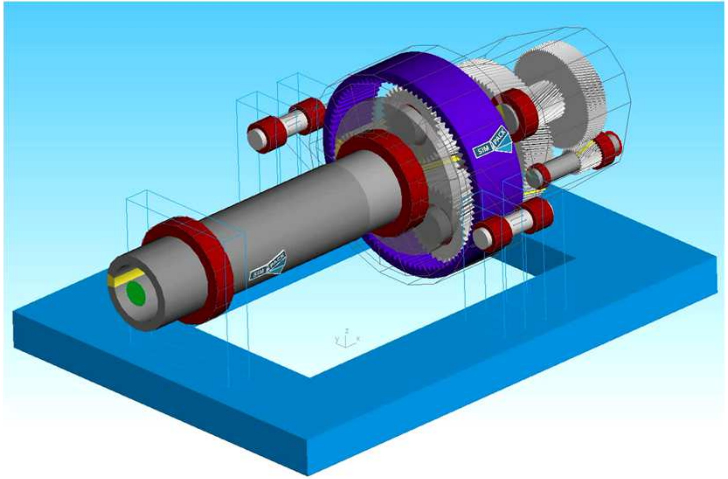
load and geometry dependent deformation

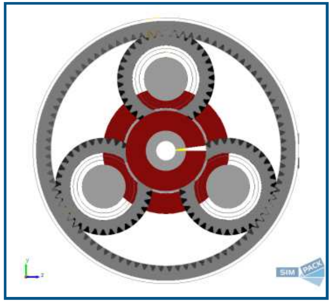


load distribution along the flank width

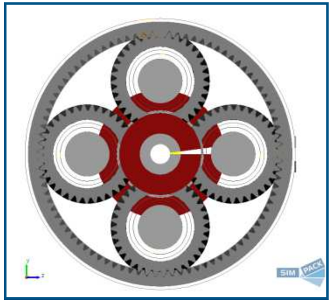
… by utilizing the Craig Bampton Method for linearizing FE models

Simpack System Model: Wind Turbine Gear Box

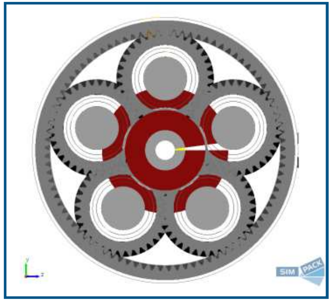




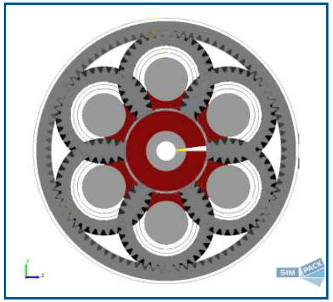
3 planets



4 planets



5 planets



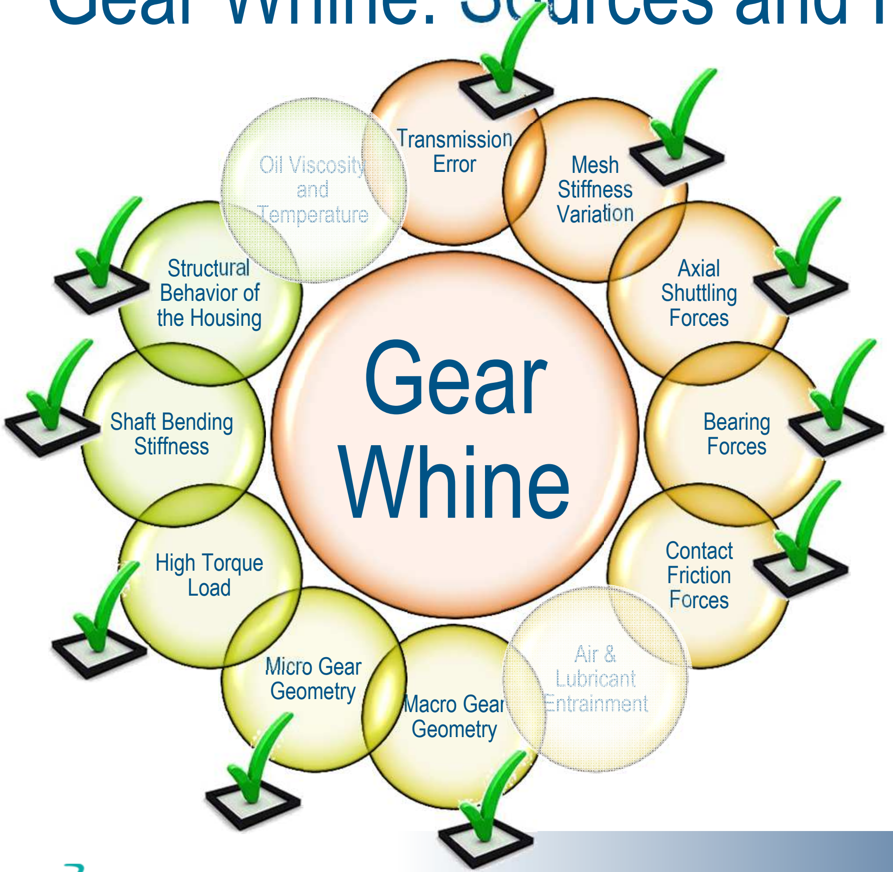
6 planets

Gear Whine: Sources and Factors

Sources and factors described in the literature that influence and impact gear whine

The complexity of this noise phenomena requires a system level view to capture all the different aspects and coupled effects of the mechanical system

Gear Whine: Sources and Factors



SIMPACK covers the physics of all these factors described in the literature for sources that can cause gear whine and factors that influence gear whine.

Gear Whine Evaluation

Planetary Gear Set Configurations

- Number of Teeth
  - Ring Gear = 89
  - Sun = 19
  - Planet = 35
- Gear Design: helical
- Load Case:
  - constant speed (1,000 rpm @ sun)
  - constant load (50 kN @ carrier)
- Number of planets: 3, 4, 6

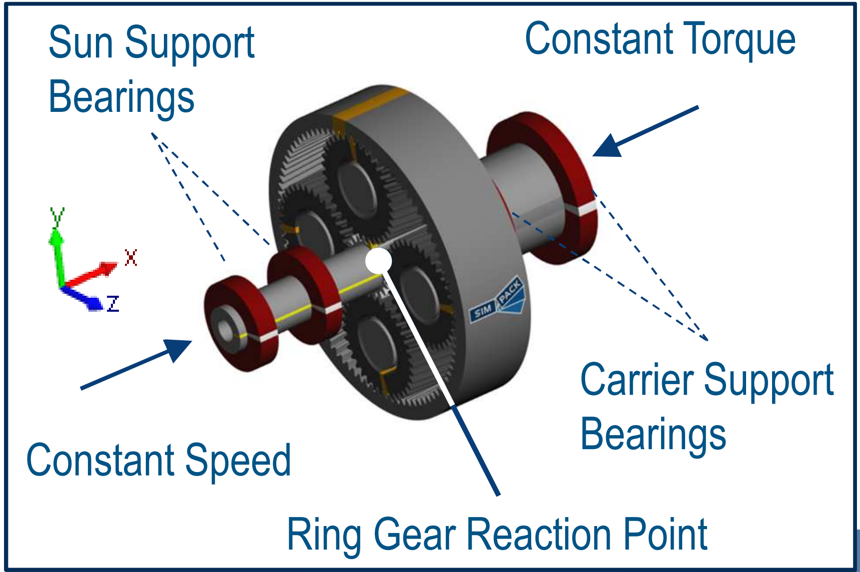
- Focus of the results is on the ring gear support (forces and moments), as this is the main transfer path of the planetary gear set to the outside

- Expected main order content at ring gear support
  - 3 planets: 90 (and multiples of 3)
  - 4 planets: 88 (and multiples of 4)
  - 6 planets: 90 (and multiples of 6)

Analysis Setup and Output

Duration and Signal Characteristic

- 110 rev's of the sun, torque ramp-up
- 20 kHz signal for sufficient FFT

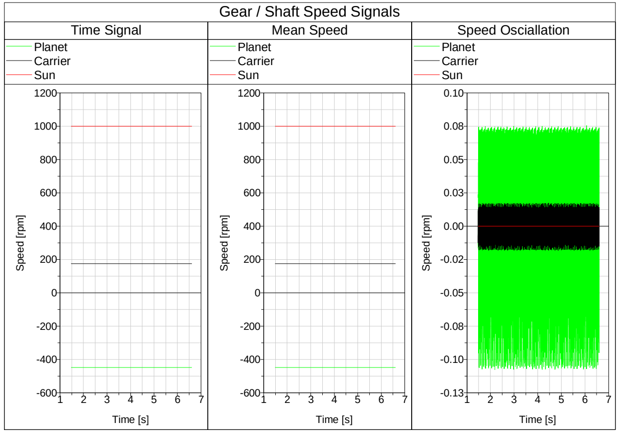


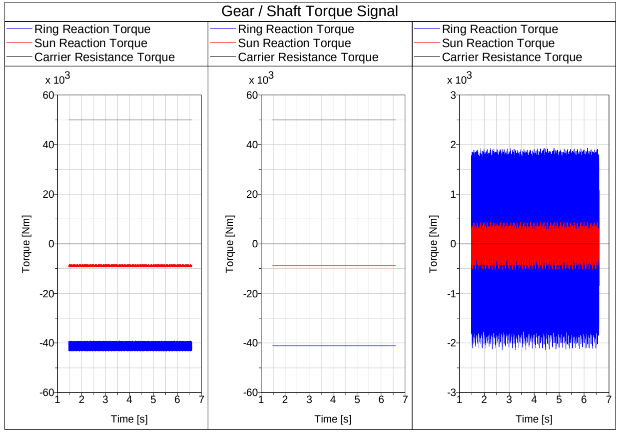
Result Output (selection)

- Speed and torque signals
- Gear contact forces (animations)
- Order content at ring gear reaction point
  - Forces in x-, y- and z-direction
  - Moments in x-, y- and z-direction
- System mode evaluation using ODS

Result Examples for 3 Planets – Speed & Torque

- 3 Planets
- Nominal
  - Ring Eccentricity = 0.0 mm
  - Carrier Eccentricity = 0.0 mm
  - Titling Angle = 0.0°
- Rigid ring gear





Carrier
Sun
Planet
Ring

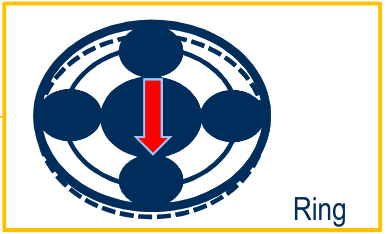
Result Comparison of the 3 Configurations

Nominal Conditions	3 planets	4 planets	6 planets
Carrier speed oscill. amp. [rpm]	+0.075 / -0.107	+0.089 / -0.092	+0.098 / -0.061
Ring torque oscill. amp. [kNm]	+1.9 / -2.1	+1.2 / -1.1	+0.3 / -0.3
areas of concern under 1,200 Hz [Hz]	264, 519, 783, 1045	258, …,784, 1044	264
areas of concern under 1,200 Hz [order]	90, 177, 267, 357	88, …, 268, 356	90
Planet bearing force [kN]	1.5 [35^{th}]	1.0 [35^{th}]	0.7 [35^{th}]
Carrier bearing force [kN]	0.17 [90^{th}]	0.40 [88^{th}]	0.12 [90^{th}]
Ring reaction force [kN] – radial	1.0 [177^{th}]	3.0 [268^{th}]	1.3 [90^{th}]
Ring reaction force [kN] – axial	0.24 [267^{th}]	0.07 [356^{th}]	0.02 [2.5^{th}]
Ring reaction moment [kNm] – radial	1.2 [90^{th}]	1.3 [88^{th}]	1.1 [90^{th}]
Ring reaction moment [kNm] – axial	1.7 [267^{th}]	0.4 [356^{th}]	0.07 [2.5^{th}]

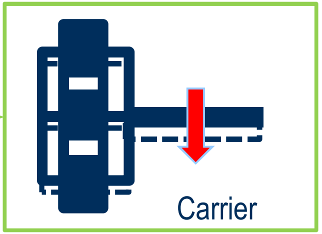
Gear Whine Evaluation

Design Study

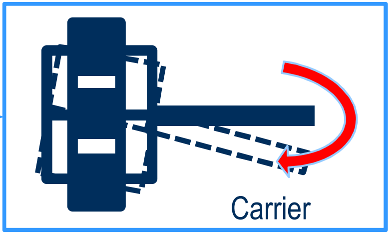
- ▶ Nominal (perfect alignment)
- ▶ Radial Ring Gear Eccentricity



- ▶ Radial Carrier Eccentricity



- ▶ Carrier Tilting Angle



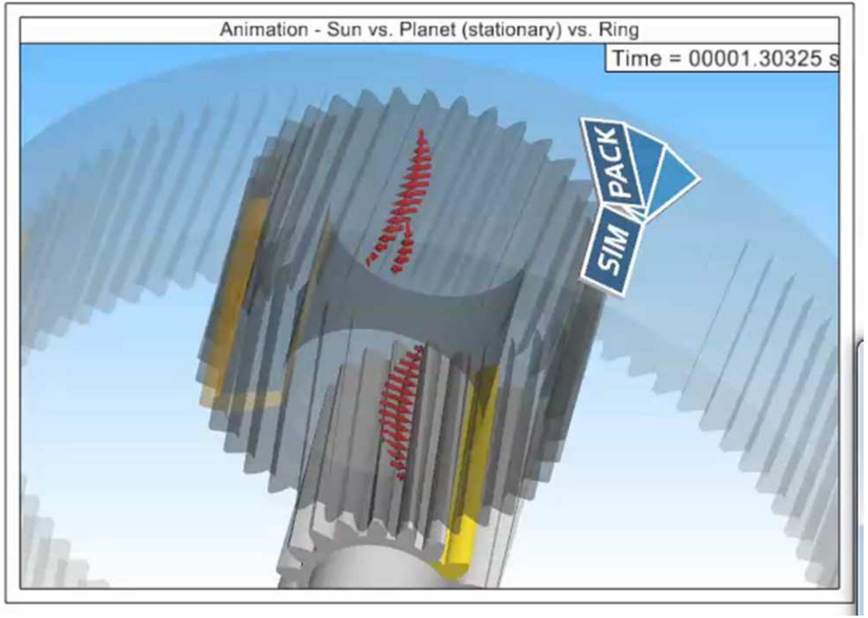
- ▶ Ring Gear: Rigid vs. Flexible

Analysis Matrix for Single Planetary Gear Set

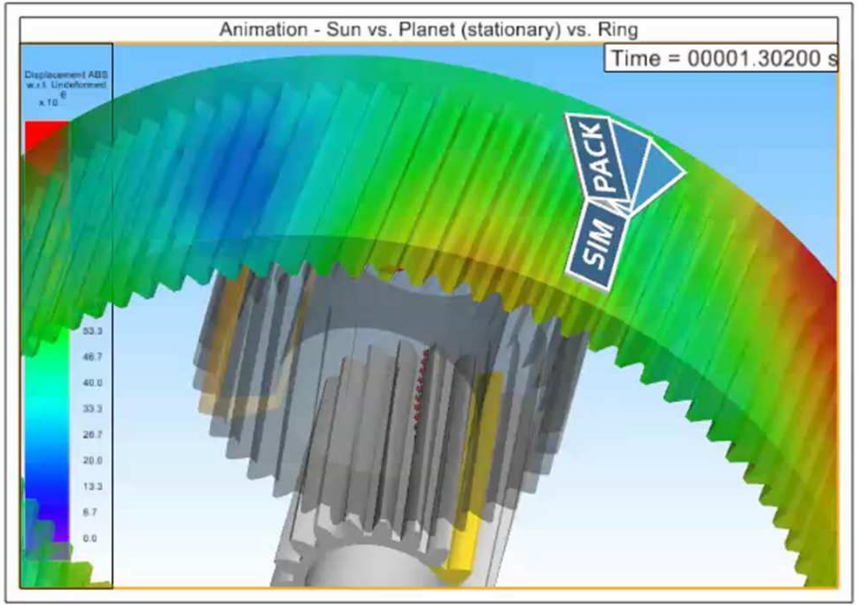
		Ring	Carrier	Carrier	Ring Gear	
# of runs	# of Planets	Eccentricity	Eccentricity	Tilting	Rigid	Flexible
1	3	0.0 mm	0.0 mm	0.0 deg	x	
2		1.0 mm			x	
3			1.0 mm		x	
4				0.3 deg	x	
5		0.3 mm	-0.3 mm	0.2 deg	x	
6		0.0 mm	0.0 mm	0.0 deg		x
7		1.0 mm				x
8			1.0 mm			x
9				0.3 deg		x
10		0.3 mm	-0.3 mm	0.2 deg		x

* applied eccentricities and tilting angle where determined by available clearance in the planetary gear sets

Gear Forces – Animation

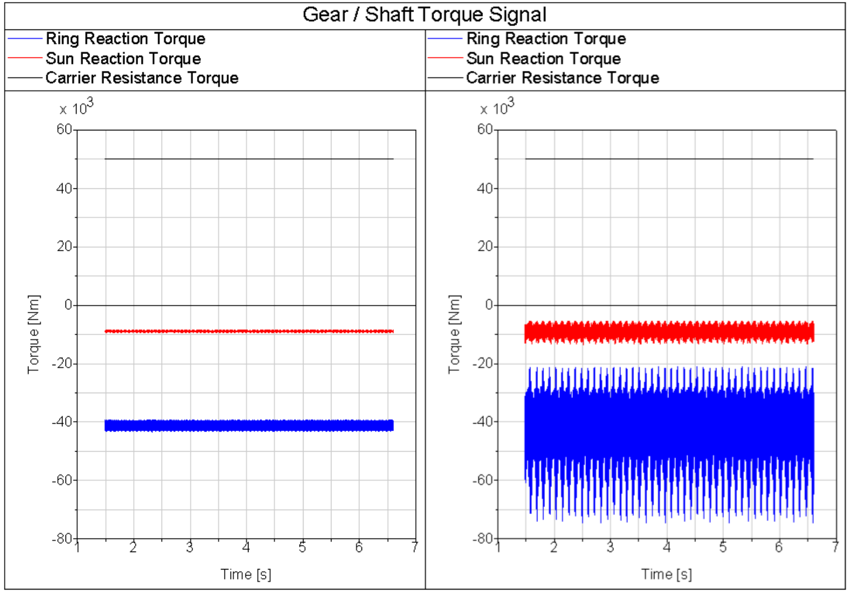


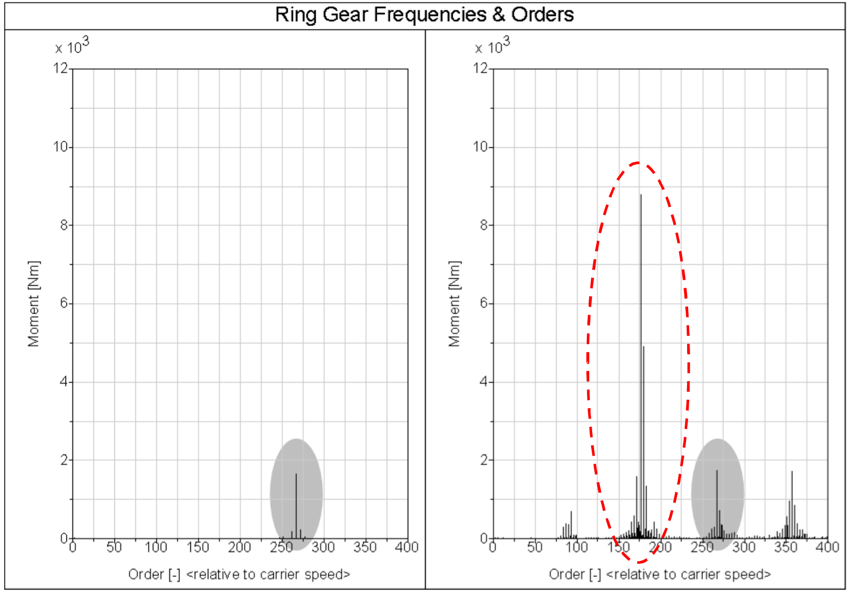
1: Nominal Conditions



10: Eccentricities, Tilting and Flexible Ring Gear

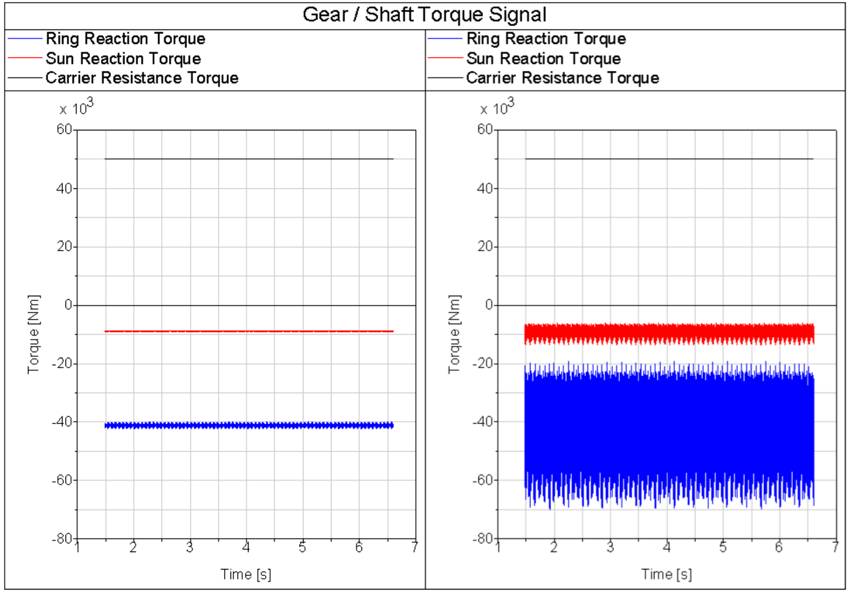
Torque Reaction Comparison between #1 and #10

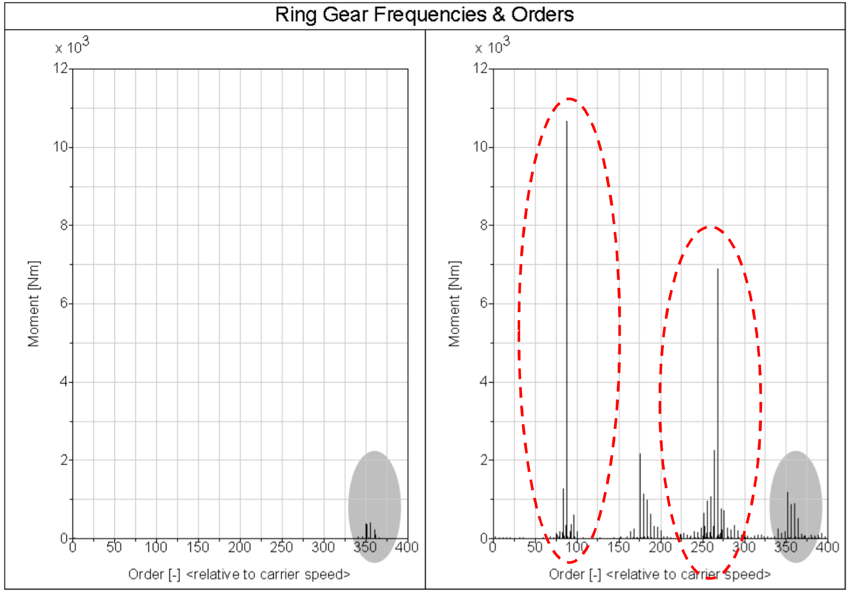




The analysis would have completely missed the system behavior, by not considering the complexity of the system and neglecting eccentricities, offsets, misalignments and compliance in the system.

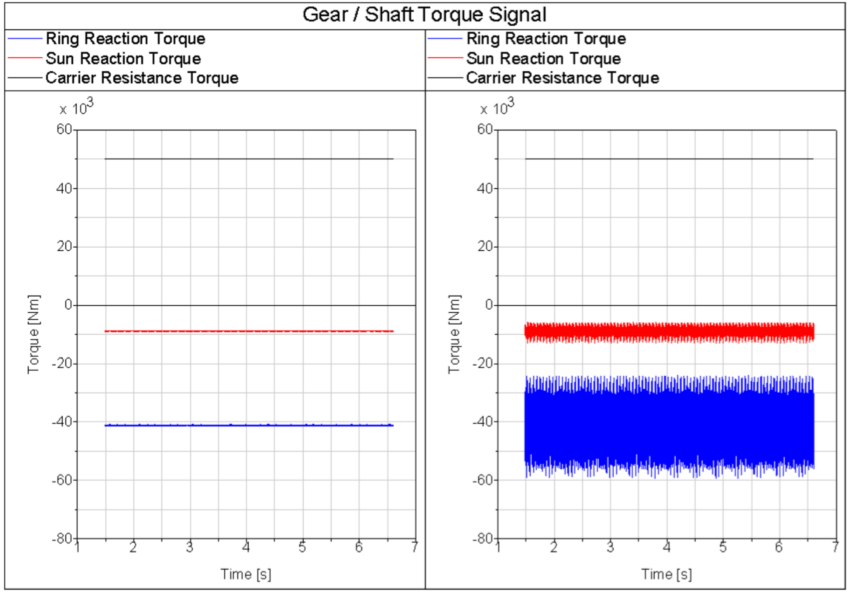
Torque Reaction Comparison between #1 and #10

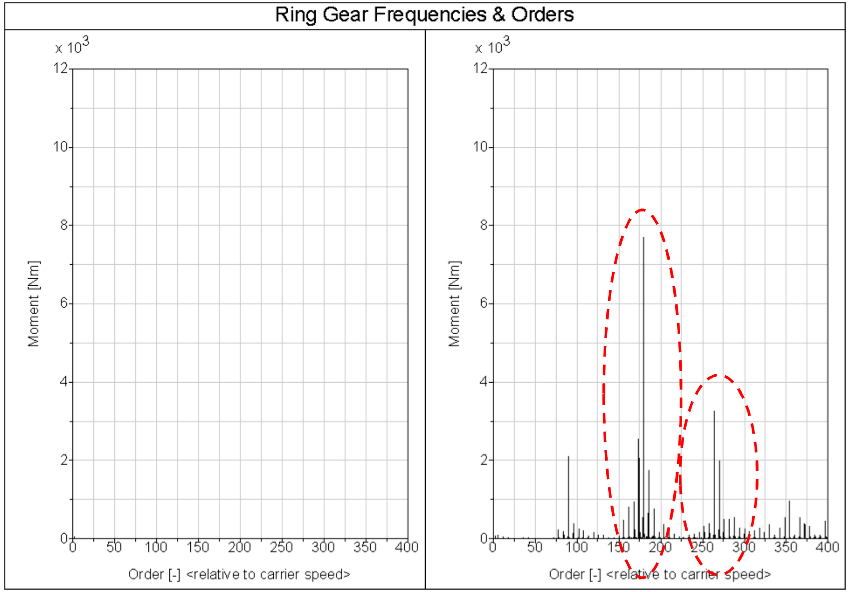




… with different implications for the different designs, here for the 4 planets

Torque Reaction Comparison between #1 and #10



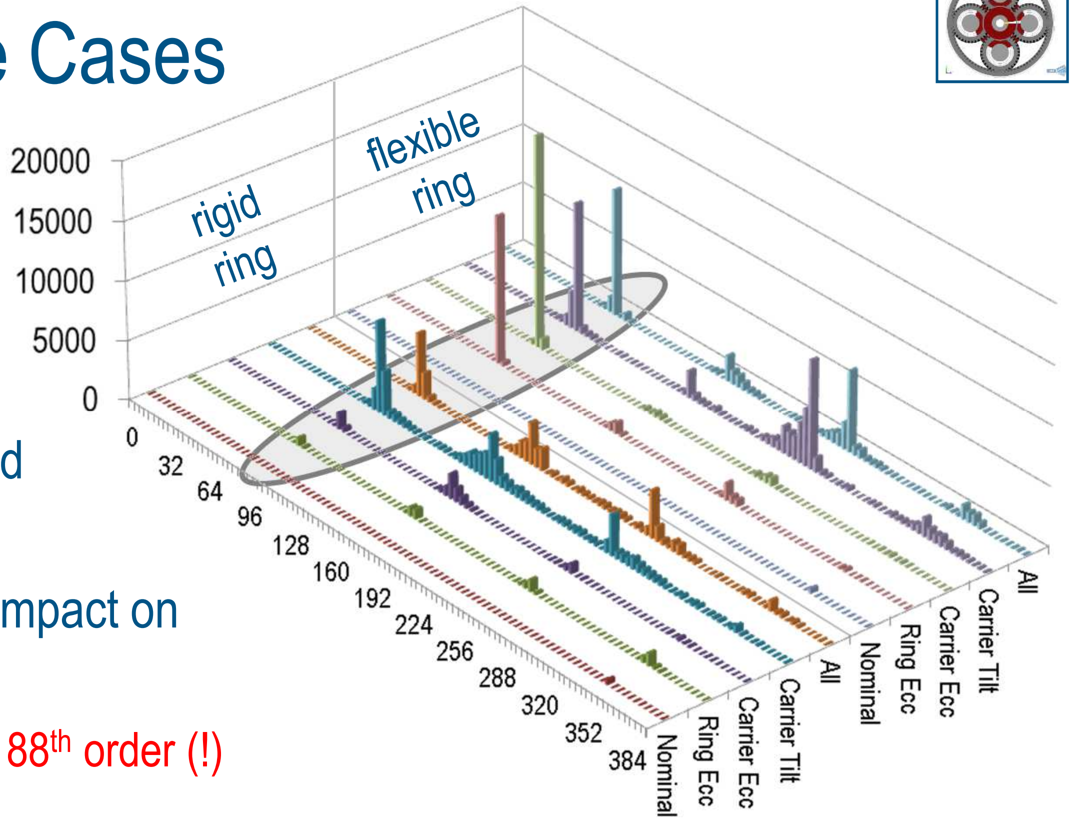


… here for the 6 planets

Comparison of all the Cases

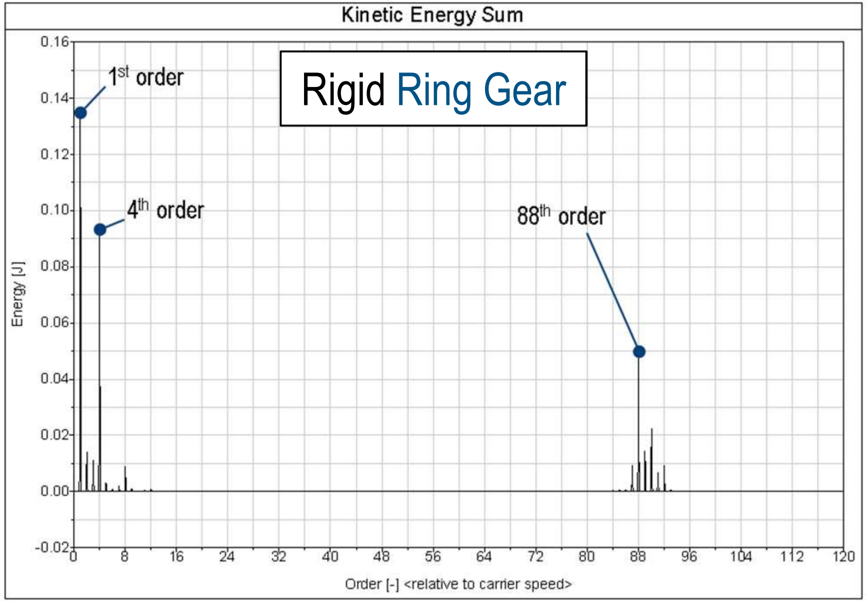
Torque Reaction (4 planets)

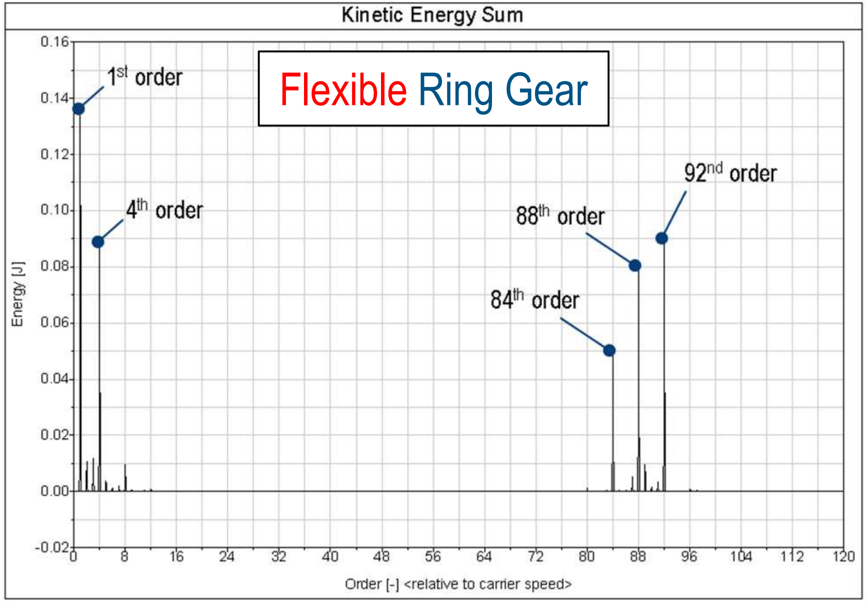
- Nominal conditions *<u>does not show any significance</u>* in the result comparison
- Carrier tilt shows biggest spread of response frequencies
- Flexible ring gear shows most impact on system frequency response
  - in respect to the response at the 88th order (!)
  - in regards of overall amplitude



* results are shown only in side band order content (4, 8, 12, 16, …, 400)

System Model Evaluation with ODS for #10

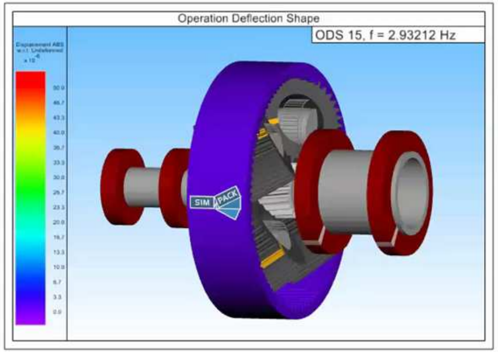




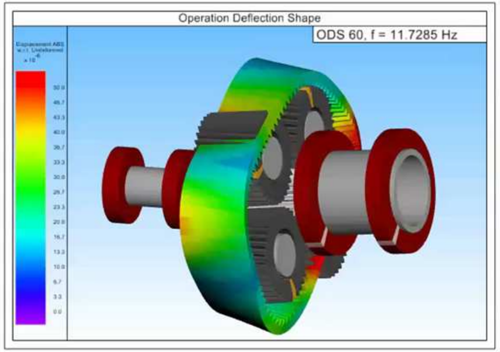
ODS - Operation Deflection Shapes

Low Frequency Modes

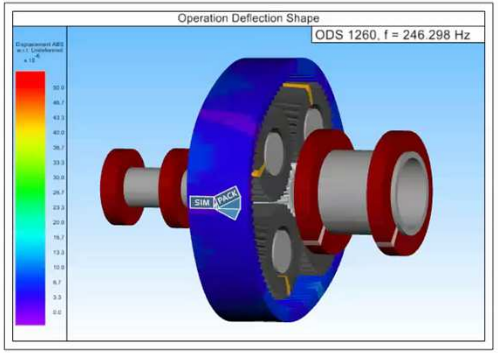
Main Gear Order Modes



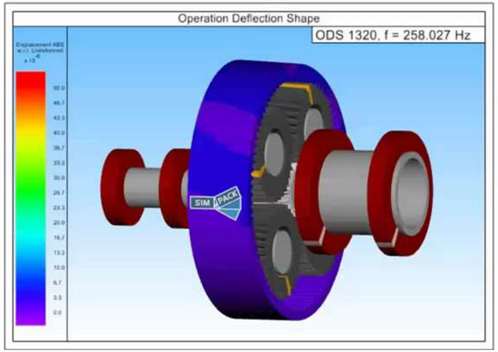
1st order



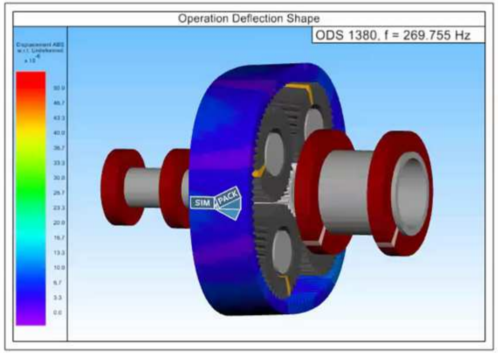
4th order



84th order



88th order



92nd order

* results are shown with a mode shape scaling factor of 500

Gear Whine Evaluation

Other ‘required’ studies to explore design space

- Bearing Characteristic (non-linear, 3D, clearance, …)
- Gear profile modifications & tolerance range
- Structural Compliance
  - Carrier
  - Sun shaft
  - Sun gear
  - Planet gear
- Planet misalignment (angular, radial)
- Load cases
  - Different speeds (Run-up)
  - Different load conditions (load sweep)
- .

The list of required DOE’s can get long, fast!

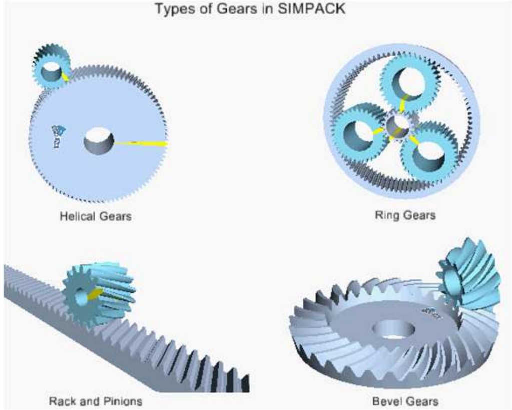
Essential to have a very efficient numerical solution available!

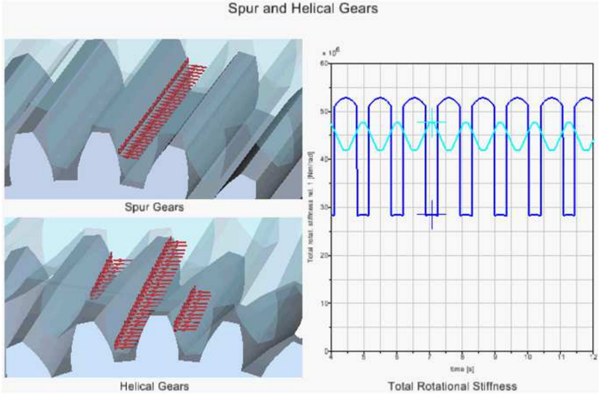
The analyses were performed on a 3 year old laptop with limited virtual memory (16 GB) and limited number of treads (4) for 6.6 sec simulated time

- Rigid Ring: 10-15 min
- Flexible Ring: 20-30 min

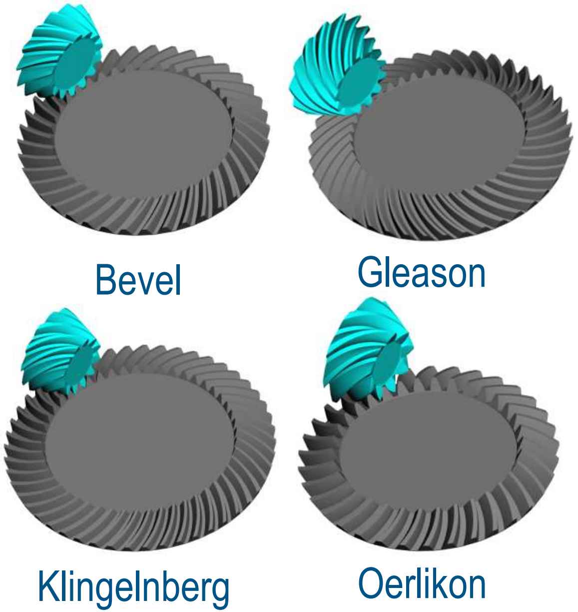
Simpack 2017.4

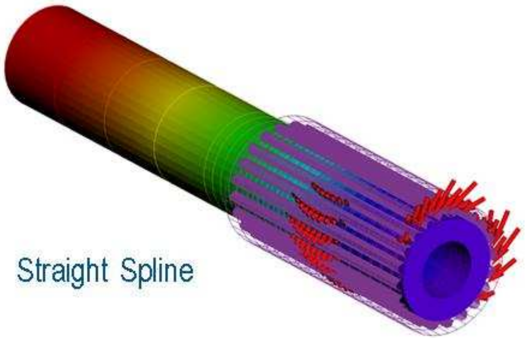
Gear Module – Overview

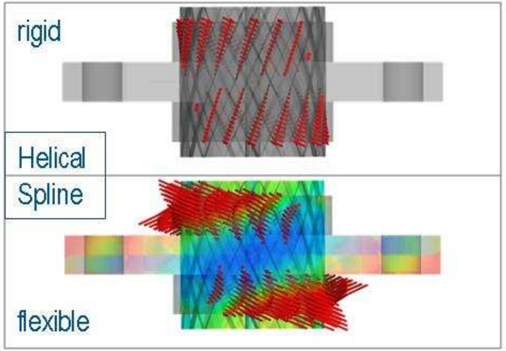




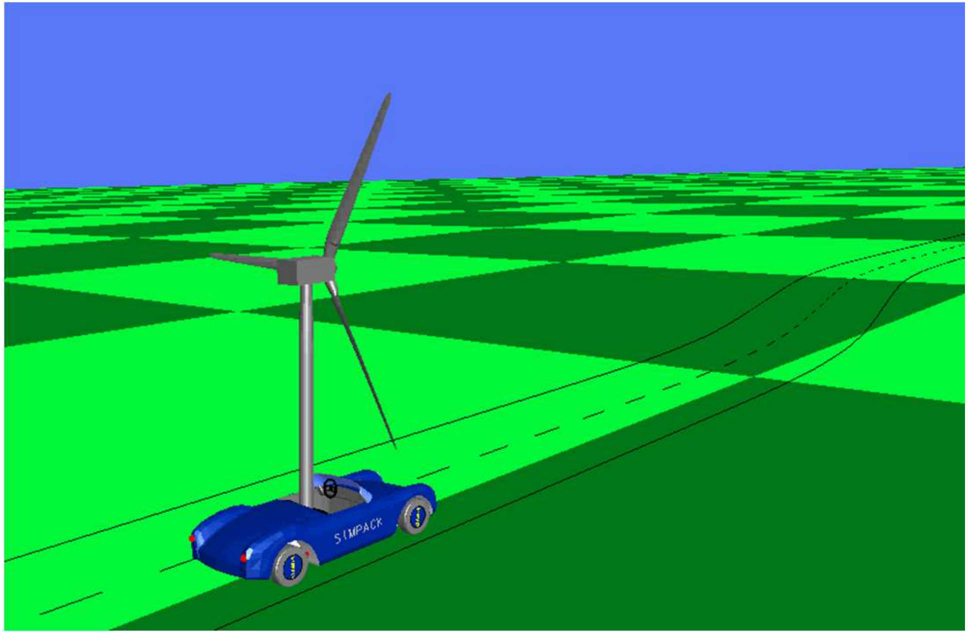
Bevel & Hypoid







Simpack – Possible to simulate almost anything



Simpack
provides the means
to eliminate
analysis assumptions
… one-by-one.

IF WE™