Modular Drivetrain Concept for Electrical Commercial Vehicles

- MAN Truck & Bus AG
- ZG GmbH

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Agenda

Introduction

Cooperation of MAN and CNL → sustainability at transport and logistics

Introduction

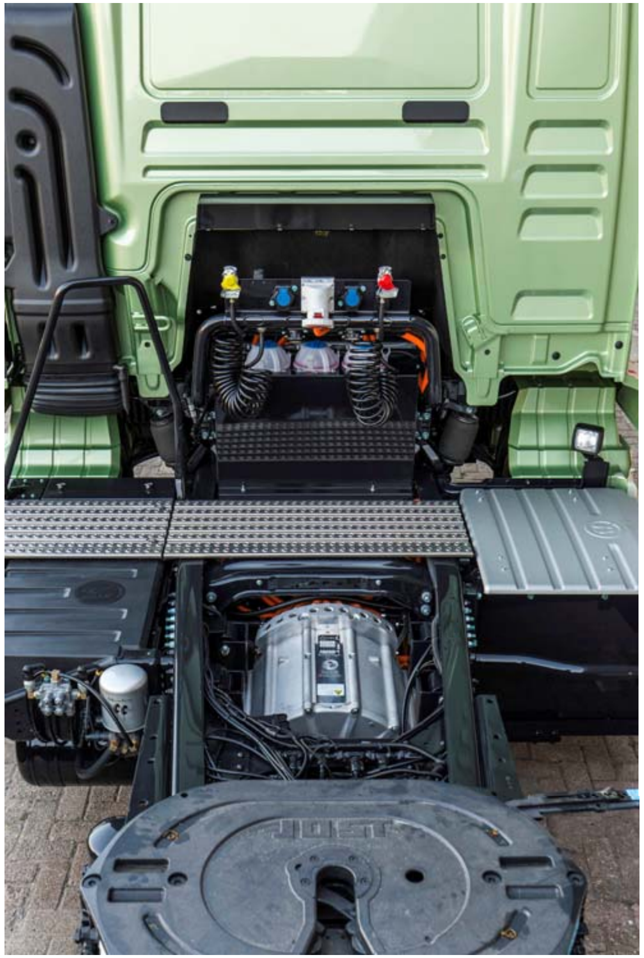
Development of e-trucks (BEV) @ MAN Truck & Bus AG

- IAA 2016: MAN presents e-truck (BEV) based on TGS (heavy-duty long haul application)
- 2017: start of cooperation between MAN and CNL (“Council für nachhaltige Logistik”); initiative comprises Austrian companies which aim at further development of sustainable transport and logistics
- 2017: MAN develops e-truck (BEV) based on TGM 6x2 with gross vehicle weight in 26-tons-class; application aims at distribution transport with range up to 200 km
- 2017 – 2018: testing of new powertrain and corresponding vehicles at MAN
- 2018: delivery of e-trucks for CNL companies will start

Introduction

Challenges for the development of the electric drivetrain

- Higher transmission ratio of ≈ 7.5 needed in order to use speed range of the electric motor
  - no suitable serial axle in portfolio, new powertrain concept has to be found
- Very short period of time for development & production (4 months)
  - simultaneous engineering team at MAN, support by ZG GmbH
- Type and interface of electric motor not finalized at the start of the project
  - development of the gearbox has to be independent of motor design, thus “backpack” gearbox solution on axle favoured
- Limited number of vehicles (10 in a first step)
  - focus on cost efficiency



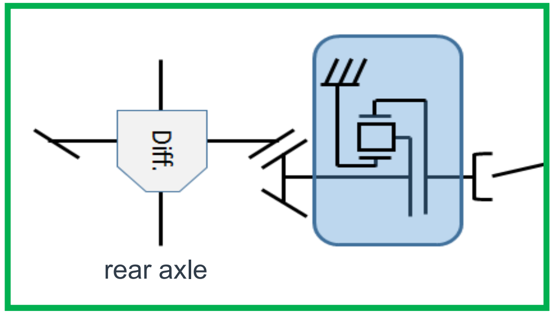
Concept finding

Boundary conditions

- Electric motor & transmission:

Max. engine speed	Max. engine torque	Total transmission ratio
3000 min^{-1}	3500 Nm	≈ 7.5

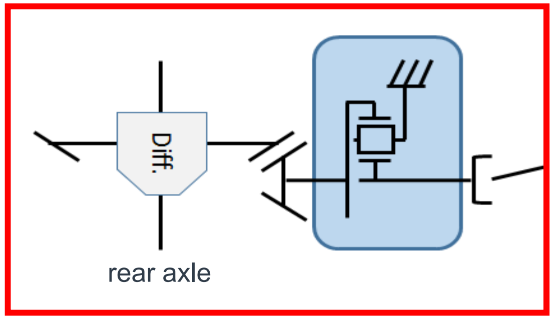
- Investigations on different transmission concepts (e.g. approaches with spur gears)
  → planetary gearbox chosen because of package reasons
- Consideration of different planetary gearbox topologies:



i_{2S} = 1.5…1.6

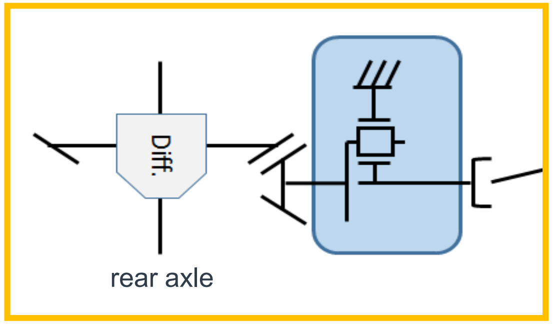
$n_1 = 0$

→ Chosen concept
→ Hypoid gear set i ≈ 4.6



i_{12} = -1.7 …-2.4
$n_{carrier} = 0$
$T_{carrier}$ = 10500 Nm

→ Load on housing too high



i_{1S} = 2.5…3.0

$n_2 = 0$

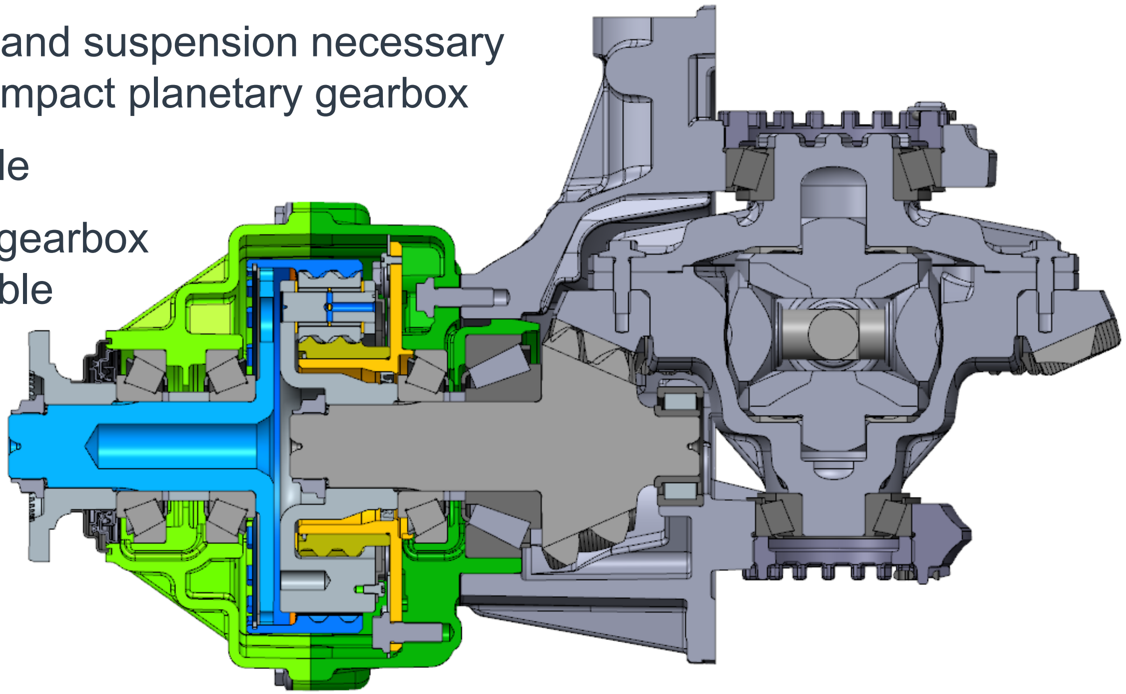
→ No suitable hypoid gear set in portfolio

Gearbox design

Modular concept

- Replacement of pinion housing with new planetary gearbox
- Carry-over of proven pinion shaft design and bearings
- Advantages:
    - Usage of an existing, already tested and homologated axle as basis
    - No changes at chassis frame and suspension necessary because of lightweight and compact planetary gearbox
    - Assembly at serial line possible
    - Combination of the planetary gearbox with different axle ratios possible
    - Adaption of this concept to all types of driven axles for truck & bus possible

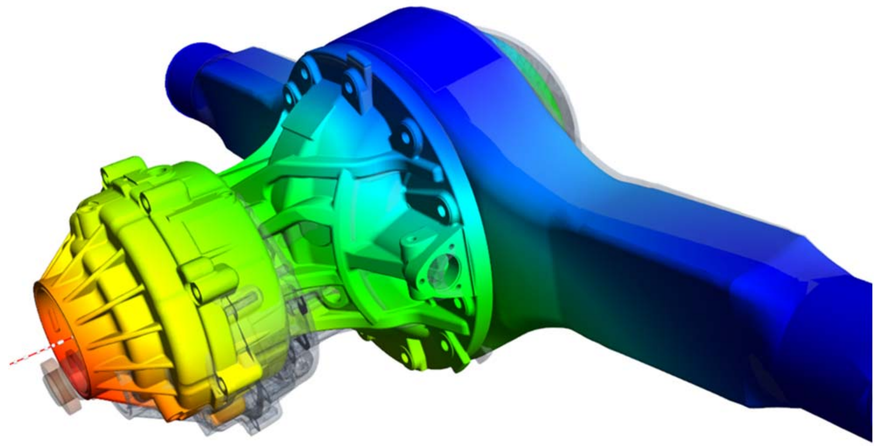
➢ **Reduction of development time and costs**

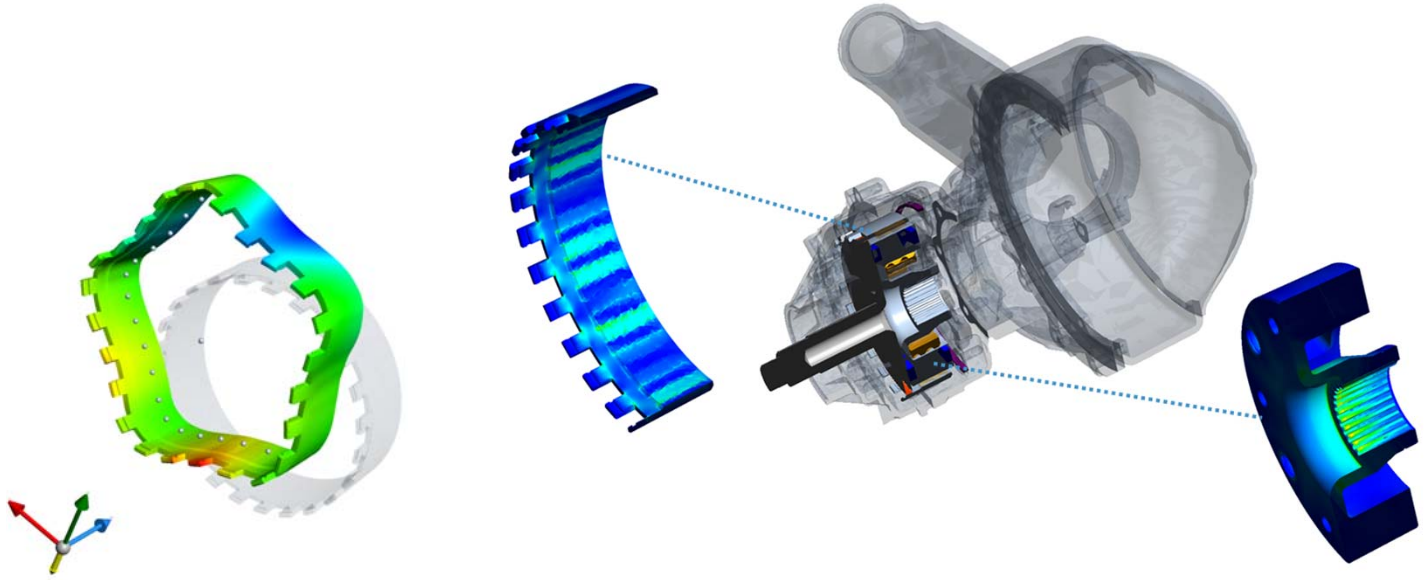


Gearbox design

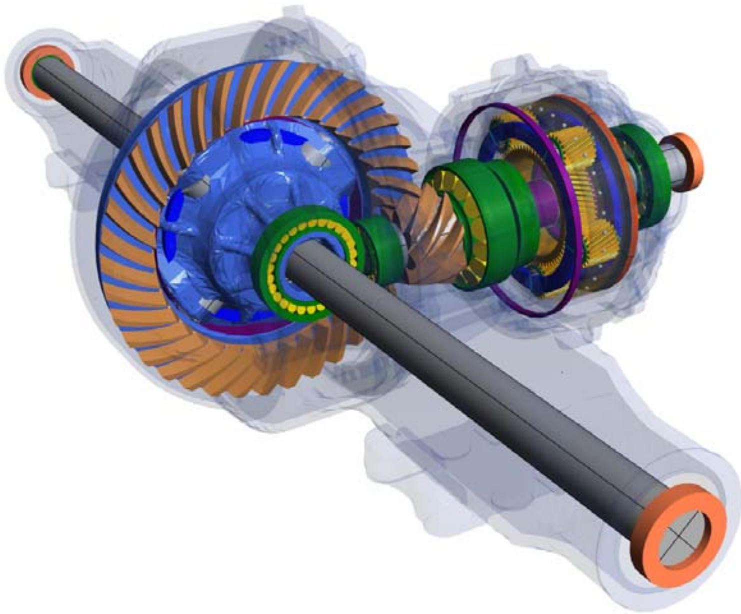
FE calculation for complex elements

- Calculation of deformation and stress for complex shafts and housing by means of FE
- Flexible mounting of the annulus in order to ensure good load sharing between the 5 planets



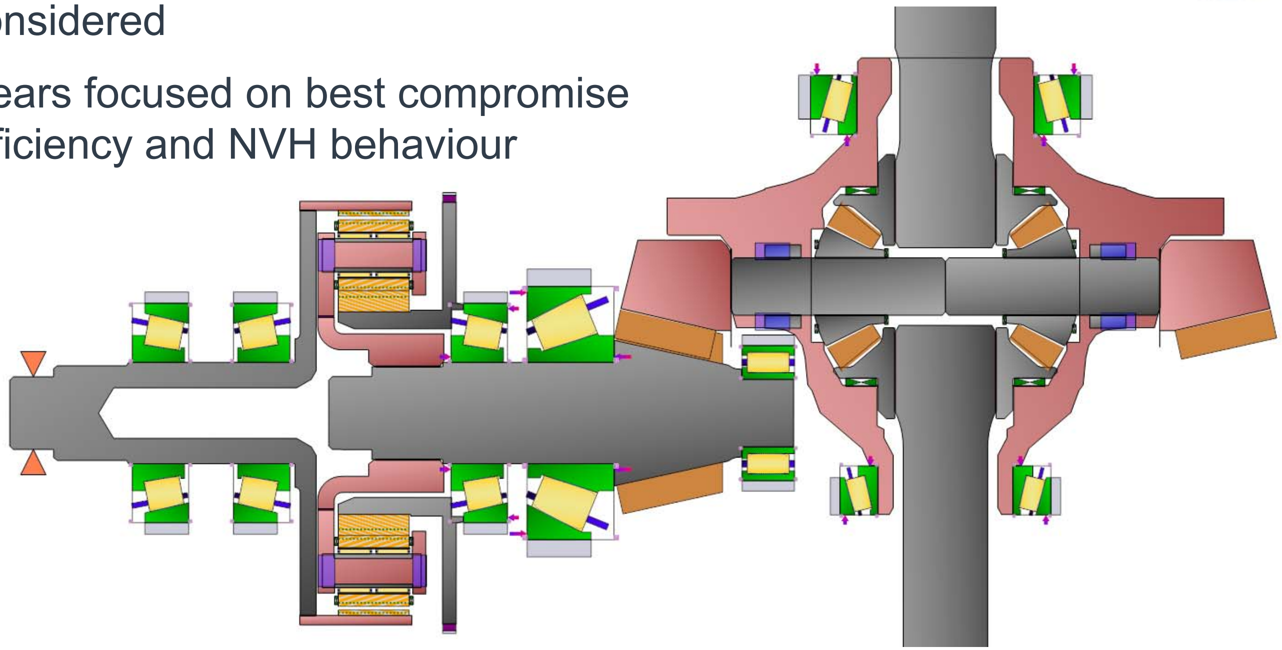


Gearbox design



Dimensioning of gears and bearings

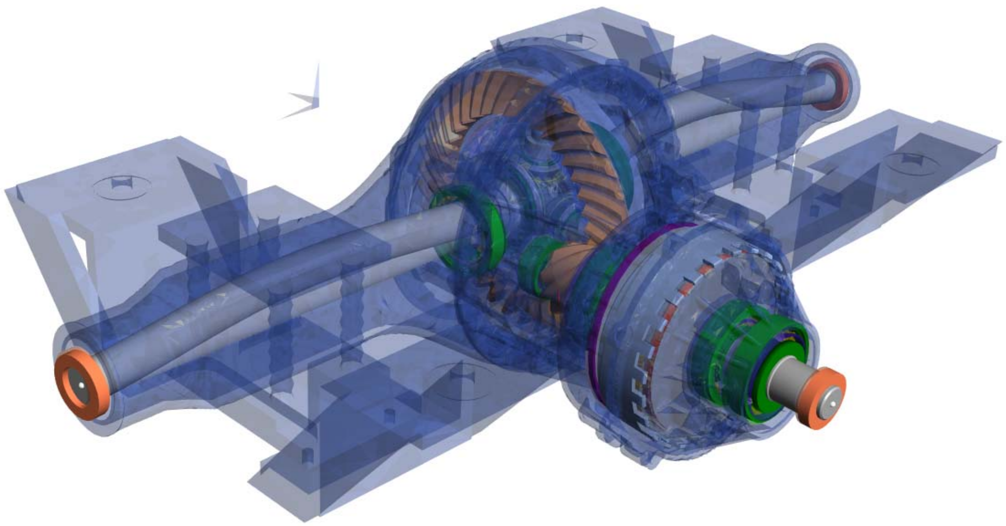
- Design of gears and bearings based on a measured load cycle of heavy urban application
- Deformation under load considered
  → usage of FE components for complex elements
- Additional forces induced by adjustments of the propeller shaft also considered
- Modifications of the gears focused on best compromise regarding strength, efficiency and NVH behaviour



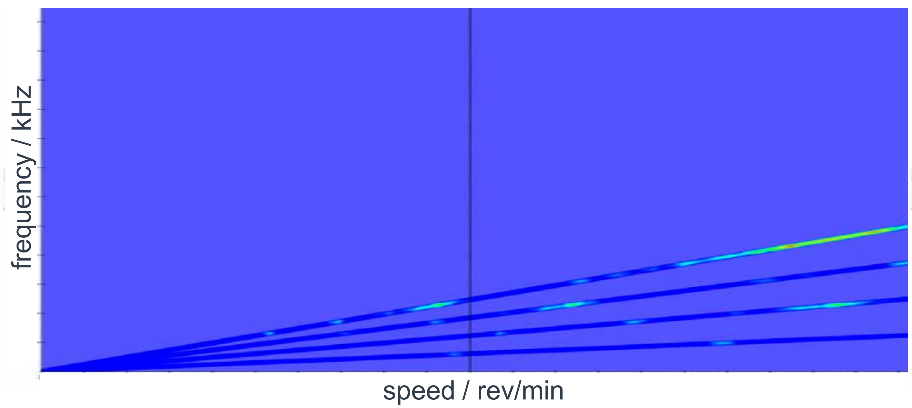
NVH Behaviour

Simulation of the acoustic behaviour

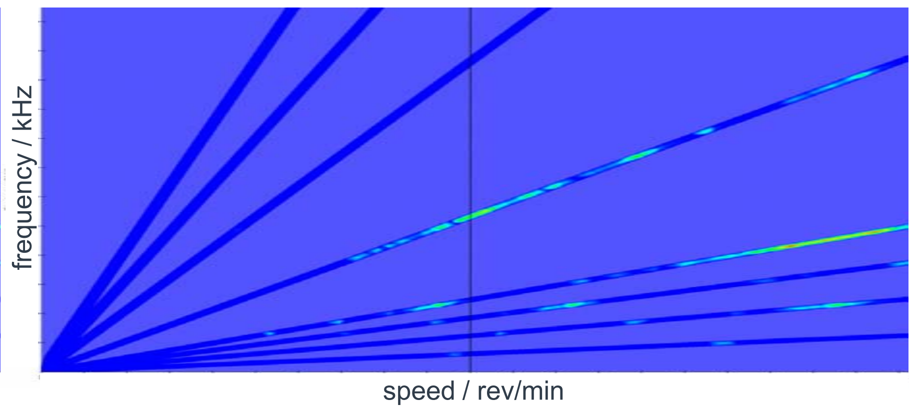
- Simulation of run-up for different load conditions
- Comparison of the acceleration of the axle housing with and without the additional planetary gear stage
- No significant worsening of the acoustic behavior due to planetary gear stage expected



without planetary gear stage (conventional drivetrain)



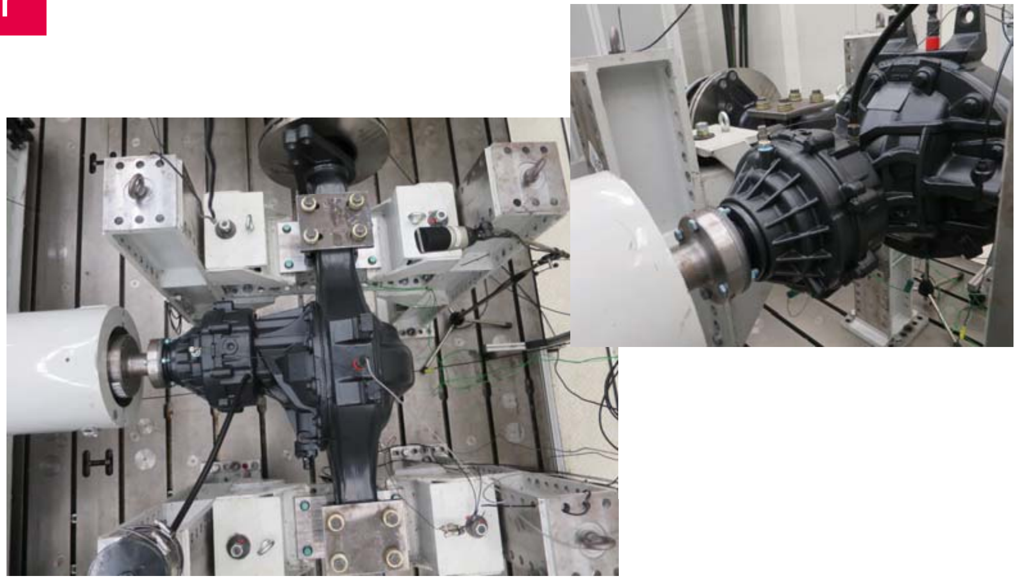
with planetary gear stage (electric drivetrain)

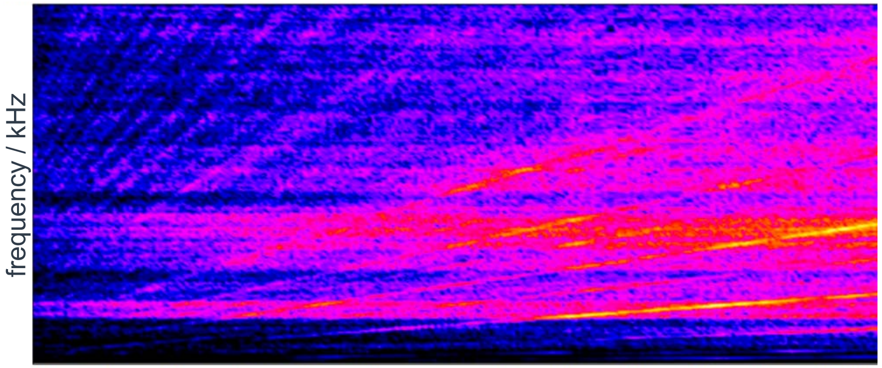


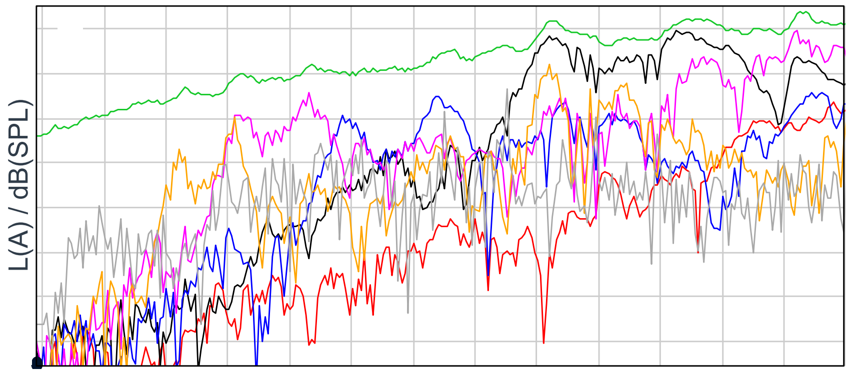
NVH Behaviour

Measurements of the acoustic behaviour

- Extensive measurements of the airborne noise have been performed at the MAN axle test rig
- Results of simulation confirmed: additional planetary gear stage does not lead to an increased noise level
- Internal limiting values for the noise emission of axles were met



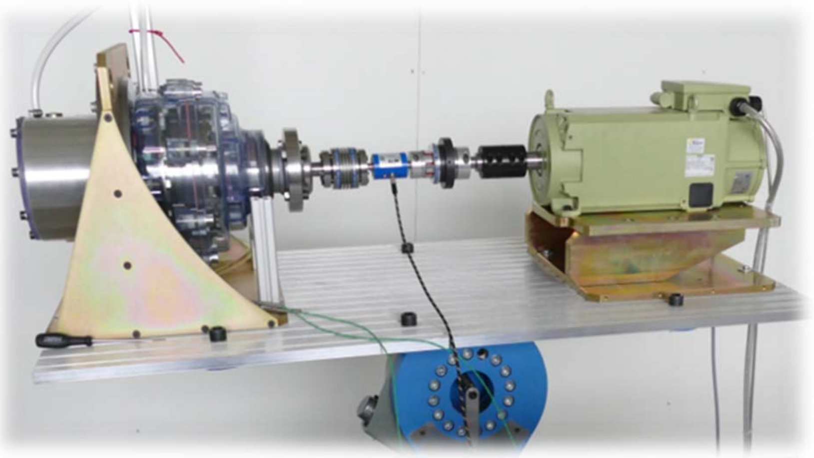


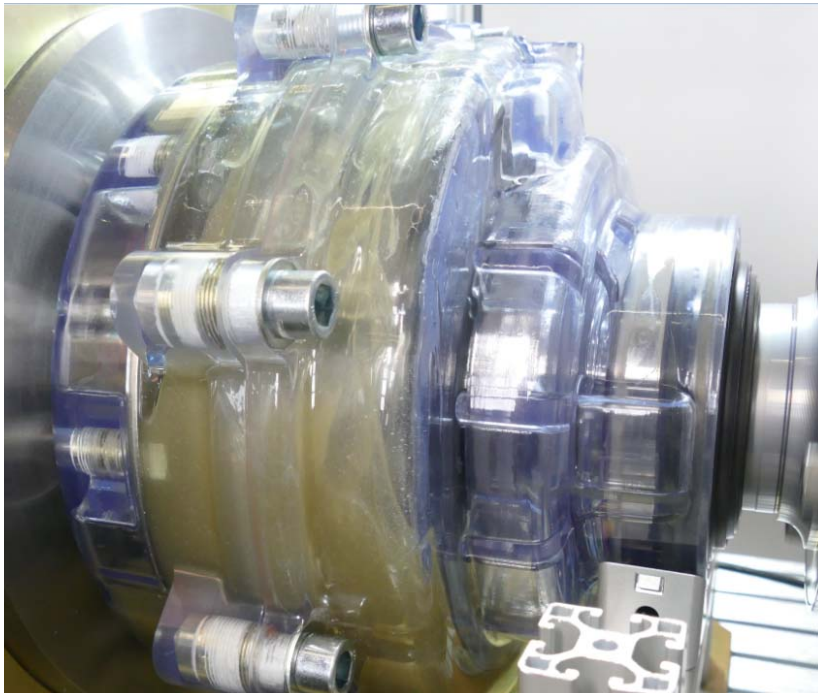


Lubrication and efficiency

Tests with transparent gearbox housing

- Extensive tests have been conducted in order to determine the optimum of the oil level for the planetary gear stage
- Lubrication of gears and bearings under all operating conditions ensured
- Optimization of measures to reduce gearbox losses due to windage and churning at high rotational speeds

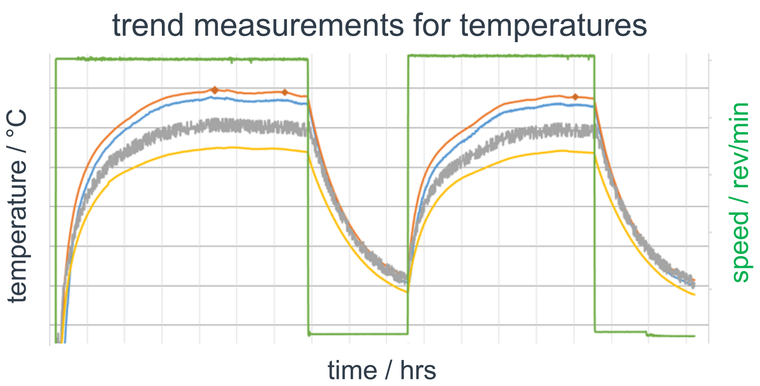




Lubrication and efficiency

Calculation of gearbox efficiency, losses and expected oil temperatures

- Calculation of gearbox efficiency and power loss maps
- Estimation of the maximum oil temperature based on the gearbox losses
- Oil temperature is not expected to reach critical values
- Confirmation by test results



Efficiency:

Annulus Torque / Nm \ Annulus Speed / min^{-1}	50	150	300	500	1000	1500	2000	2500	2700	2950	3000
3500	99,19	99,19	99,18	99,22	99,39	99,44	99,48	99,53	99,55	99,58	99,58
3250	99,17	99,16	99,15	99,20	99,37	99,42	99,45	99,51	99,53	99,56	99,56
3000	99,14	99,13	99,12	99,17	99,34	99,39	99,43	99,49	99,51	99,54	99,55
2750	99,11	99,10	99,09	99,13	99,31	99,36	99,40	99,46	99,49	99,52	99,52
2500	99,07	99,06	99,05	99,09	99,27	99,32	99,36	99,43	99,46	99,49	99,49
2250	99,02	99,02	99,00	99,05	99,23	99,28	99,32	99,39	99,42	99,46	99,46
2000	98,97	98,96	98,94	98,99	99,18	99,22	99,26	99,34	99,38	99,42	99,42
1750	98,90	98,89	98,87	98,92	99,11	99,15	99,20	99,28	99,32	99,37	99,37
1500	98,84	98,83	98,81	98,85	99,04	99,07	99,11	99,21	99,25	99,30	99,31
1250	98,76	98,75	98,72	98,76	98,94	98,96	99,00	99,11	99,16	99,22	99,22
1000	98,67	98,66	98,62	98,66	98,81	98,81	98,85	98,97	99,03	99,10	99,11
750	98,56	98,54	98,49	98,51	98,62	98,58	98,60	98,75	98,83	98,91	98,92
500	98,34	98,31	98,24	98,23	98,23	98,11	98,12	98,31	98,43	98,55	98,56
250	97,65	97,59	97,46	97,34	97,05	96,70	96,64	96,99	97,20	97,43	97,45

Power loss:

Annulus Torque / Nm \ Annulus Speed / min^{-1}	50	150	300	500	1000	1500	2000	2500	2700	2950	3000
3500	0,15	0,45	0,90	1,42	2,24	3,08	3,84	4,32	4,43	4,56	4,60
3250	0,14	0,43	0,86	1,37	2,15	2,98	3,72	4,18	4,28	4,40	4,44
3000	0,14	0,41	0,83	1,31	2,07	2,88	3,60	4,04	4,13	4,25	4,29
2750	0,13	0,39	0,79	1,25	1,99	2,77	3,47	3,90	3,99	4,09	4,13
2500	0,12	0,37	0,75	1,19	1,90	2,67	3,35	3,76	3,84	3,93	3,97
2250	0,12	0,35	0,71	1,12	1,81	2,56	3,22	3,61	3,68	3,77	3,80
2000	0,11	0,33	0,66	1,06	1,72	2,44	3,08	3,46	3,52	3,60	3,64
1750	0,10	0,30	0,62	0,99	1,63	2,33	2,95	3,30	3,36	3,43	3,46
1500	0,09	0,28	0,56	0,90	1,51	2,19	2,78	3,12	3,17	3,23	3,26
1250	0,08	0,25	0,50	0,81	1,39	2,04	2,61	2,92	2,97	3,02	3,05
1000	0,07	0,21	0,43	0,70	1,25	1,87	2,41	2,70	2,74	2,78	2,81
750	0,06	0,17	0,35	0,58	1,09	1,68	2,19	2,46	2,48	2,52	2,54
500	0,04	0,13	0,28	0,46	0,93	1,48	1,97	2,21	2,22	2,24	2,26
250	0,03	0,09	0,20	0,35	0,77	1,30	1,76	1,97	1,98	1,98	2,00

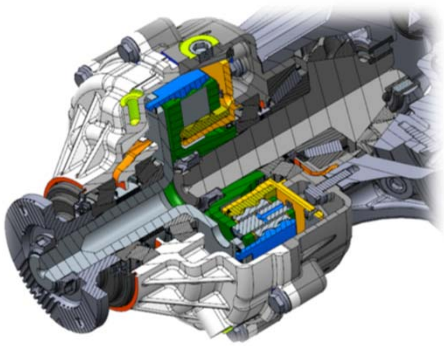
Oil temperature:

area not relevant for this drivetrain

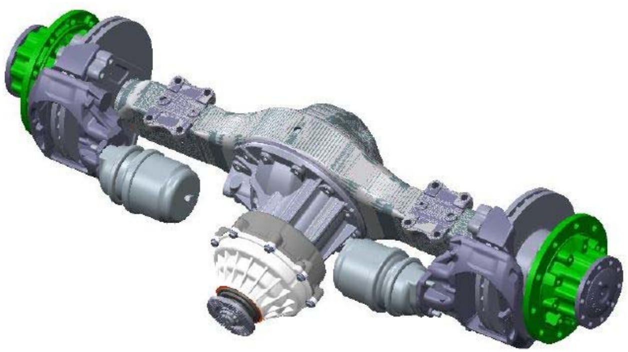
Annulus Torque / Nm \ Annulus Speed / min^{-1}	50	150	300	500	1000	1500	2000	2500	2700	2950	3000
3500	22,99	57,02	91,07	116,76	137,33	154,73	163,02	163,38	161,50	159,22	159,19
3250	22,13	55,14	88,32	113,46	133,91	151,30	159,59	159,86	157,93	155,60	155,57
3000	21,26	53,21	85,49	110,07	130,43	147,82	156,13	[illegible]	[illegible]	151,95	151,91
2750	20,35	51,20	82,54	106,53	126,83	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	148,18
2500	19,41	49,10	79,44	102,82	123,07	140,51	148,88	148,93	146,86	144,36	144,33
2250	18,43	46,89	76,18	98,90	119,12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	140,32
2000	17,40	44,55	72,71	94,74	114,97	132,53	141,03	140,95	138,77	136,17	136,12
1750	16,31	42,06	69,00	90,30	110,55	128,22	136,80	136,66	134,43	131,77	131,73
1500	14,94	38,88	64,24	84,59	105,02	122,91	[illegible]	131,51	129,23	126,52	126,48
1250	13,43	35,33	58,89	78,17	98,87	117,06	126,04	[illegible]	123,55	120,77	120,74
1000	11,64	31,07	52,41	70,31	[illegible]	[illegible]	[illegible]	[illegible]	116,06	[illegible]	[illegible]
750	9,59	26,06	44,69	61,05	82,90	102,16	111,85	111,79	109,32	106,43	106,41
500	7,48	20,76	36,38	51,01	73,65	93,57	103,73	103,68	101,11	98,12	98,11
250	5,37	15,29	27,63	40,42	64,21	85,01	95,71	95,68	92,99	89,87	89,87

Quality and production

High quality standards, assembly at serial production line



- High quality standards
  for manufacturing and assembly
- Quality assurance by detailed documentation of component measurements and assembly process
  → good traceability
- Final assembly of axles at **serial assembly line** in Munich MAN plant



Summary and outlook

Next steps

- Delivery of the e-trucks to the customers
- Close surveillance and support of the vehicles by MAN
- Gain field experience by measurement of BEV load cycles under realistic operating conditions in demanding transport application of trade, production and logistics companies
- Basis for future development of commercial vehicles with electric drivetrains