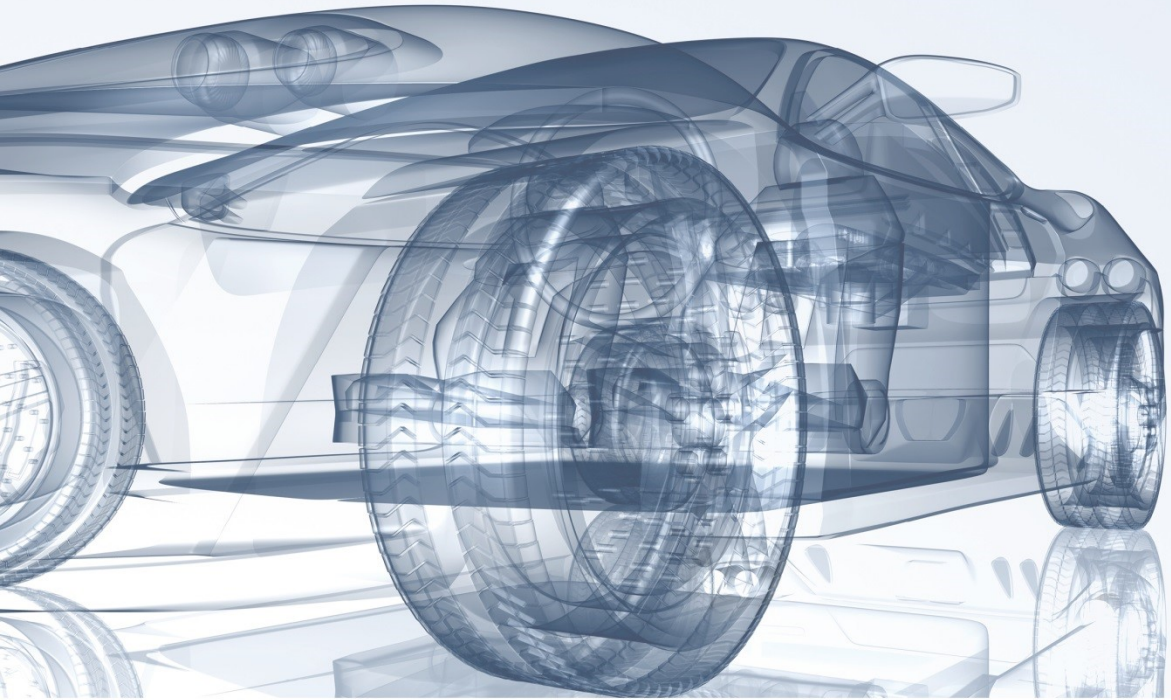
evs 30



The 30th International
Electric Vehicle
Symposium & Exhibition

October 9–11, 2017

Messe Stuttgart, Germany

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Design of a gearless wheel hub motor for BEV based on a switched reluctance machine

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EFRE.NRW
Investitionen in Wachstum und Beschäftigung

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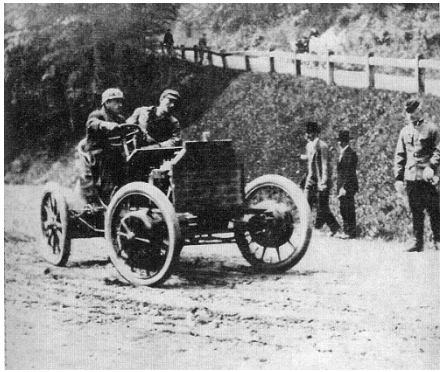
für regionale Entwicklung

Ministerium für Wirtschaft, Energie, Industrie, Mittelstand und Handwerk des Landes Nordrhein-Westfalen

Design of a gearless wheel hub motor for BEV based on a switched reluctance machine

- motivation, project-introduction
- design of first machine prototype
- measurements & results of first prototype
- final drive-unit design
- summary & outlook

motivation



modern BEV:

- „classic" single axle central motor drive
- permanent-magnet synchronous motor
- high vehicle costs

➢ low acceptance & interest

historical background (year 1900):

- gearless wheel hub motors
- DC-motor
- no friction brake included
- low power density
- high Mass

project targets

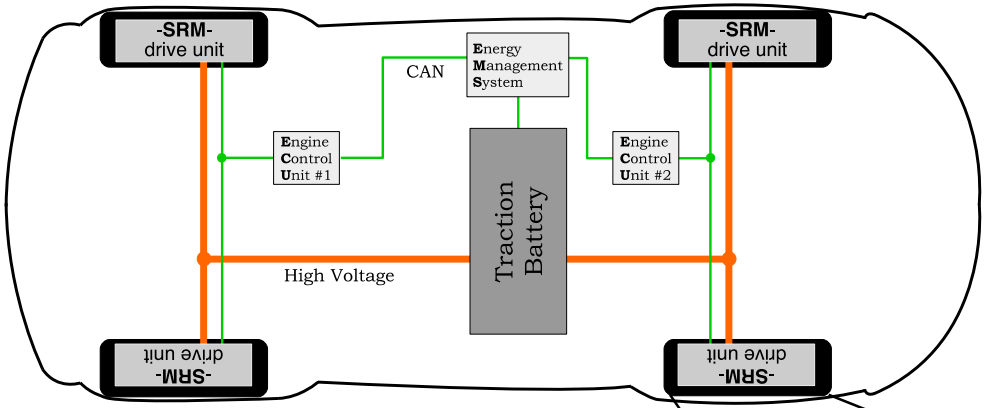
SR4Wheel:

- development of a single wheel drive
- based on a switched reluctance machine (SRM)
- integrated power electronics
- absolute identical installation space
- safe and redundant
- high efficiency
- low cost
- low weight

Why SRM?

- mechanical robust machine
- no permanent magnets
  - low cost, environment friendly and “price-stable”
  - no cogging torque

drivetrain-topology



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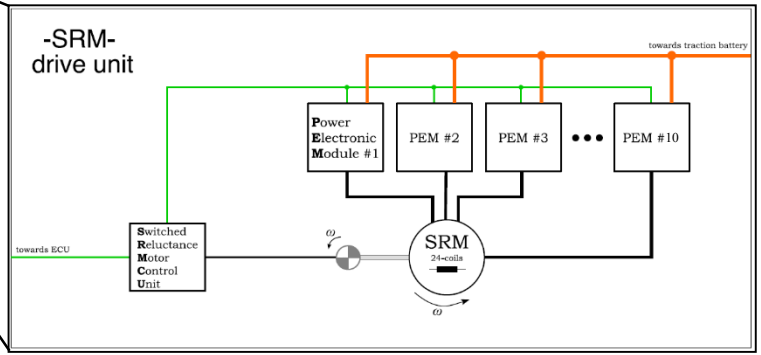

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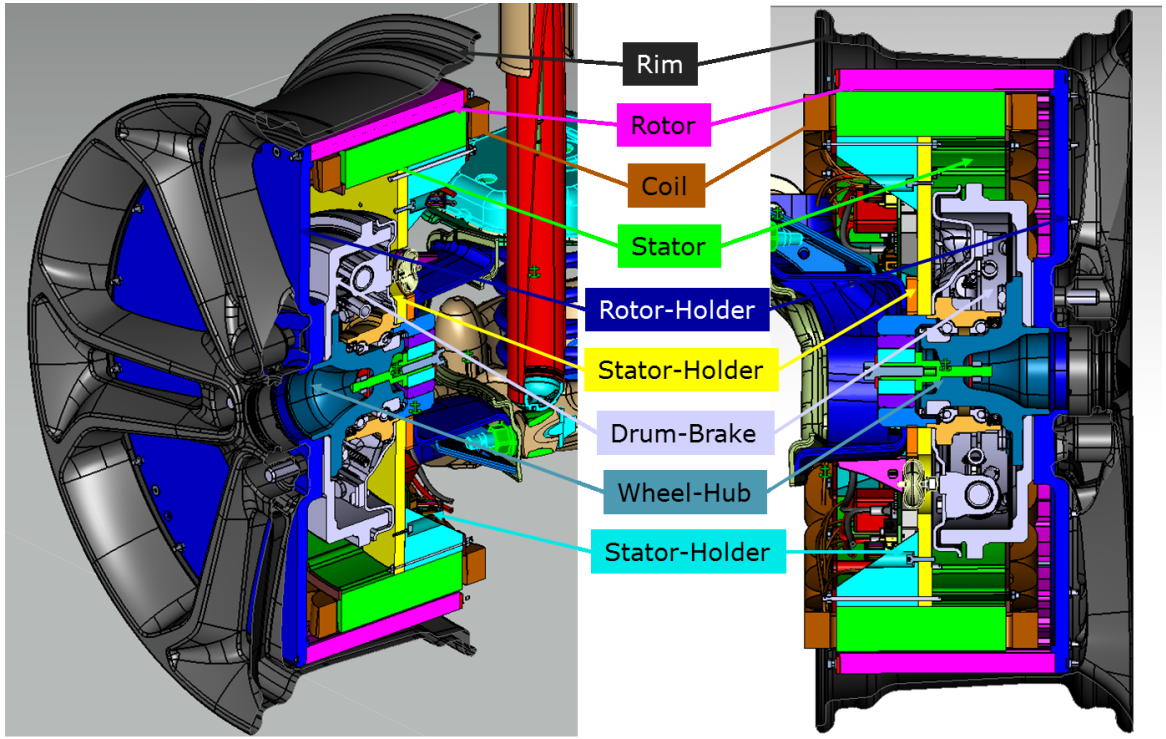
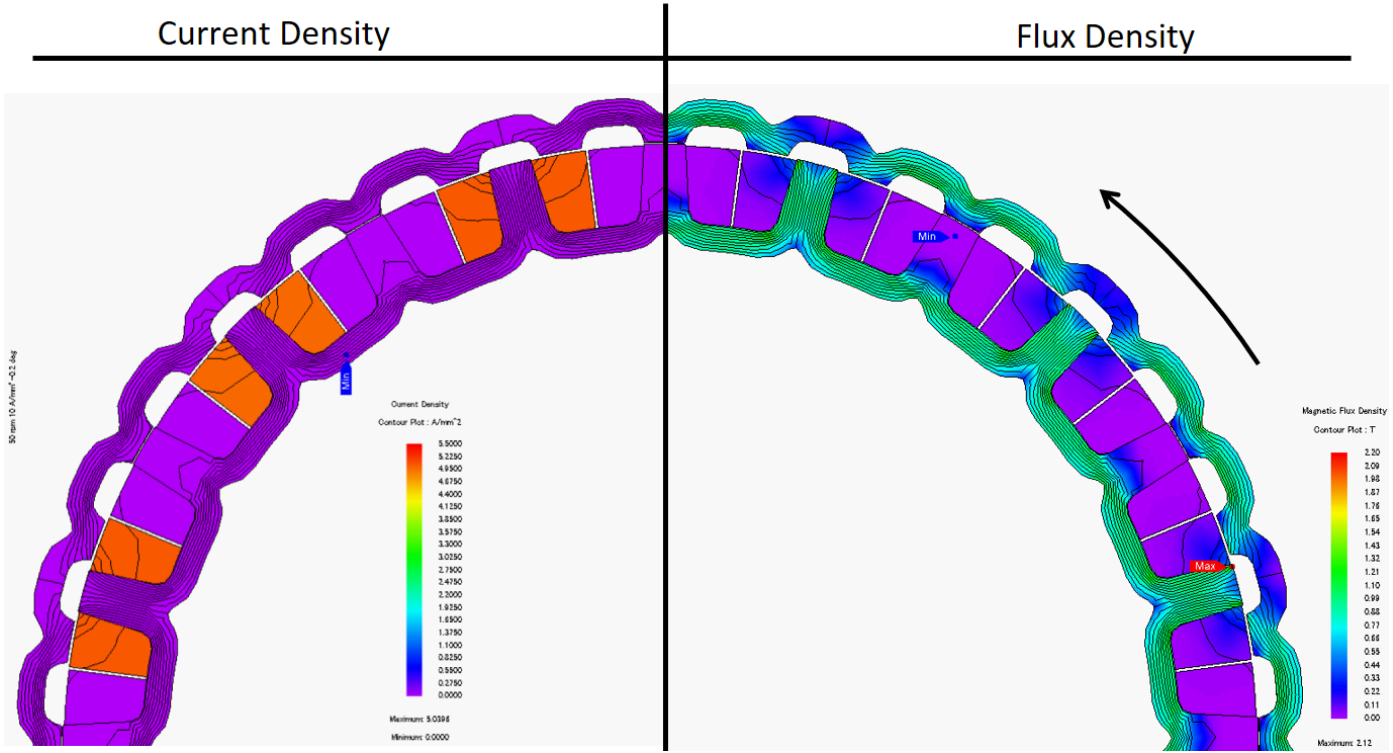
concept of „rim-machine“, first prototype



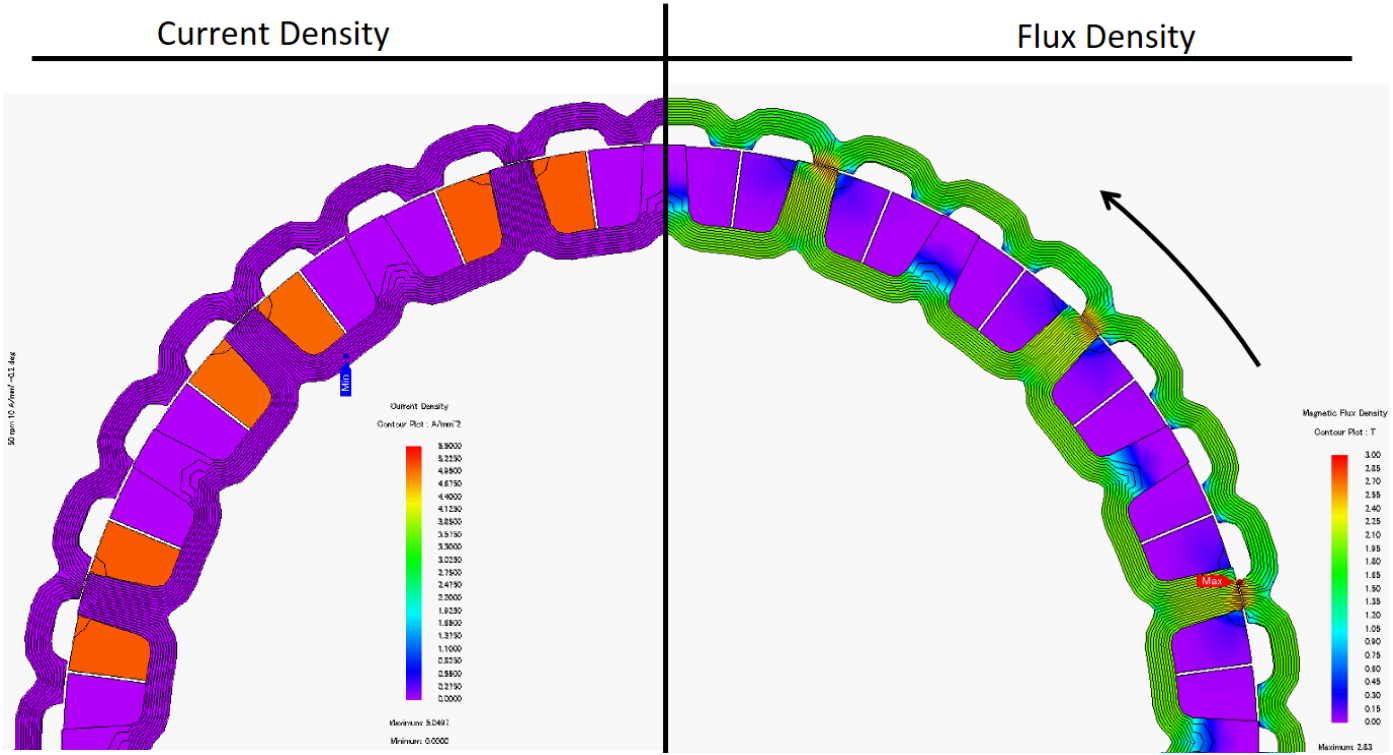
integration of an Outer-Rotor machine, instead of a “classical” Inner-Rotor type

- air gap radius increased
- no changes to friction brake needed
- use of original bearing system
- small axial volume
- fast upgrade possibility of ICE cars to (P)HEV, due to integrated power electronics and no changes to original car parts

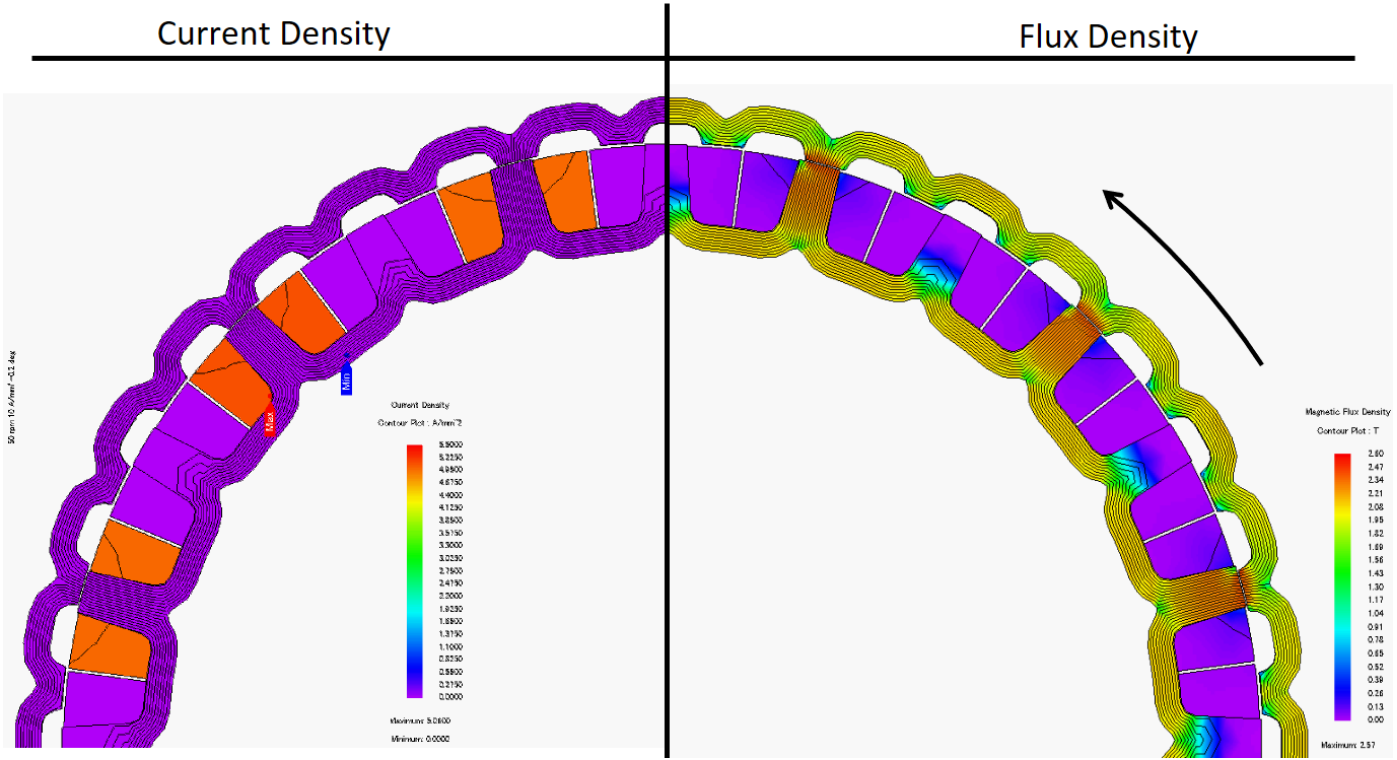
2-Phase SRM, function principle



2-Phase SRM, function principle

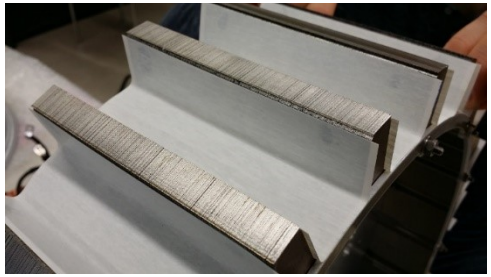


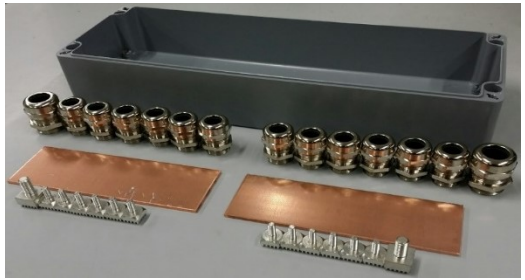
2-Phase SRM, function principle

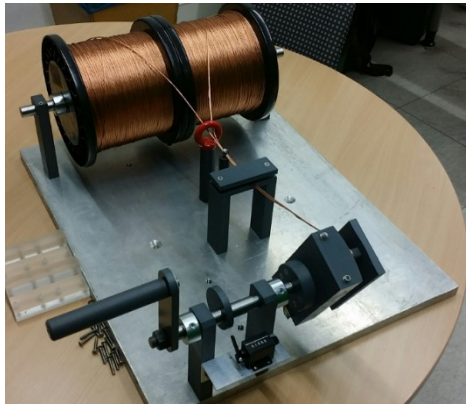


build up of first prototype

impressions of building process:







build up of first prototype

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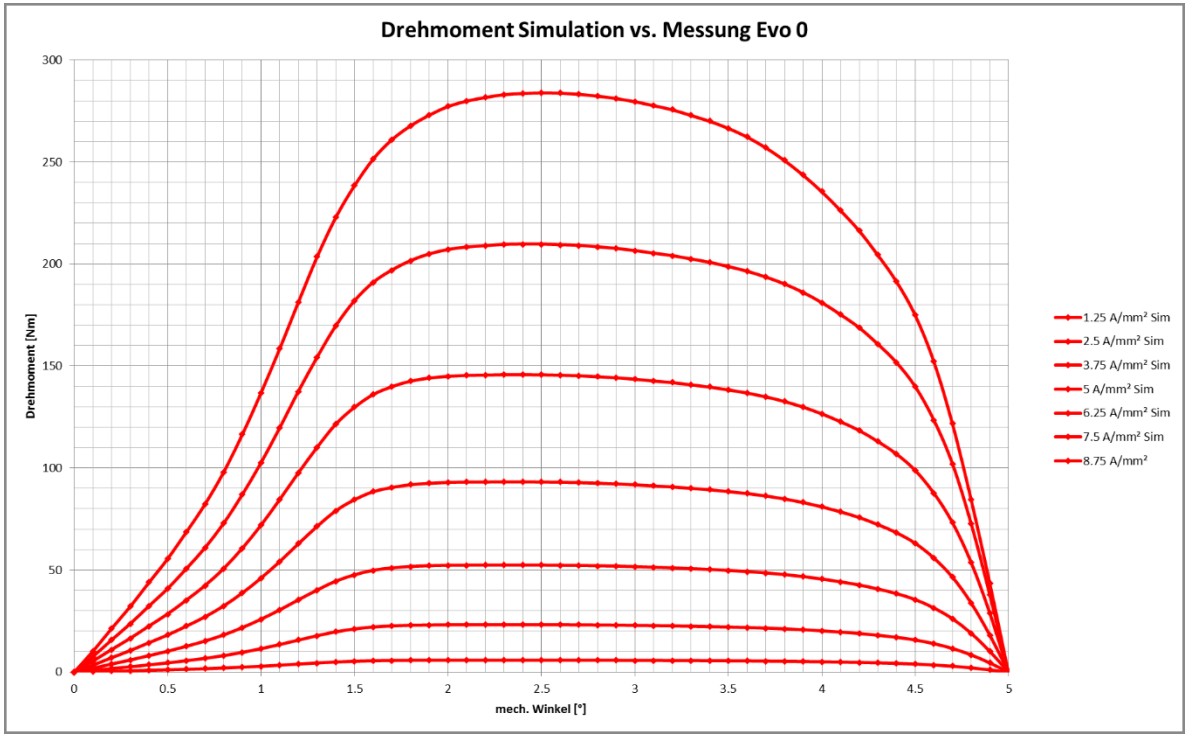
first measurement results

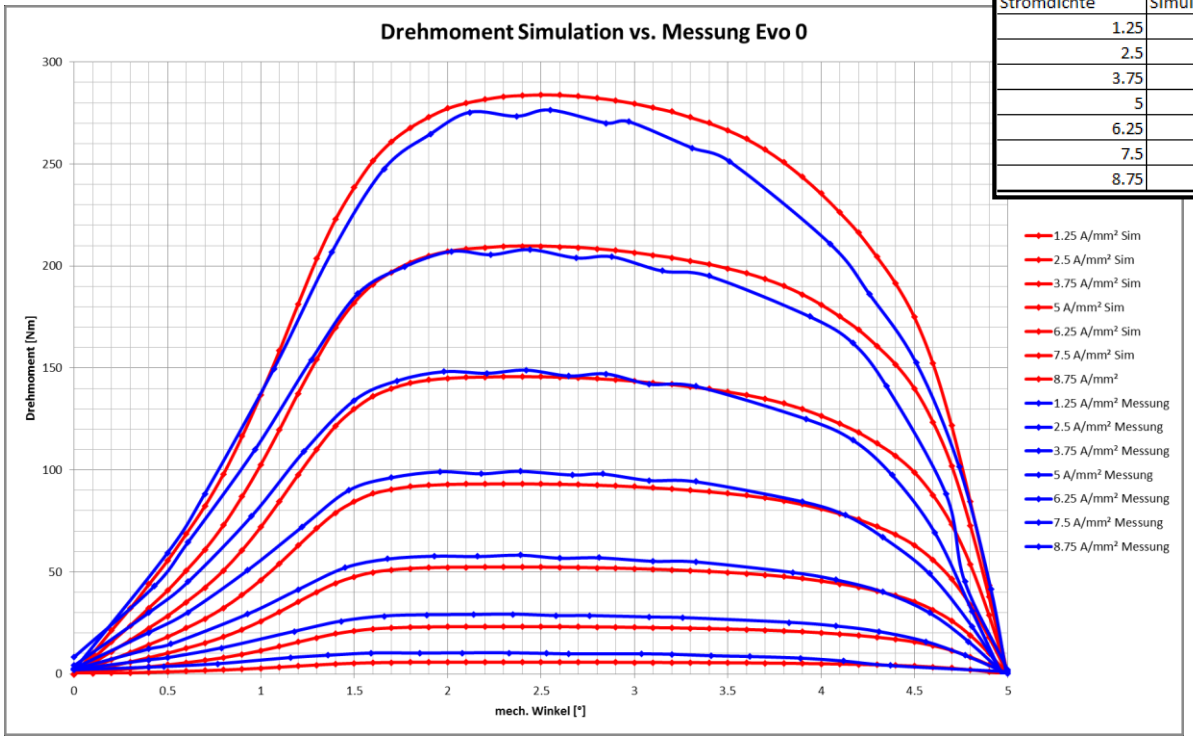
verification of standstill Torque-Shape:



first measurement results

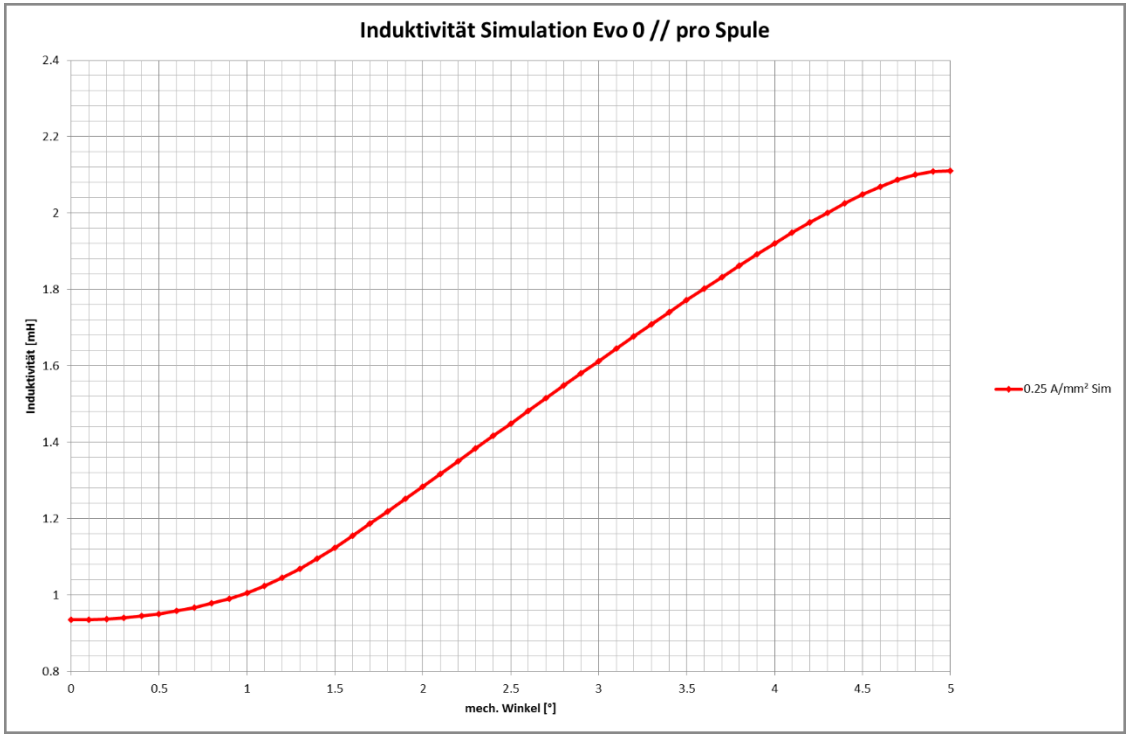
verification of standstill Torque-Shape:

Drehmoment Mittelwert			
Stromdichte	Simulation [Nm]	Messung [Nm]	Abweichung [%]
1.25	4.02	7.39	83.65
2.5	16.29	19.905	22.23
3.75	36.81	39.345	6.90
5	65.54	67.08	2.36
6.25	102.23	99.79	-2.39
7.5	148.70	140.11	-5.78
8.75	193.16	179.085	-7.29



first measurement results

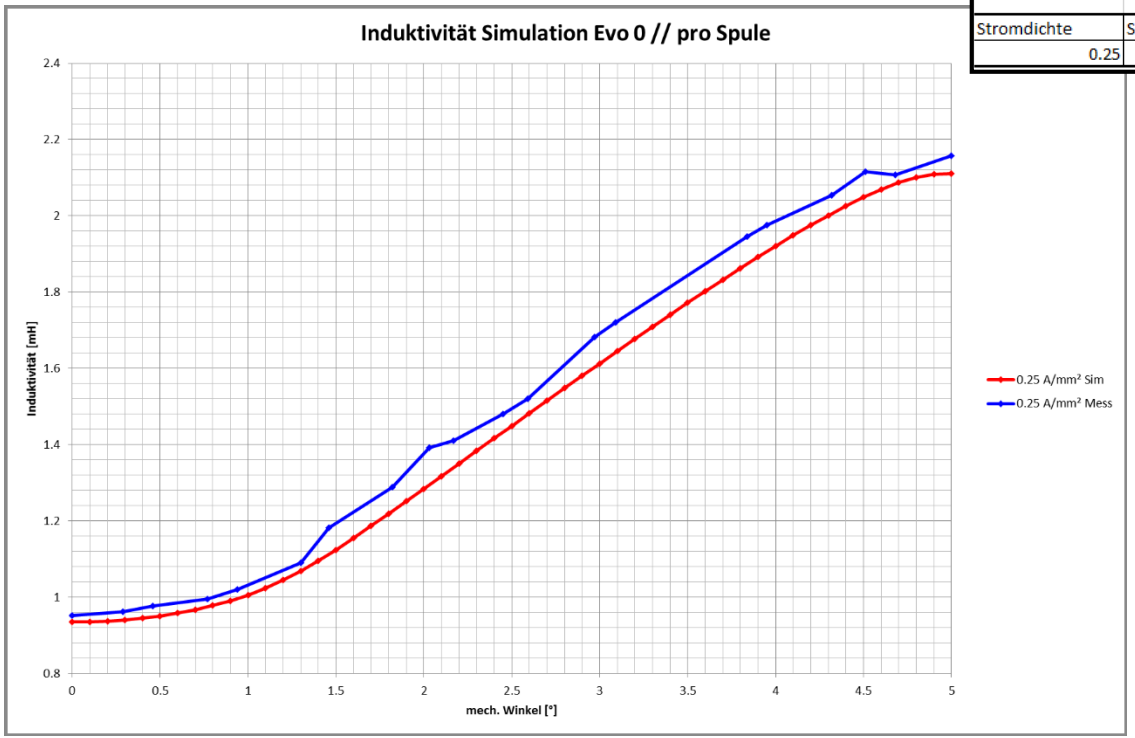
verification of un-saturated inductance of a single coil:



first measurement results

verification of un-saturated inductance of a single coil:

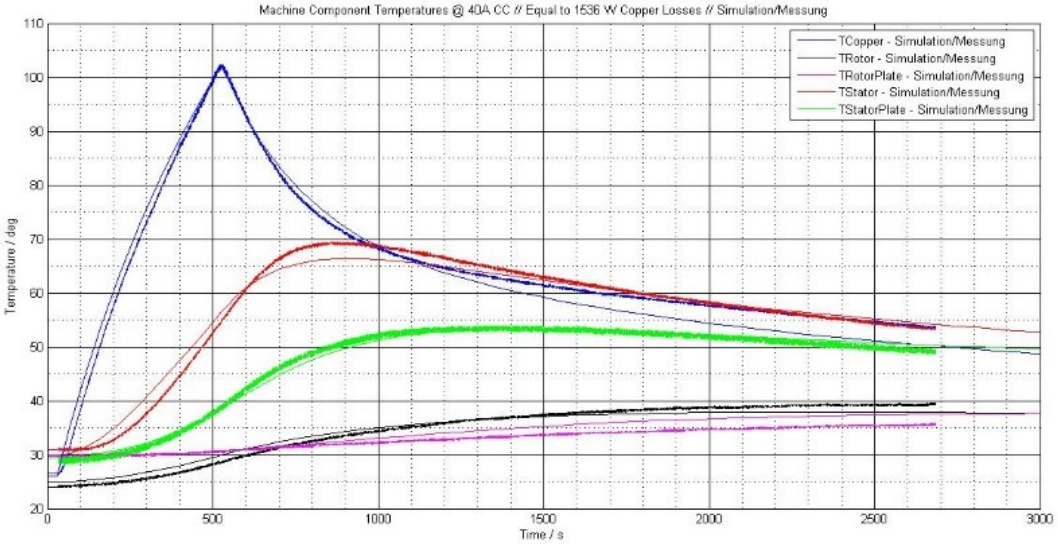
Induktivitäts-Abgleich (Mittelwert)			
Stromdichte	Simulation [mH]	Messung [mH]	Abweichung [%]
0.25	1.47	1.50	2.14

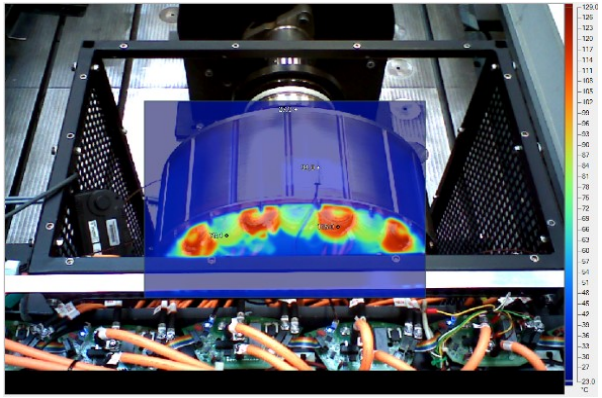


first measurement results

verification of multi-body thermal simulation:

- maximum offset ±3°C
- temperature-hotspot: Coil-head
- pure air cooling not sufficient to reach stable temperature level at desired working point





Liquid cooling needed

lessons-learned first prototype

Approved:
• temperature and magnetic FEA calculations successful validated • mechanical build-up & installation-space integration successful • maximum speed & peak-launch torque reached • programming & robust behaviour of distributed integrated power-electronics approved

To be improved:
• Torque-Ripple of a 2-Phase SRM too high, for comfortable NVH behaviour • no successful protection against harsh environments • no temperature saturation reached • machine weight high, to be implemented in unsprung wheel

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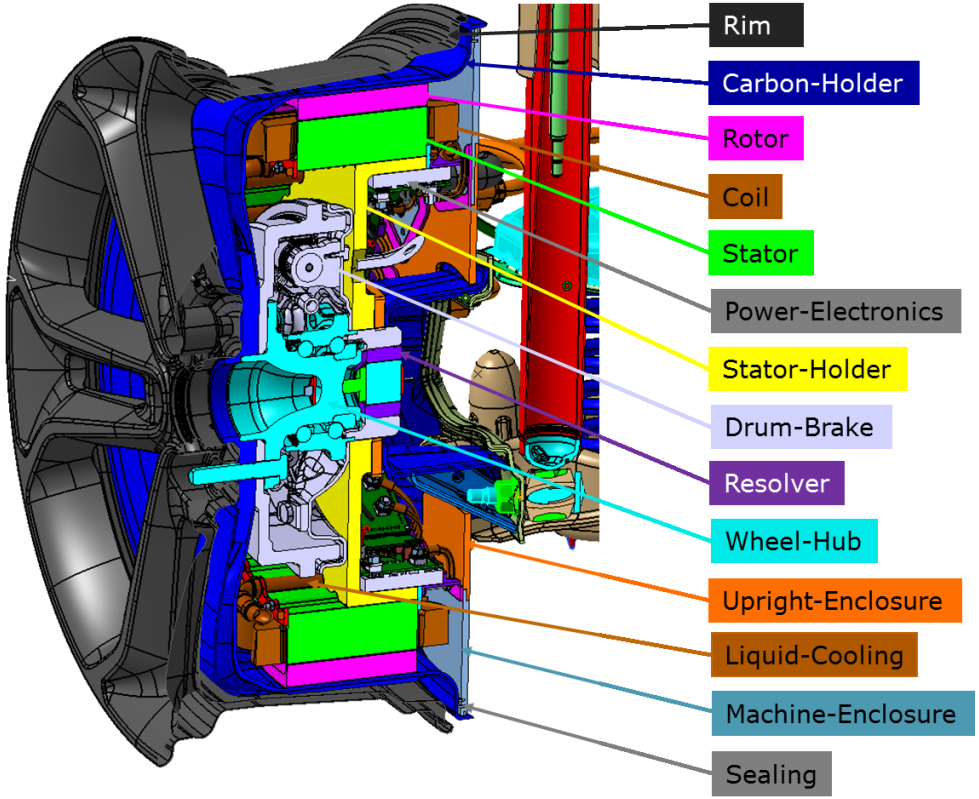
final drive unit design: mechanical layout

major changes:

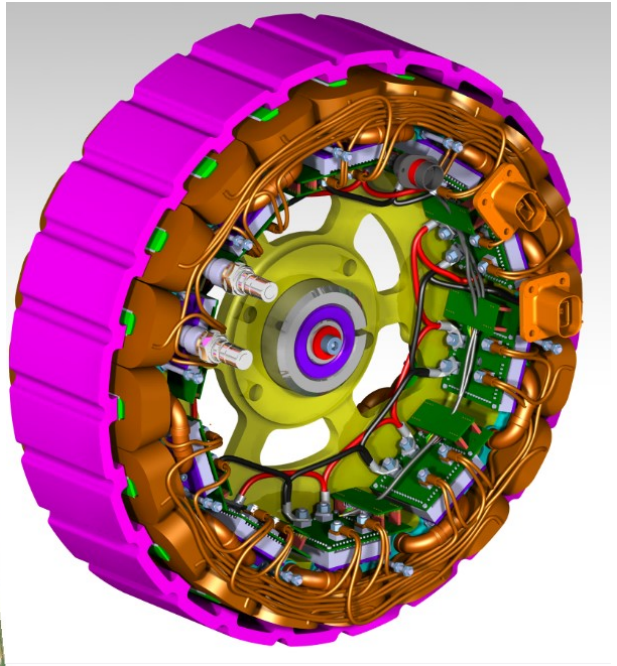
- liquid cooled machine
- carbon-fibre Rotor Holder
- full encapsulation against environment
- Five-Phase machine
- active machine length deceased by 30%
- increased performance

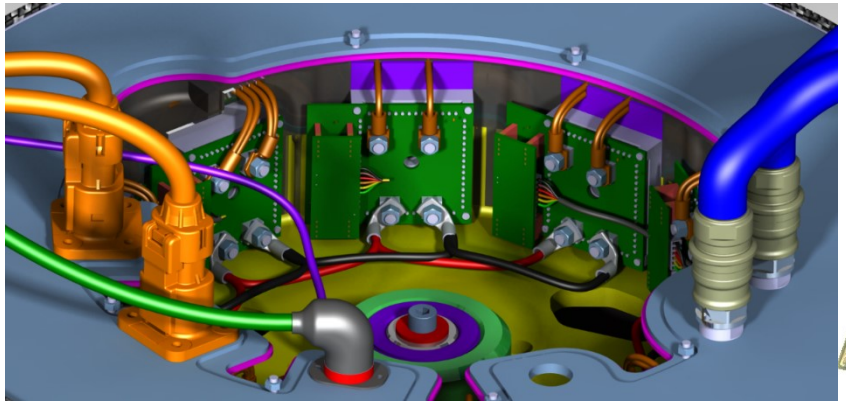


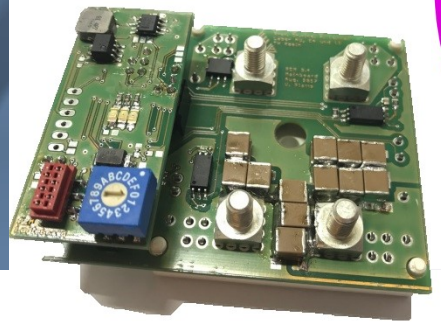
final drive unit design: power electronics

power electronics are completely integrated and ideal short attached to the windings:

- liquid cooling is placed between windings and power electronics
- two separate pcb‘s allow maximum service flexibility
  - base pcb for power-switching and peripherals
  - logic board attached on top of base pcb
- µController and software already approved on first prototype

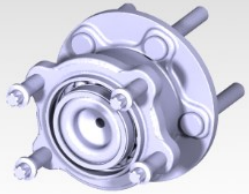






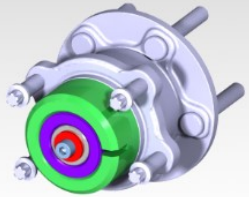
final drive unit design: virtual machine assembly

wheel-hub



final drive unit design: virtual machine assembly

resolver-integration



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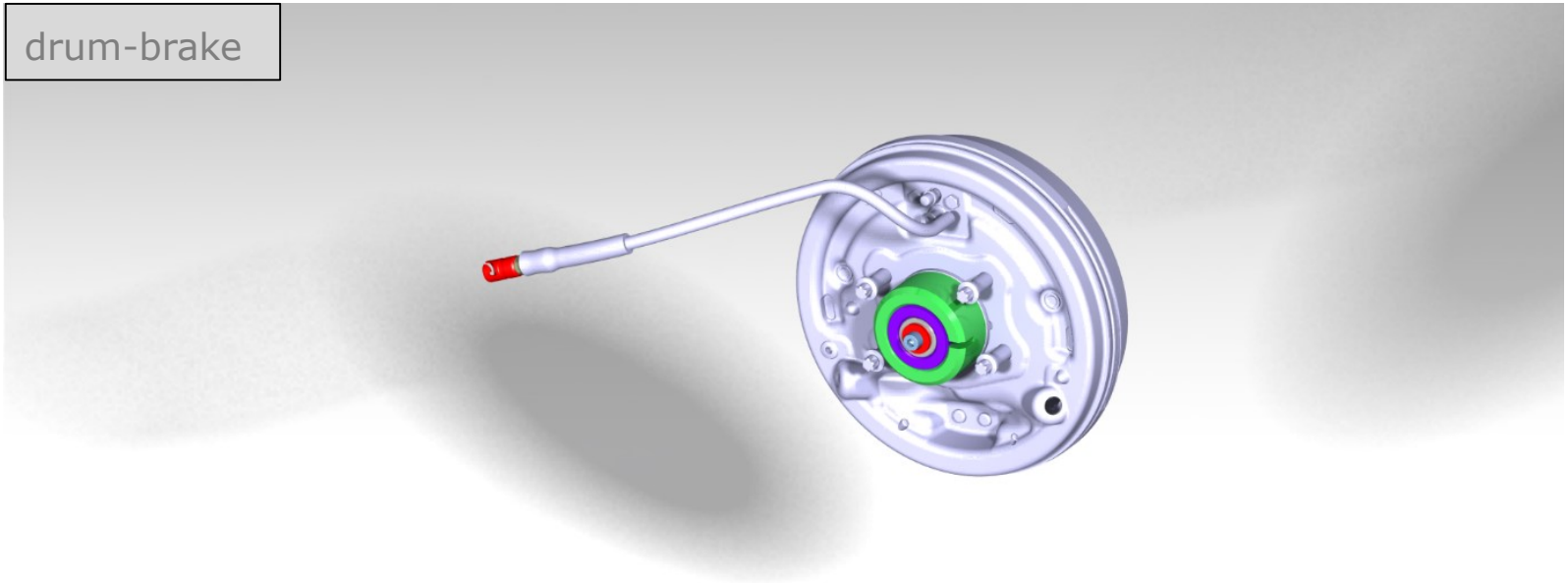

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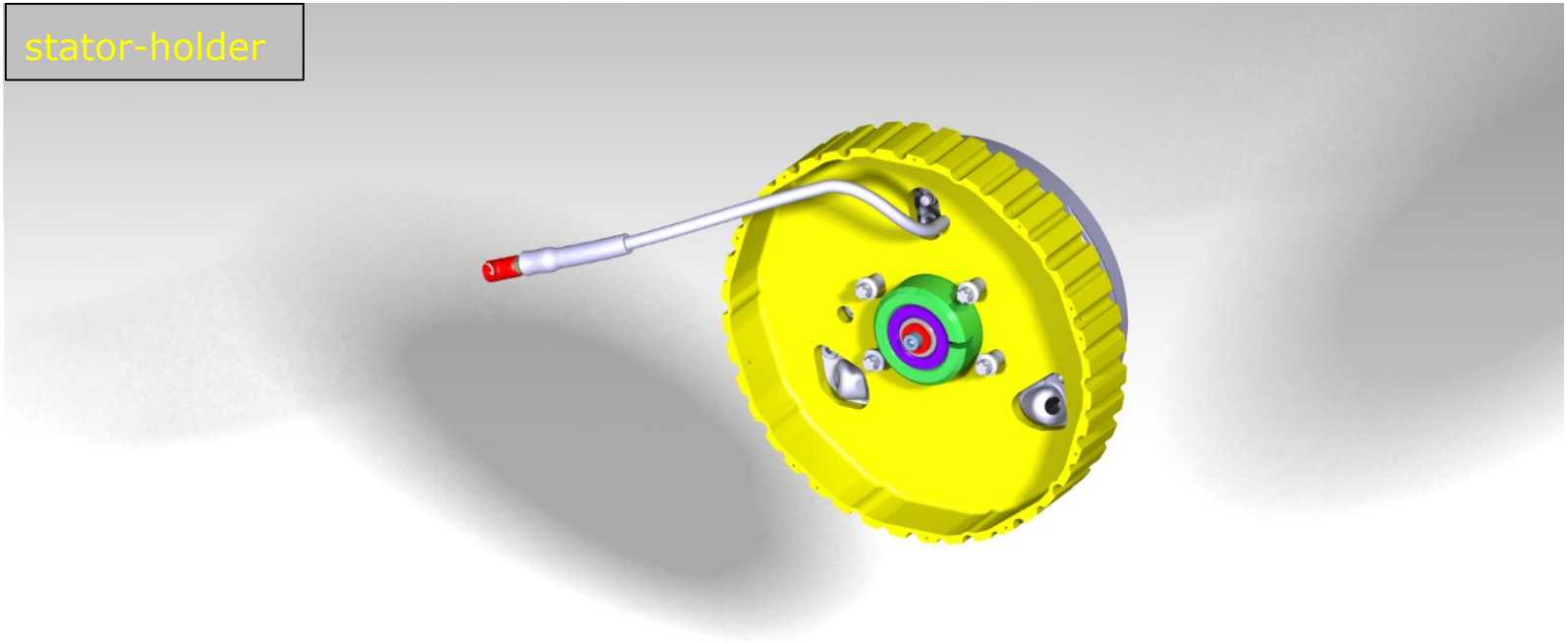

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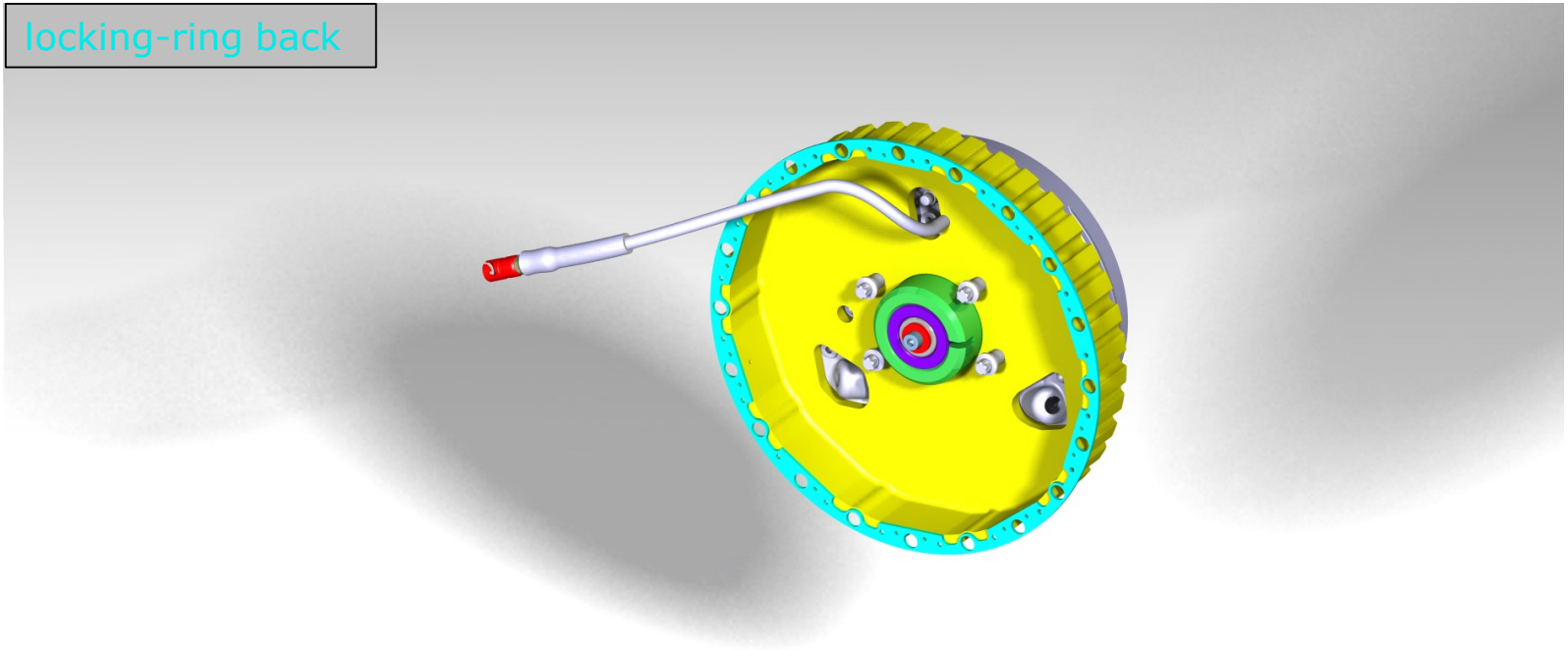

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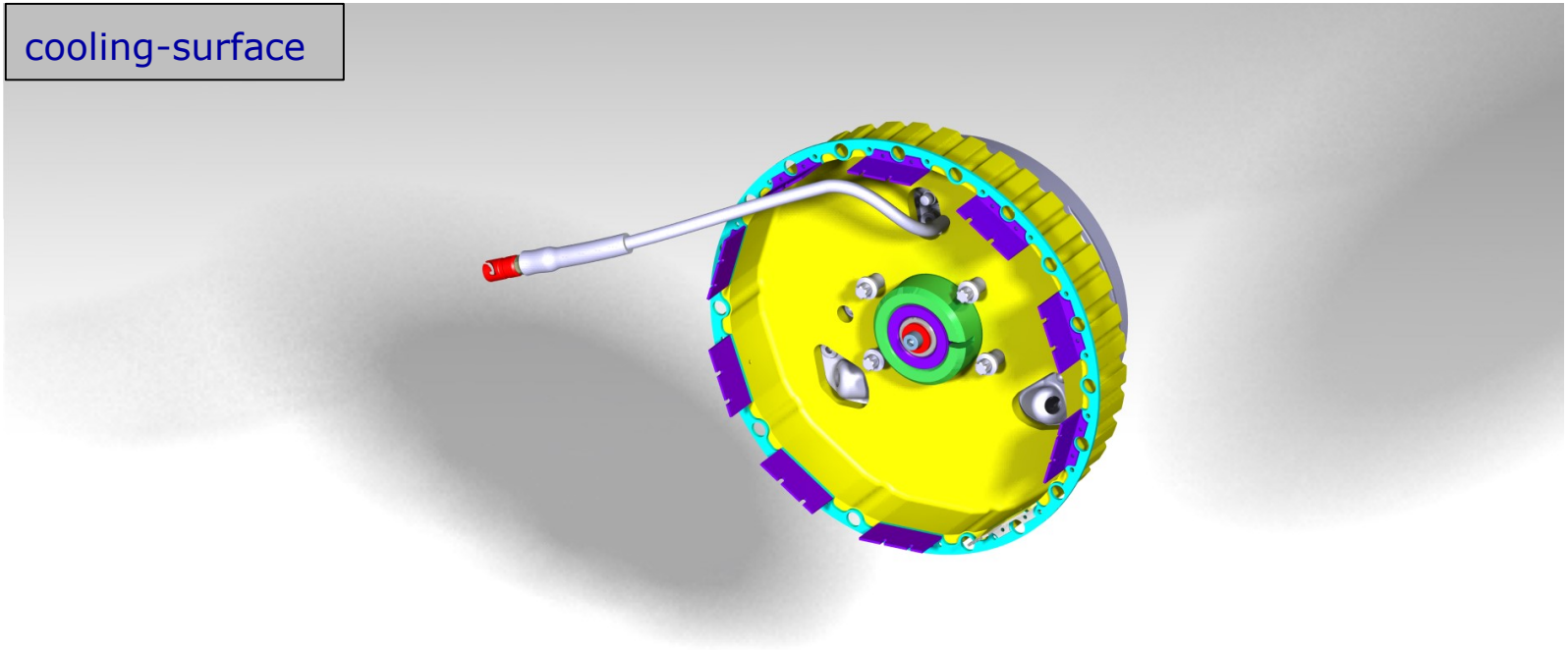

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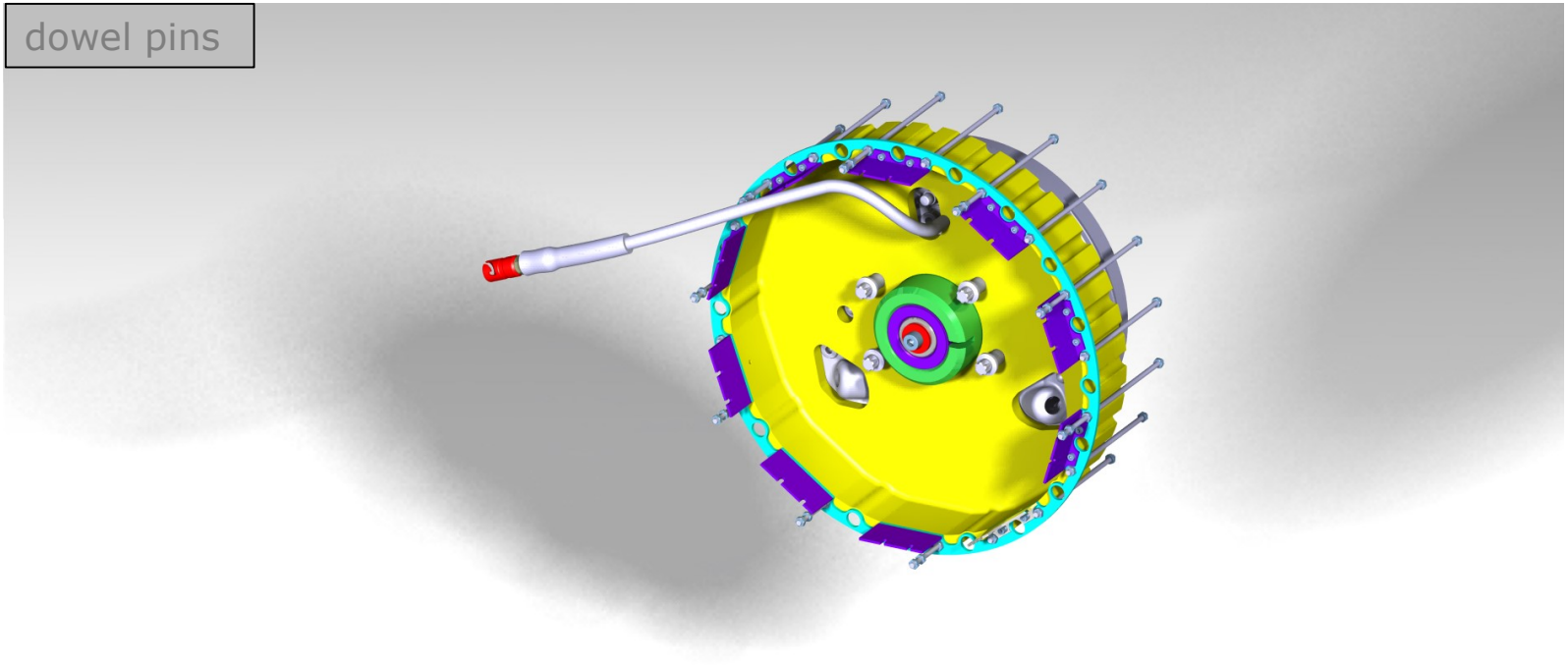

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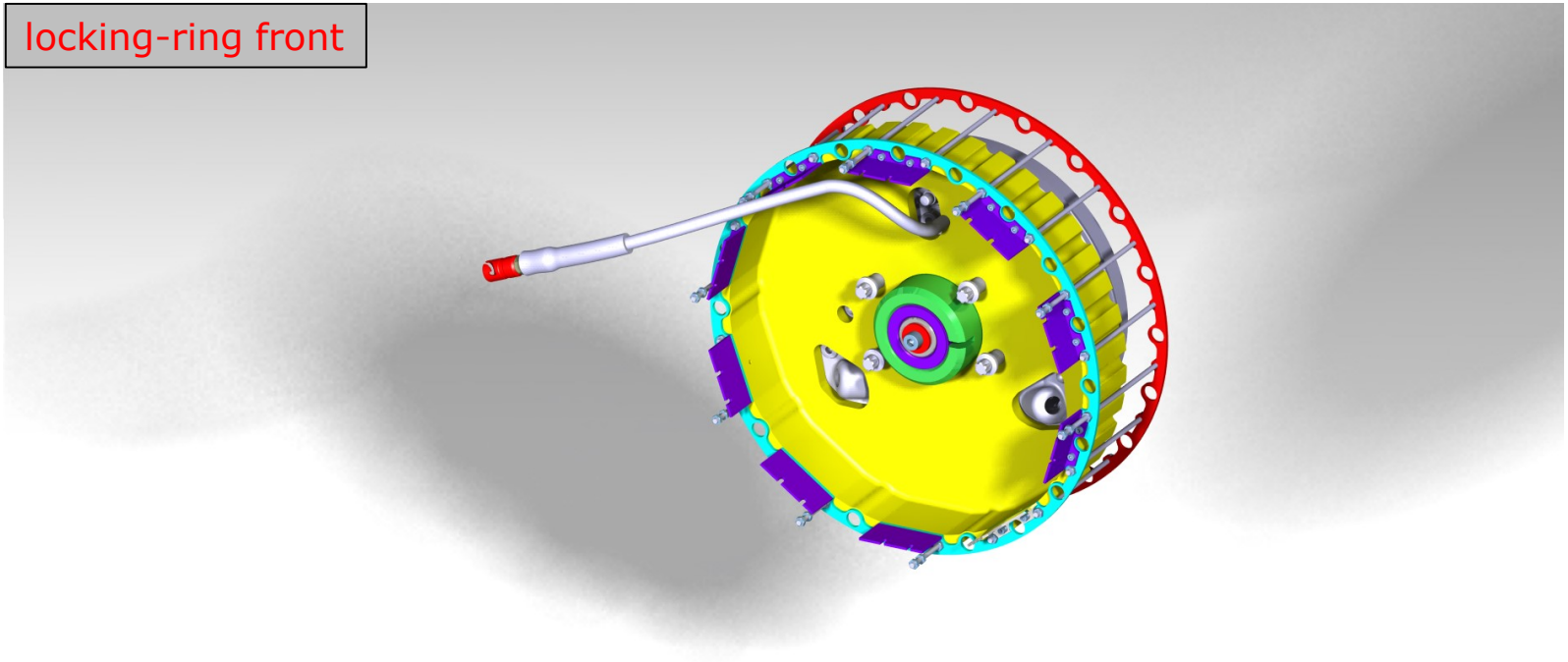
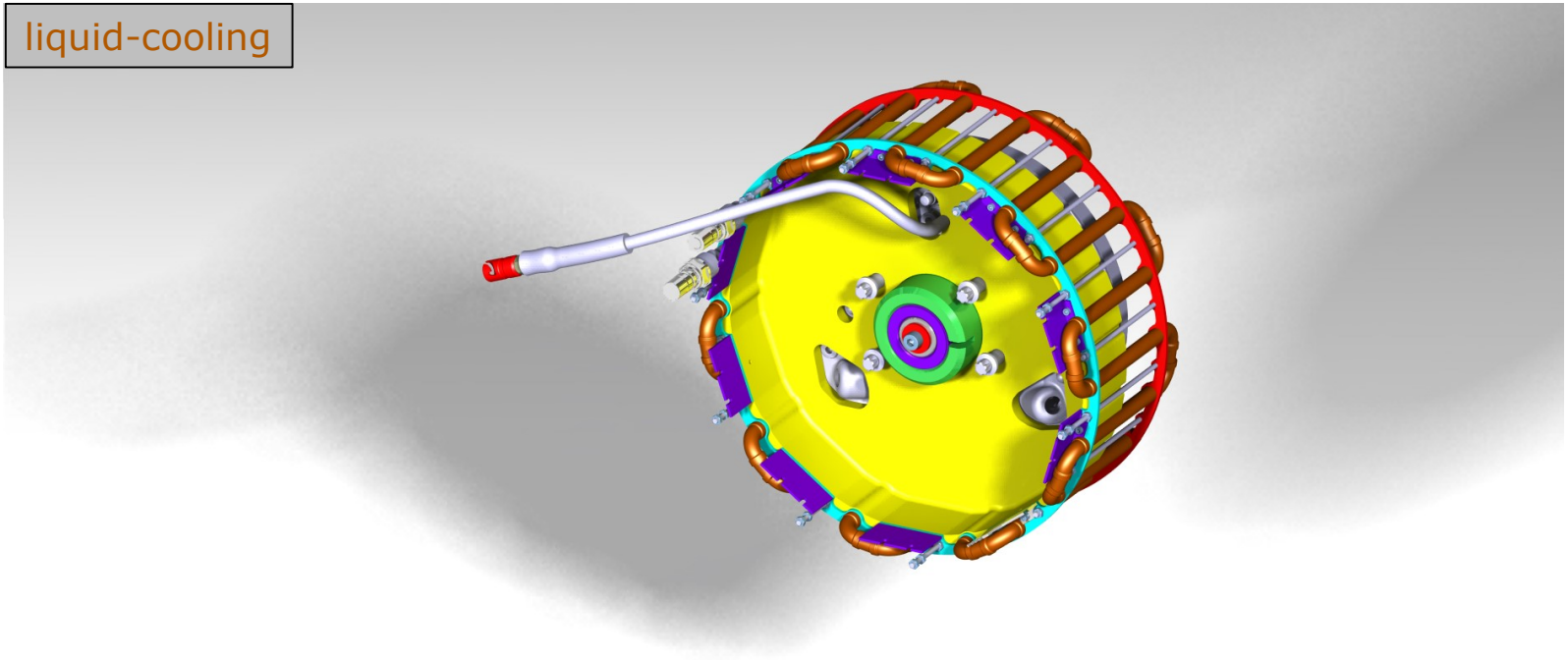


final drive unit design: virtual machine assembly

liquid-cooling



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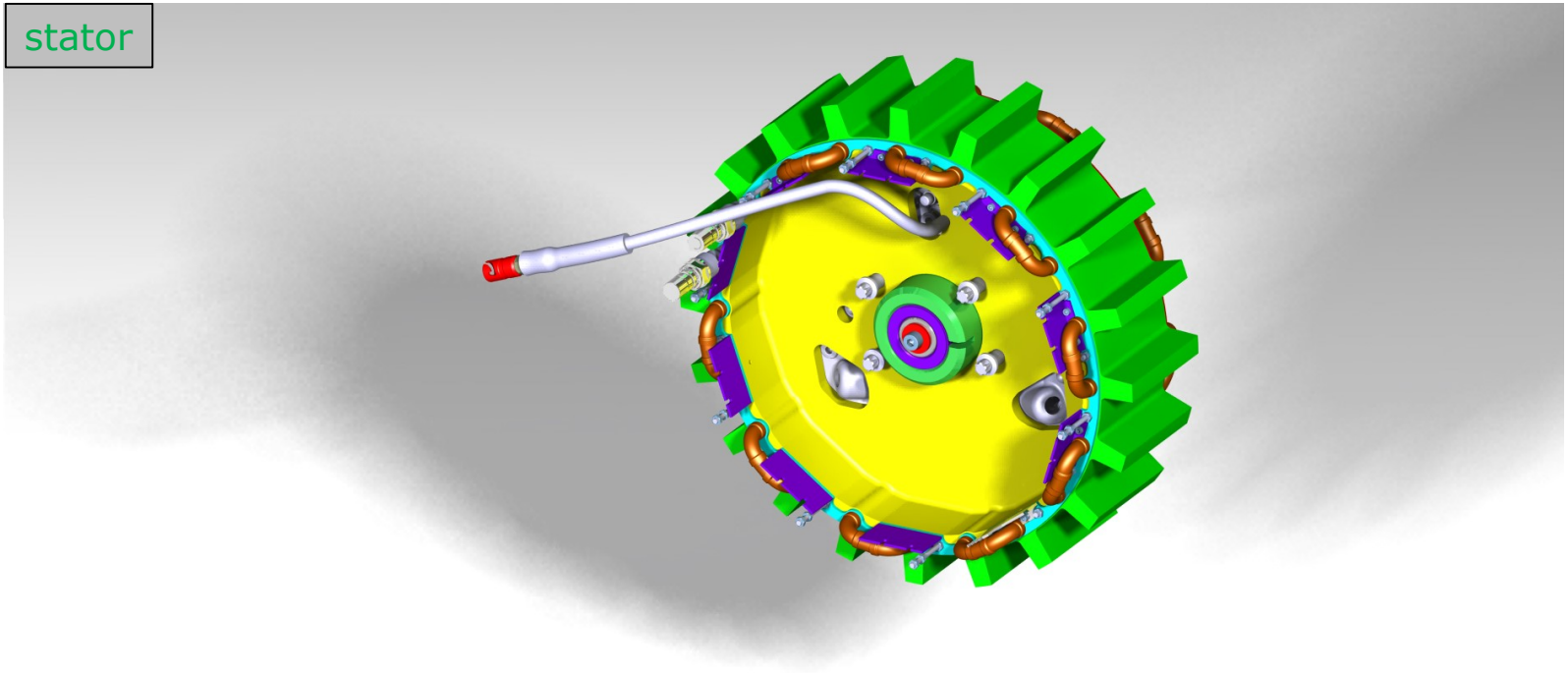

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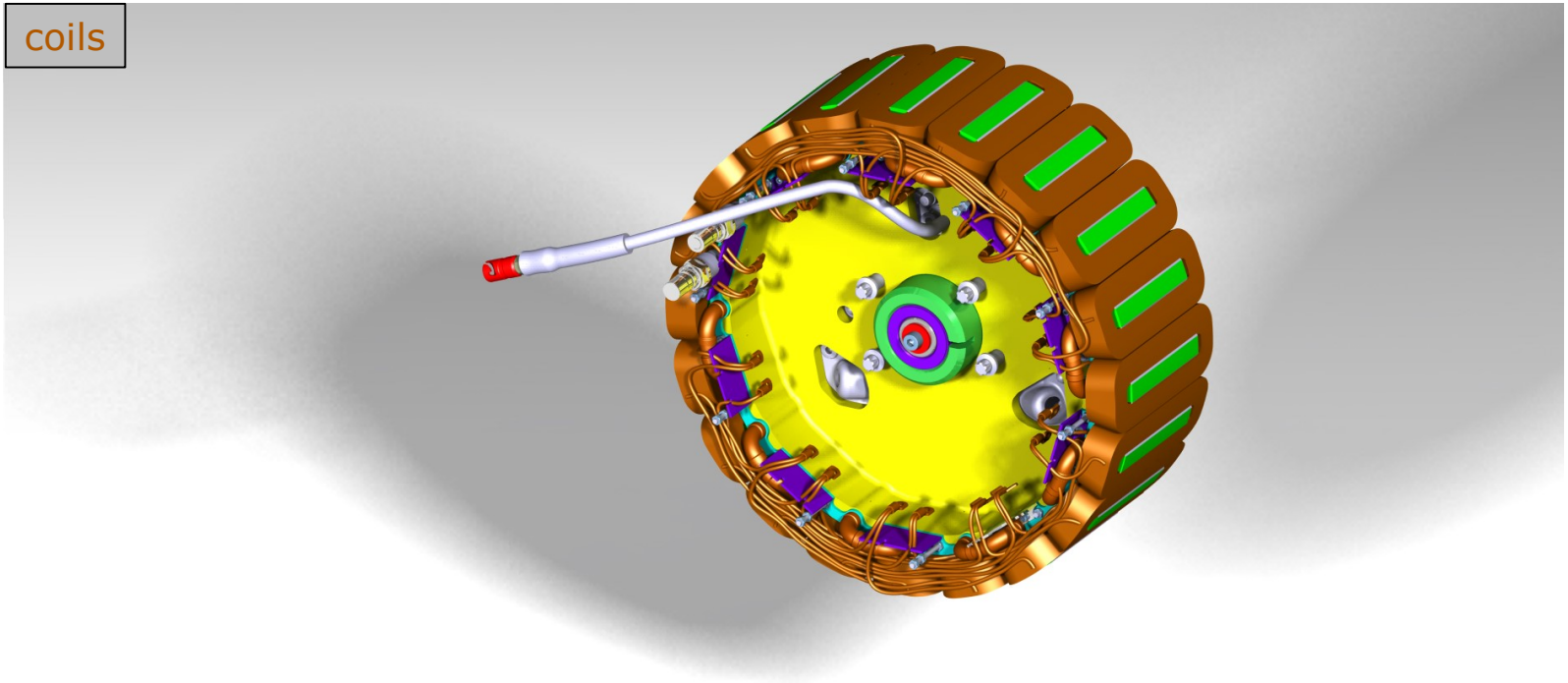

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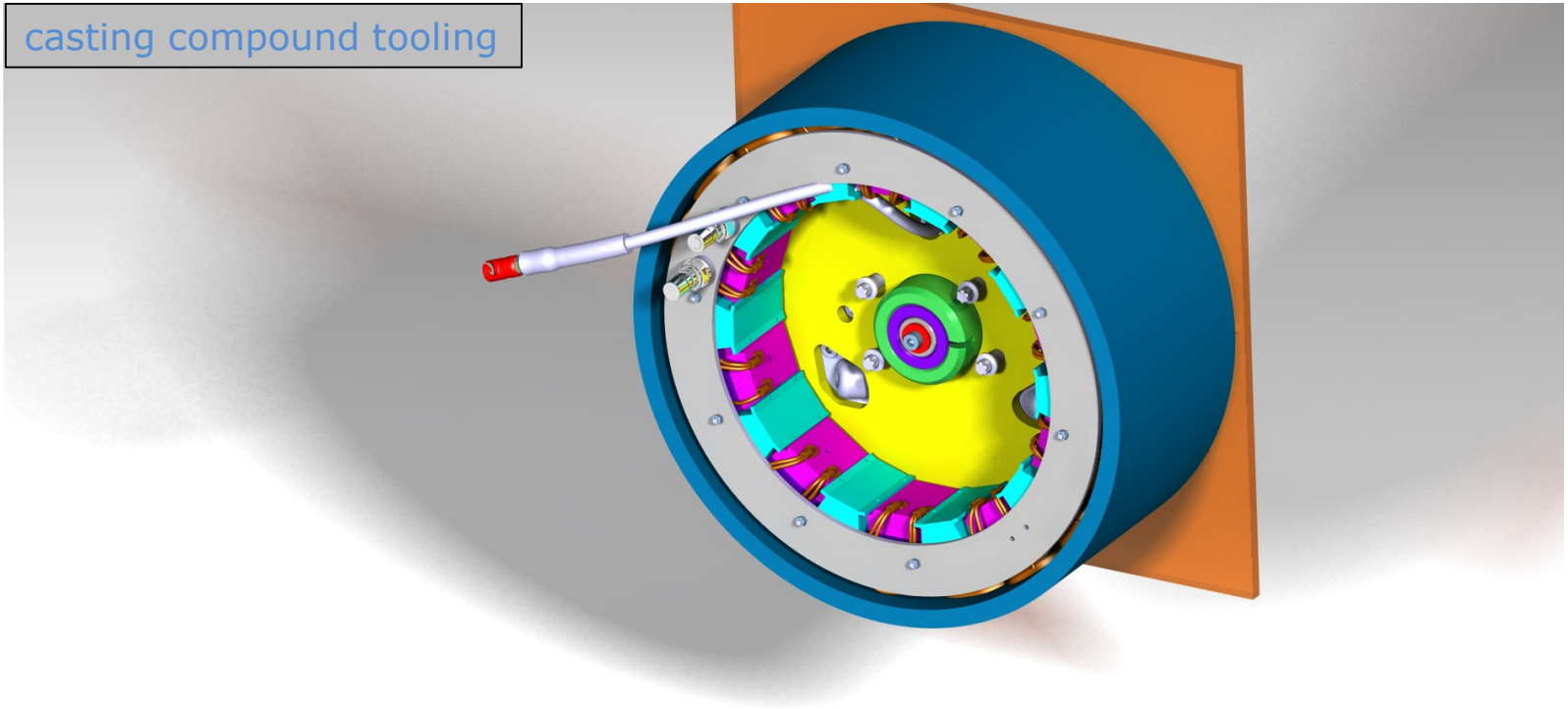

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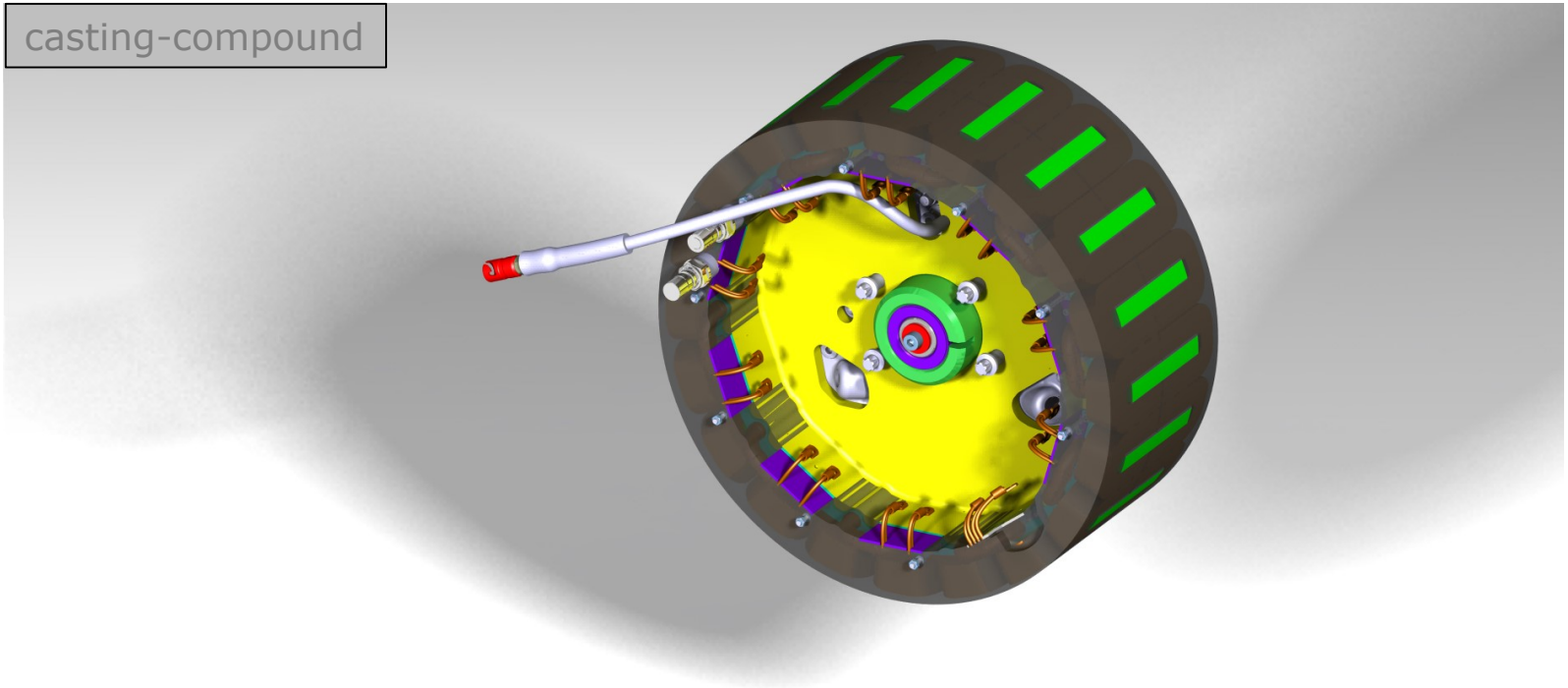
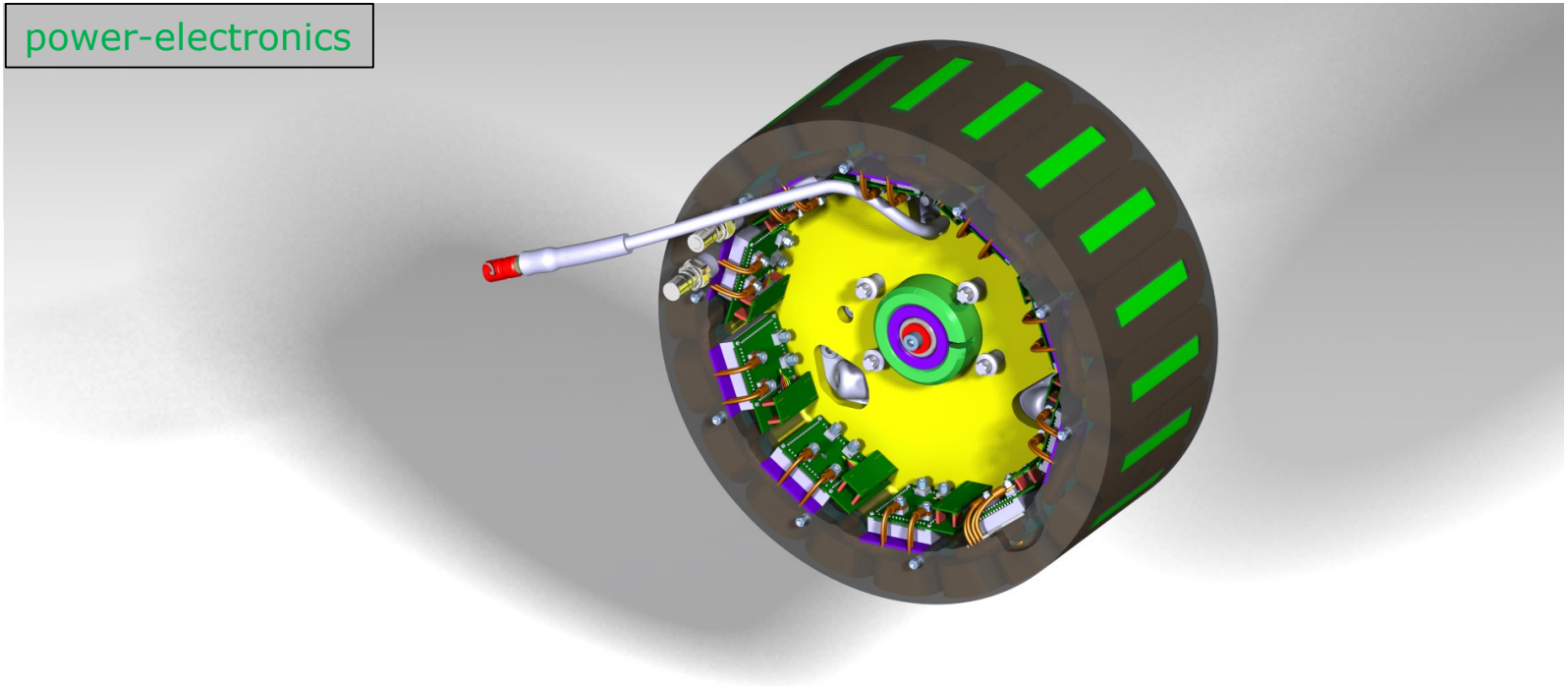


final drive unit design: virtual machine assembly

power-electronics



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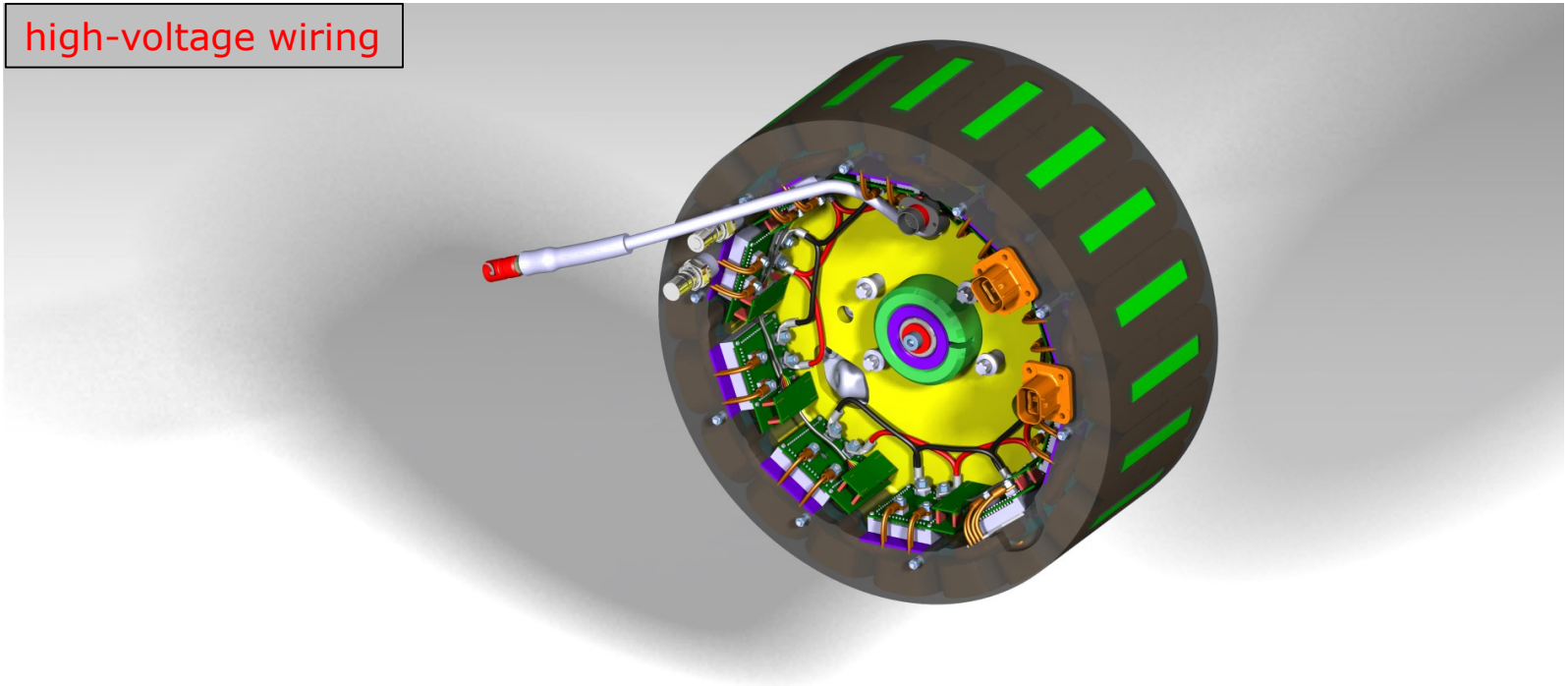

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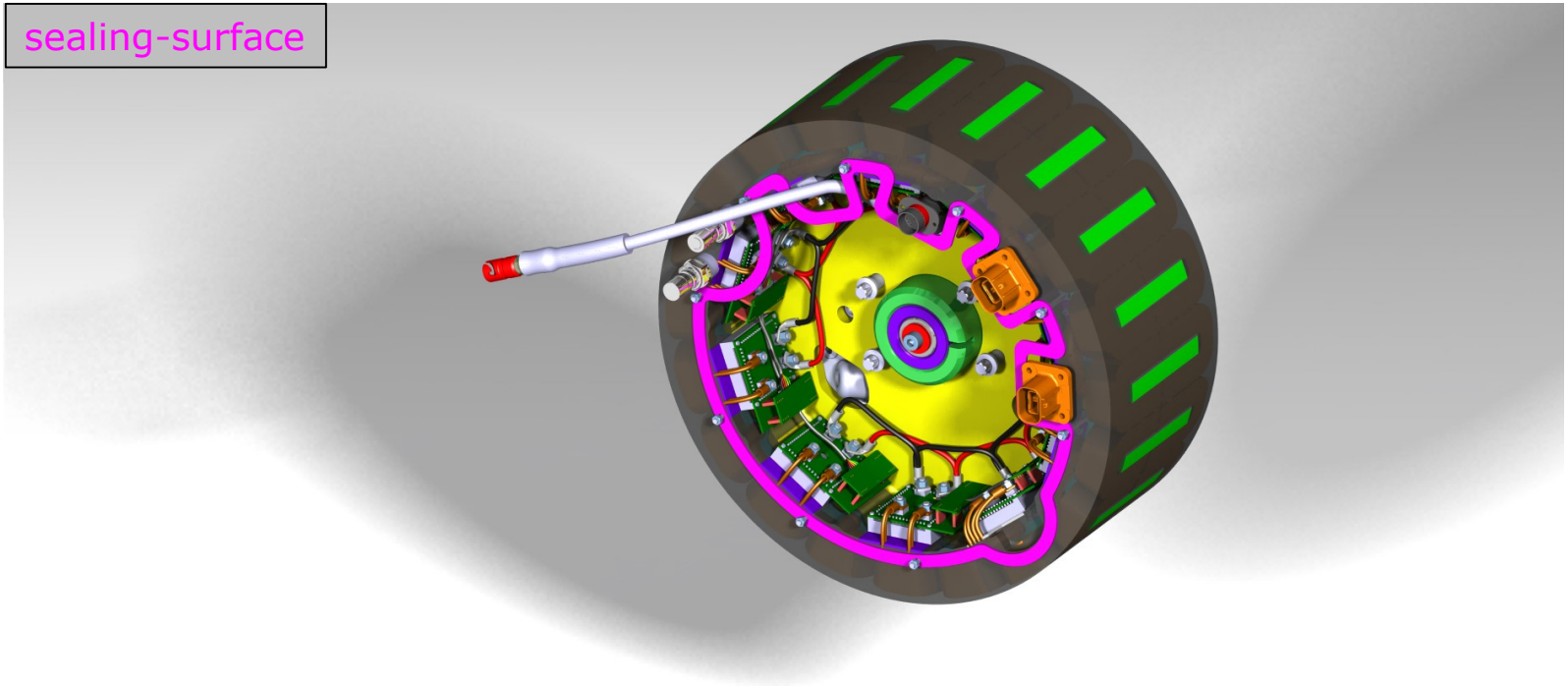

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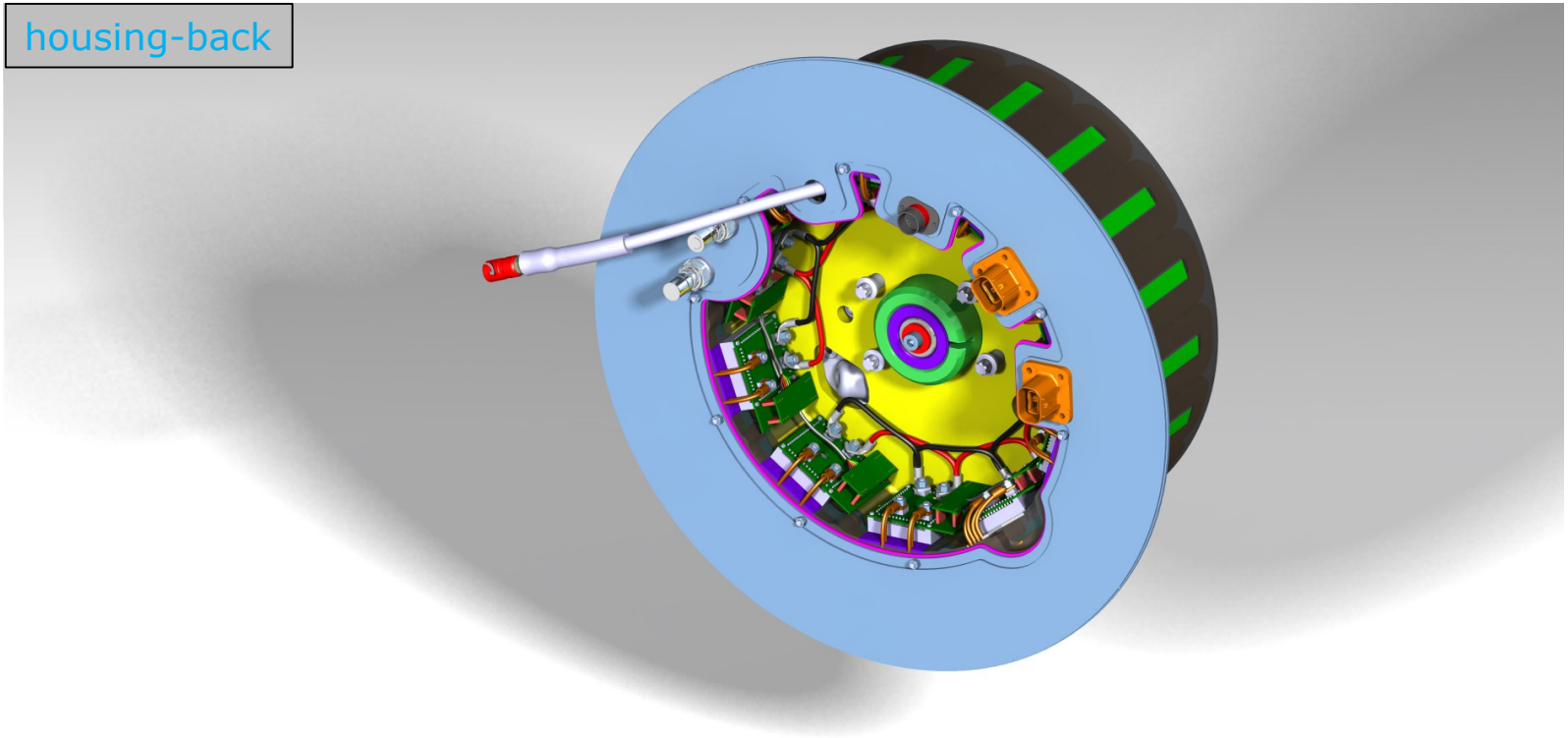
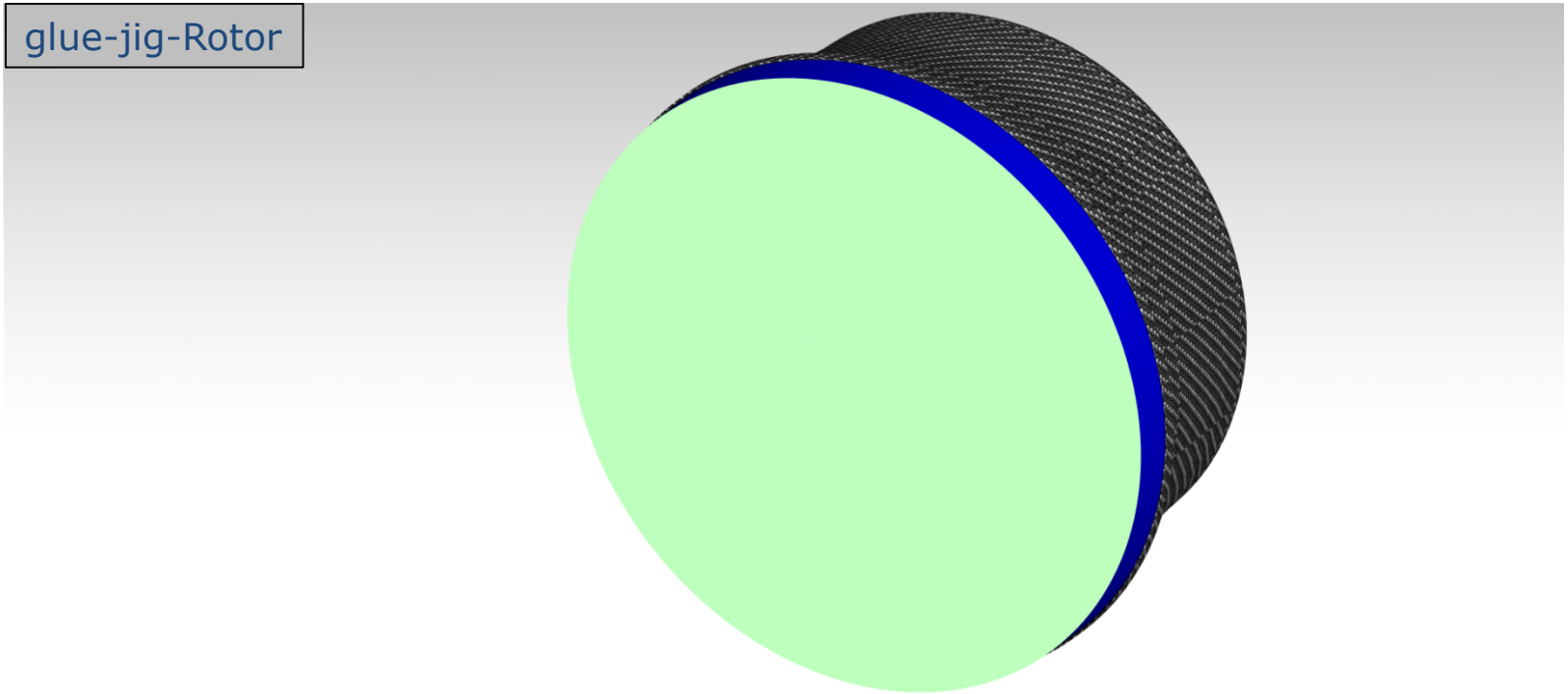


final drive unit design: virtual machine assembly

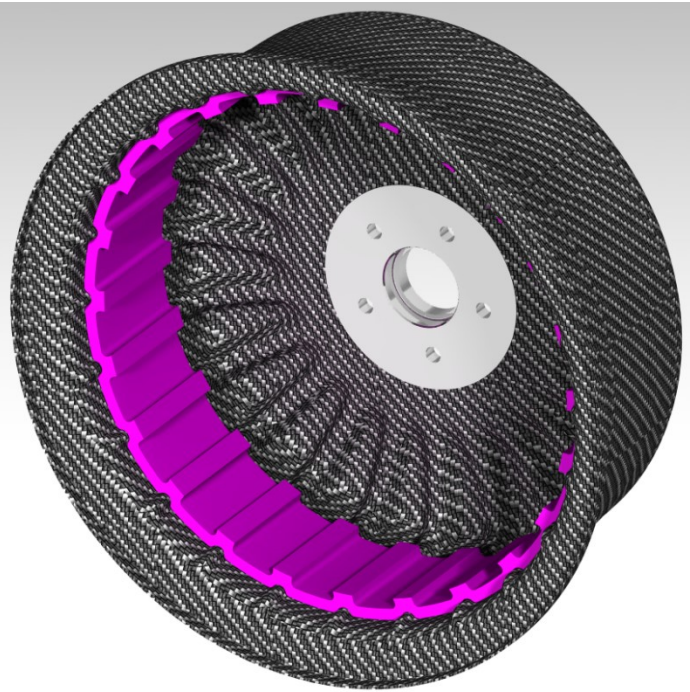
carbon-fibre-Rotor-Holder

final drive unit design: virtual machine assembly



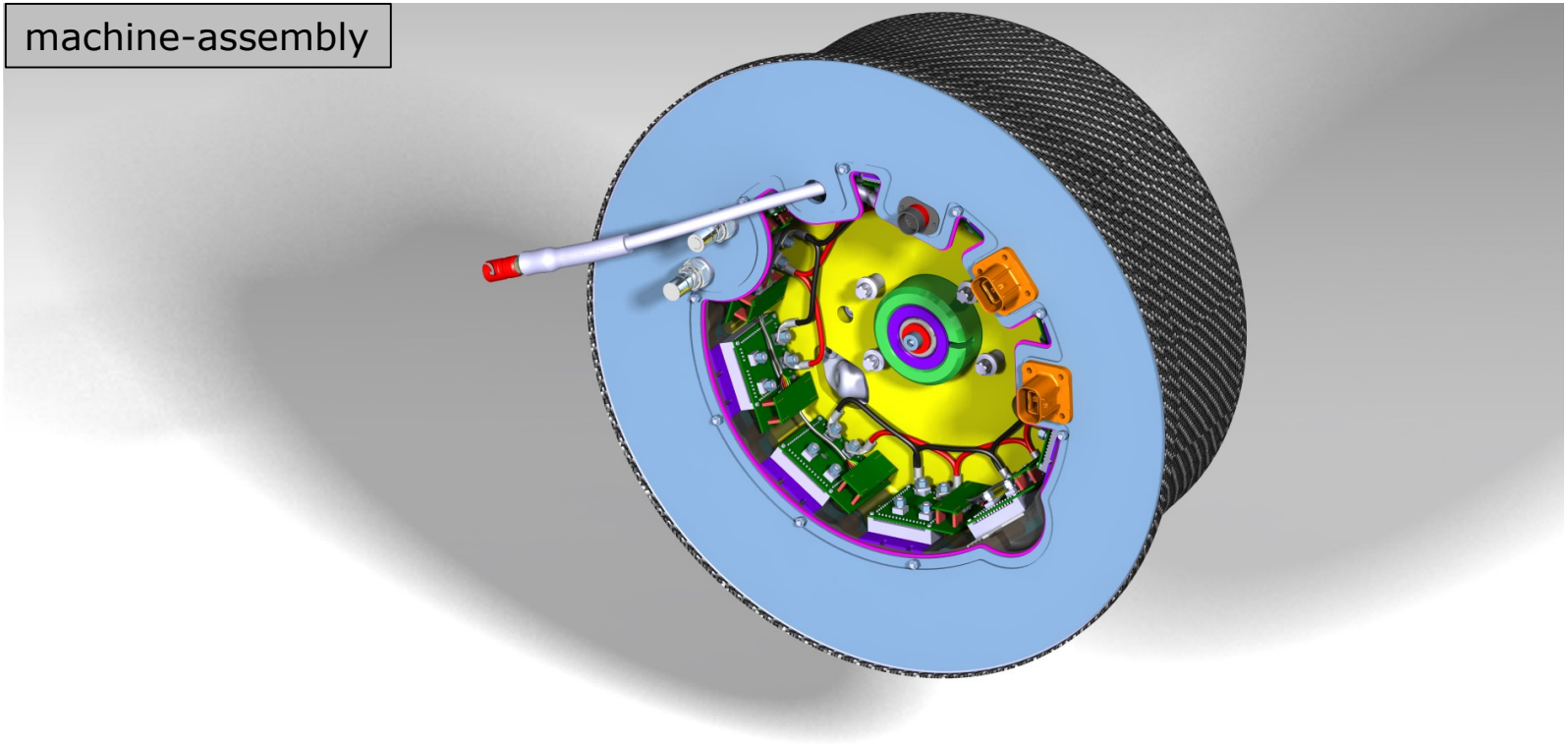
final drive unit design: virtual machine assembly

rotor-assembly



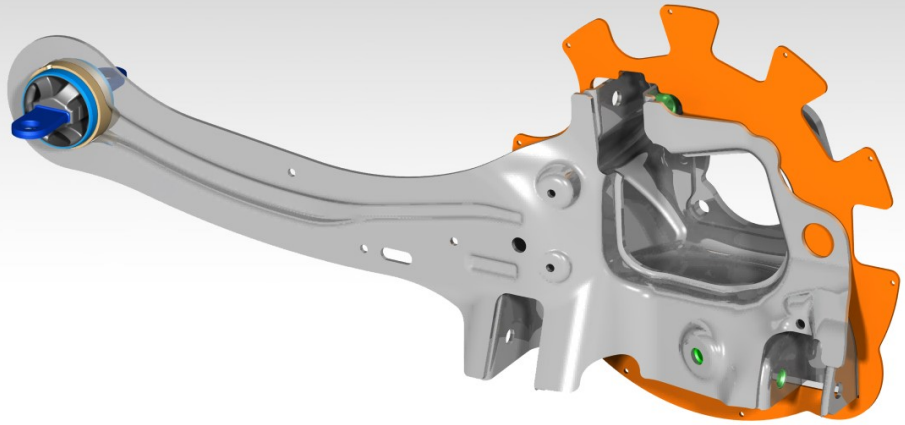
final drive unit design: virtual machine assembly

machine-assembly



final drive unit design: virtual machine assembly

upright-sealing-surface



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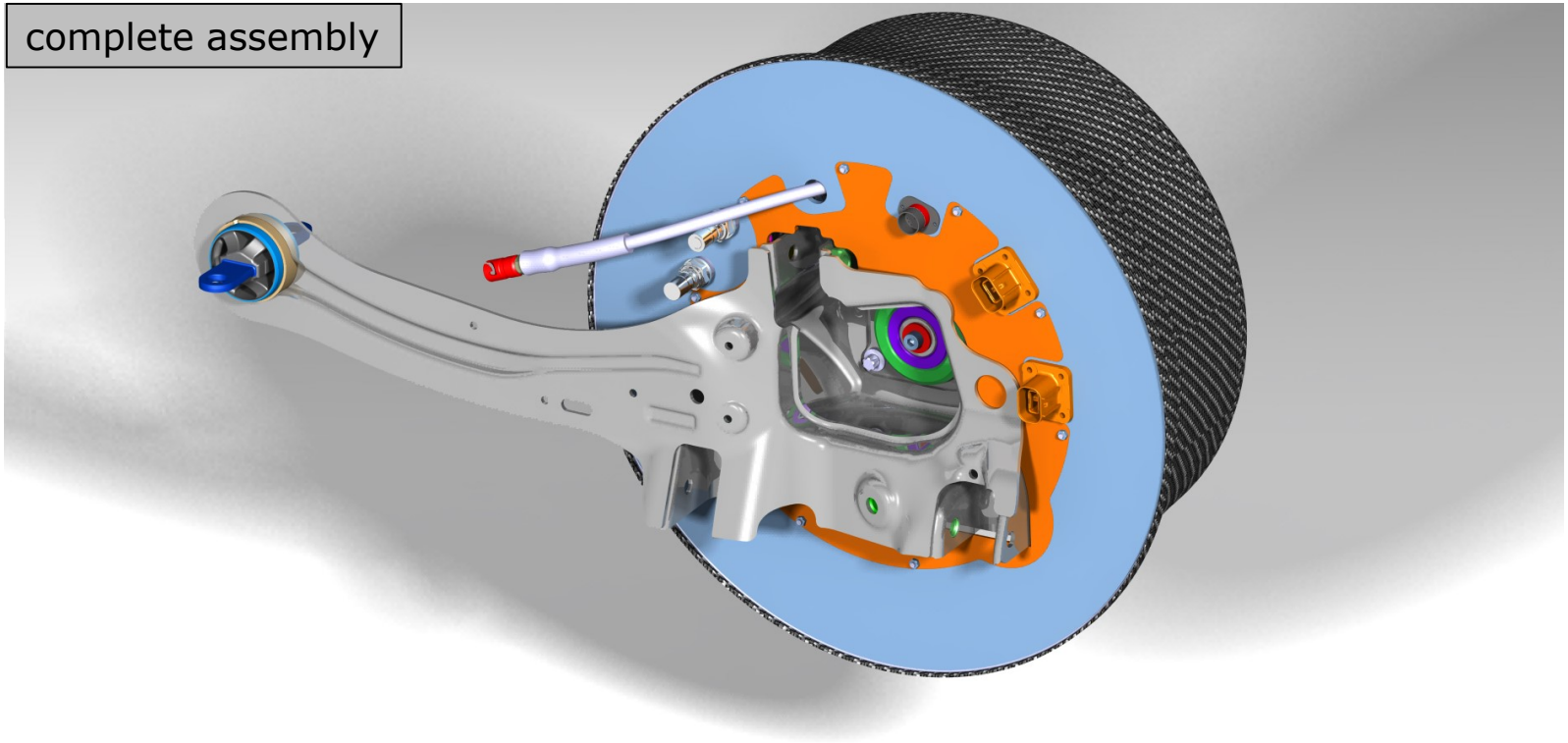

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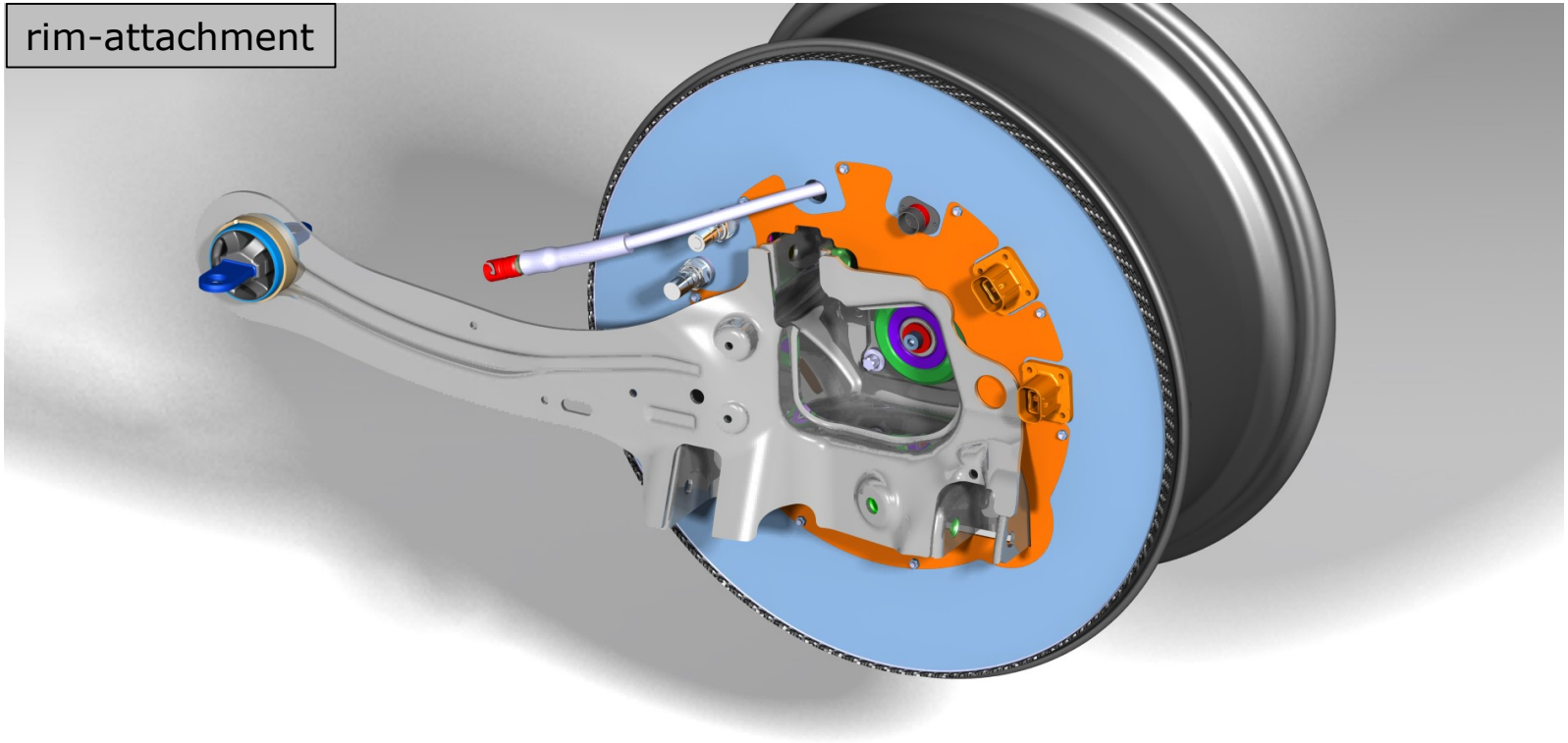

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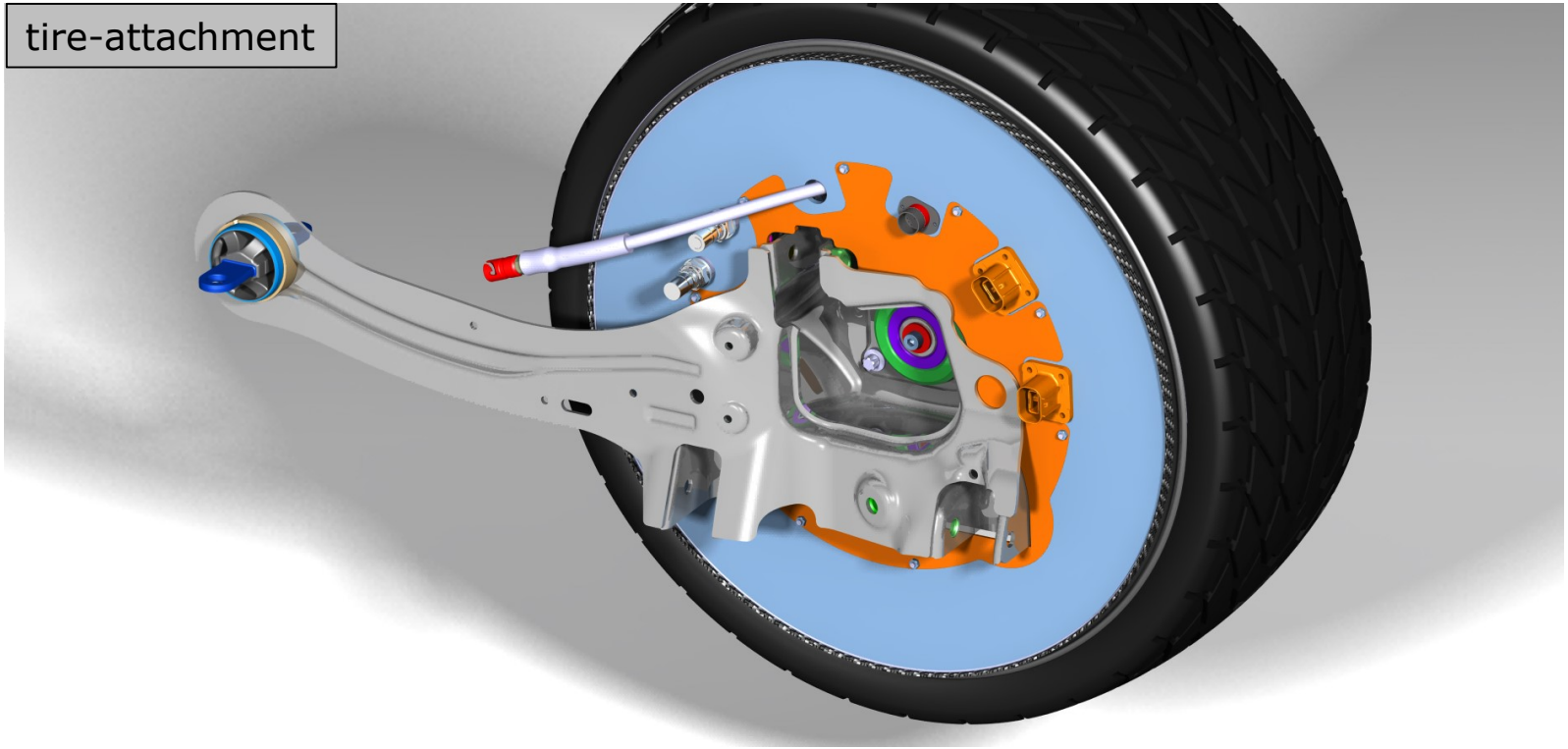

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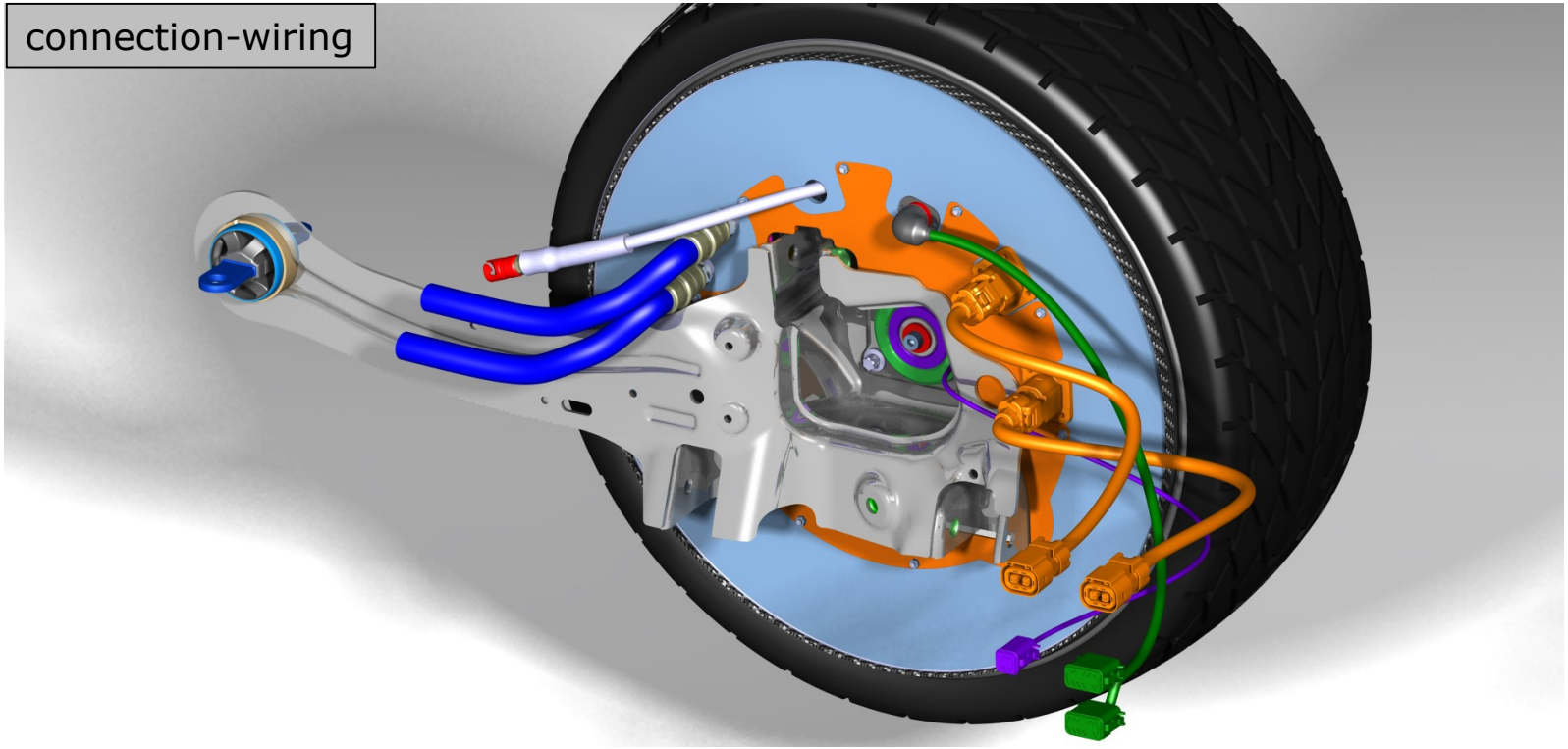

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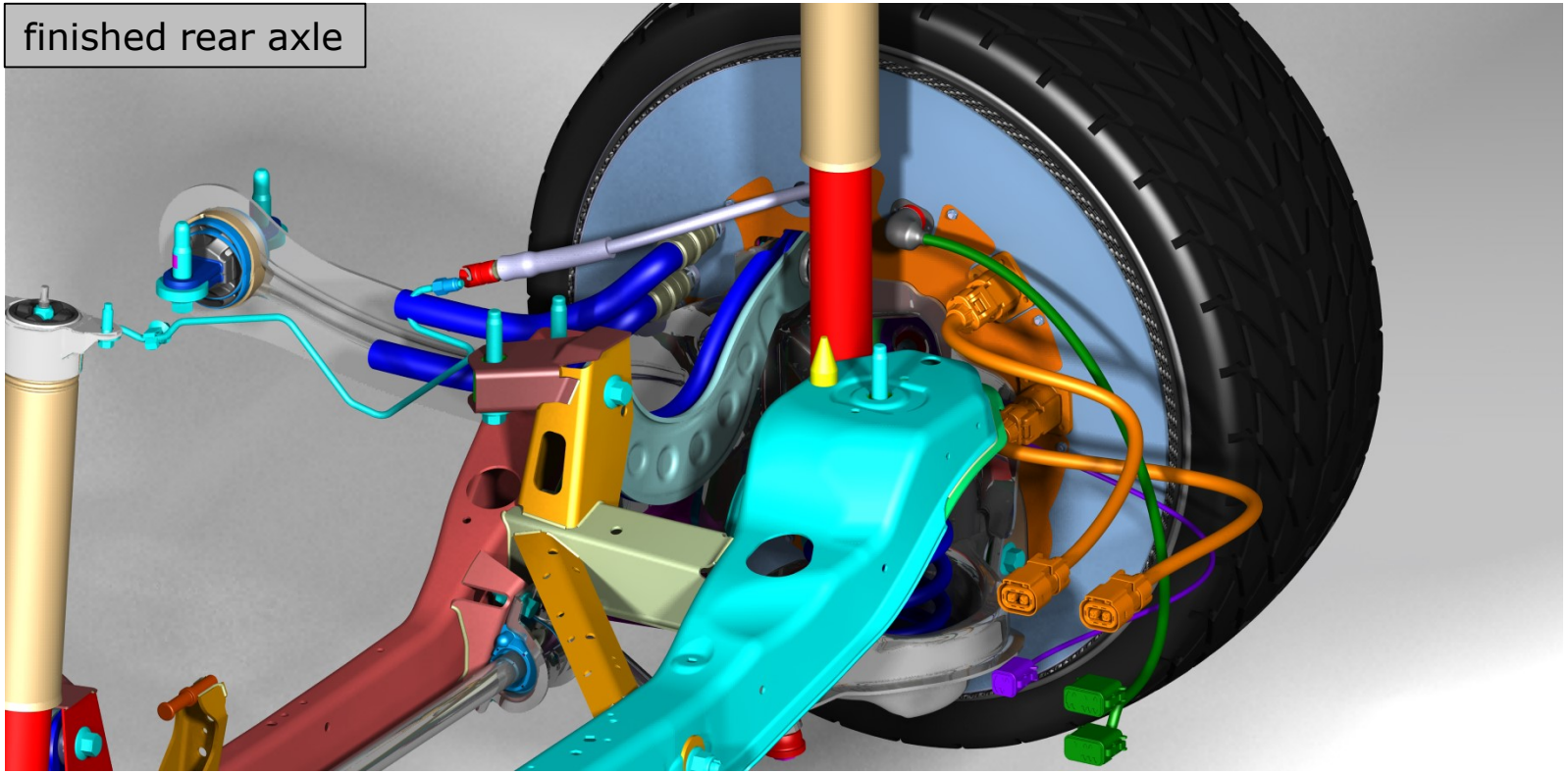

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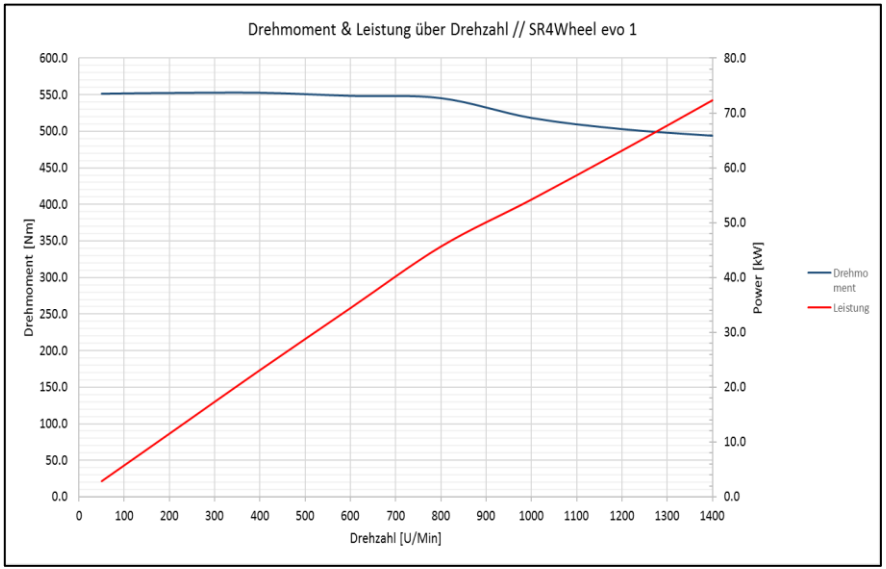
outlook: final machine performance

simulation results:



Parameter	Value	Unit
Motor-Type	SRM	-
Input Voltage	300 – 600	VDC
Constant-Power*	40	kW
Peak-Power*	70	kW
Constant-Torque*	400	Nm
Peak-Torque*	550	Nm
Max Speed	>1400	rpm
Weight	< 45	kg
Efficiency*	> 94	%
Cooling	Liquid	-
Power-Electronics	Integrated	-
Power transfer	Without gearbox	-

* At 600 VDC

summary: SR4Wheel

Summary & Outlook:

1. the development and testing of a SRM wheel hub motor was presented
2. the new machine is able to be integrated into the given space between original rim and original friction brake
3. due to this, it is ideal for the conversion of ICE cars to 4WD (P)HEV
4. the presented machine is able to work without rare-earth materials and is a serious „price-stable" alternative to permanent magnet synchronous machines
5. two machines are already sufficient for the electric traction of a BEV
6. due to the complete integration into the wheel (incl. power-electronics) it allows great freedom regarding vehicle platform design (Life & Drive Module)
7. advanced lateral vehicle control algorithms (e.g. Torque Vectoring) can be applied
8. currently two machine prototypes are build up, and will be tested in Dec.2017 on the road

Thanks a lot for your Attention !

Looking forward to your questions !