Presentation of a Steer-by-Wire Force Feedback Actuator with Direct Drive E-Motor and MR-Brake

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Interreg Bayern-Österreich
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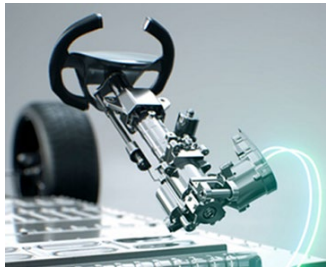
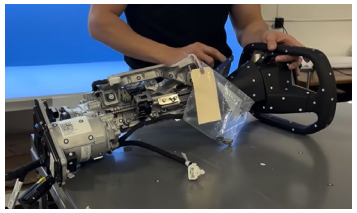
Current Force Feedback Actuator Designs

HL Mando



TESLA



JTEKT

ZF

nexteer AUTOMOTIVE

HYUNDAI MOBIS

Worm Gear / Belt Drive

thyssenkrupp

SCHAEFFLER

Gaming „Wheelbase“

Direct Drive

- Cost, package, weight, fail operational
- Low power consumption
- ADAD/AD and Automatic Emergency Steering
- Parking comfort / NVH
- Consistent steering feel
- Torque >> 20Nm (defined stops)
- Stowable
- …
- **On center steering feel?**
- **Feedback?**

Requirements

Dis-/Advantages Force Feedback Actuator Designs

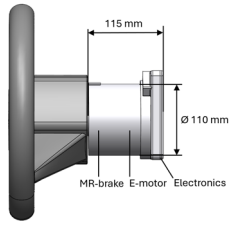
Requirement: steering wheel torque of >> 20 Nm (end stops; stop at curbstone; stop at entering/exiting the car)

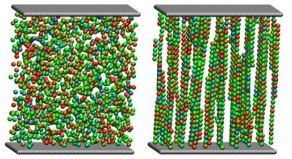
+ Cost, package and weight
+ Proven (EPS-C)
- High(er) friction, wear
- Low (worm) gear efficiency
- Low stiffness
- Torsionbar required
- “Questionable“ Steering Feel

Worm Gear/Belt Drive

+ No additional parts
+ Modelled/flexible (end) stop
+ “Best” Steering Feel
+ High load on boardnet/ECU
- Substantial mass/dimensions
- High e-motor torque vs. driver (functional safety aspect)

Direct Drive





+ Small E-motor, package, cost
+ Low energy consumption
+ Hardware fail-safe (permanent magnet - Inhomogeneous redundancy)
+ Modelled/flexible (end) stop
+ Low response time
- Additional hardware part
+/- Steering feel ?

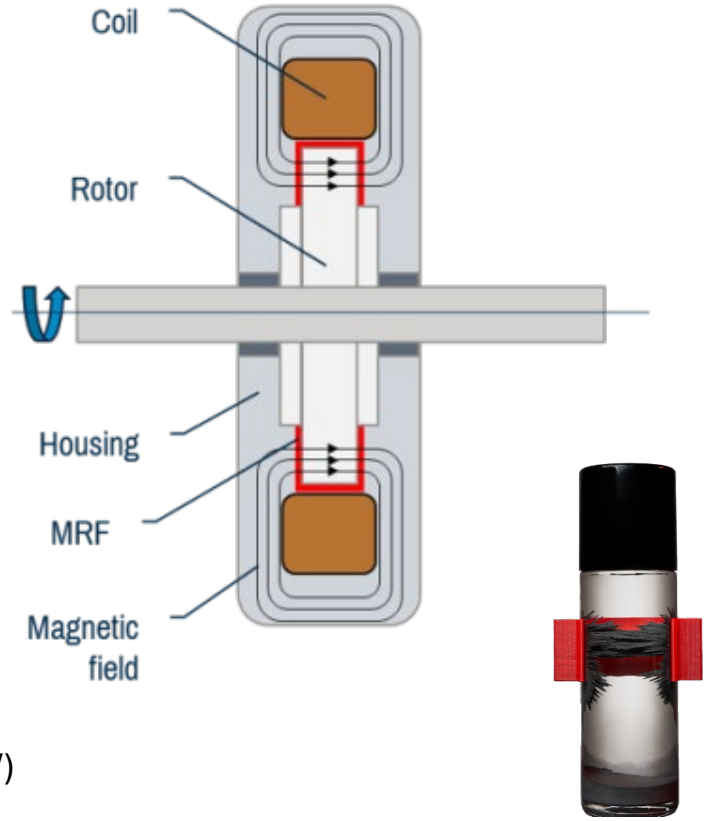
Direct Drive and MR-Brake

Semi-Active Magnetorehological (MR-) Brake

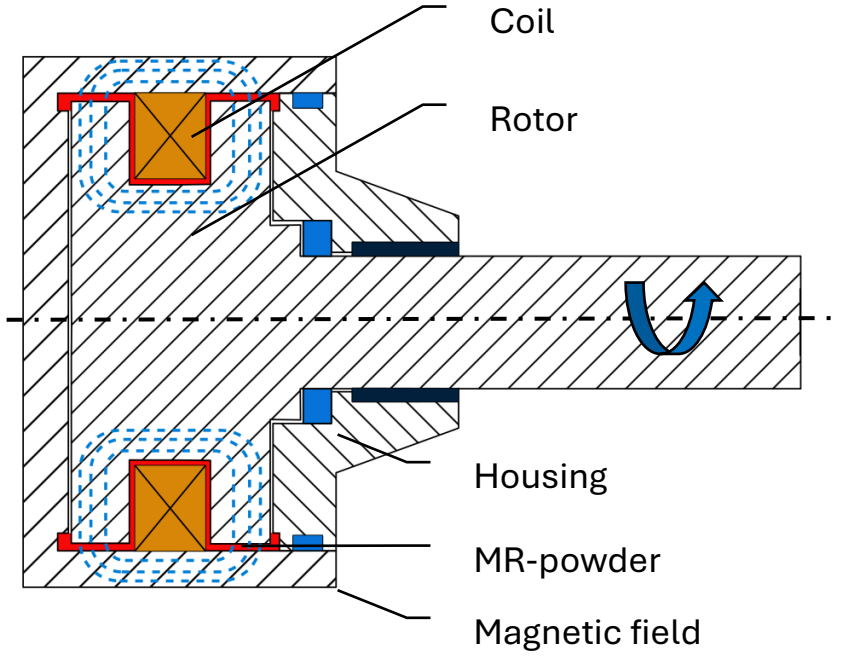
- MR-brake consist of:
  - Bearing and a coil
  - Magnetizable carbonyl iron particles

- INVENTUS brake concept
  - High maximum torque
  - Cost ratio 1:10 to E-motor
  - Small dimensions
  - Low minimal (basic) torque
  - Response time in ms
  - Smooth/stepless controllability
  - Low power consumption
  - 60 W at 12 V for 25 Nm (E-motor >> 600 W)

State of the art MR-Fluid brake



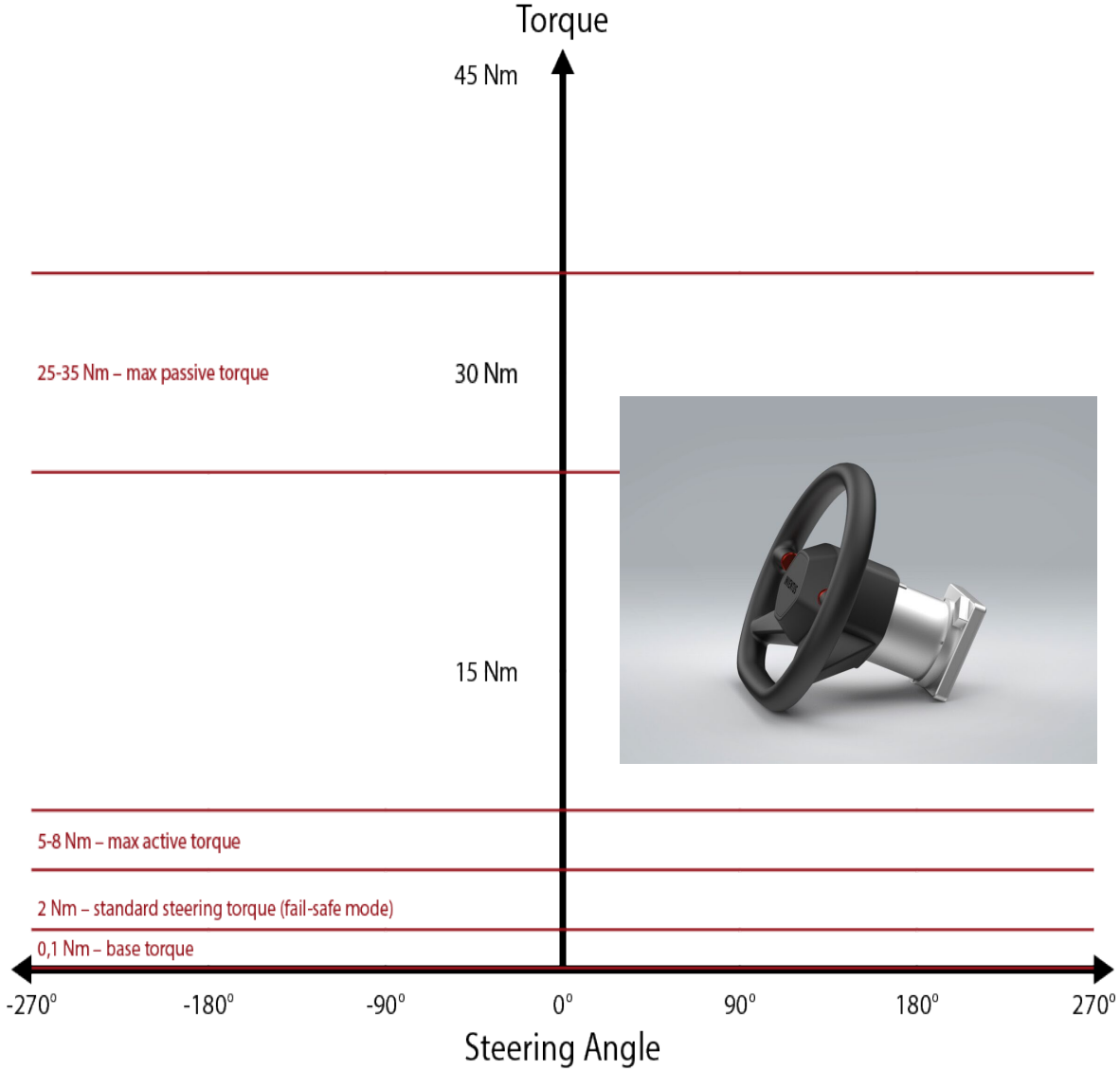
INVENTUS patented MR-brake



Hot Topics: Combination an E-motor with a MR-brake

- New, non automotive technology (proven in haptics e.g. Razer V2 Pro)

- Handover/blending between low torque E-motor and high torque MR-brake
- Additional system/ complexity
- MR-brake as a redunancy:
  - Steering feel with controlled MR-brake only possible
  - Passive torque by permanent magnet/ battery



Force Feedback with Direct Drive E-Motor and MR-Brake*

- ***Requirement analyses and SbW simulation***
- ***Demonstrator built up on static driving simulator***
- ***Controller optimization and customer study***
- ***Workshops/ analysis of MR-technology potential***
- ***Analysis of sustainability of production/operation***

*Public Funded Project

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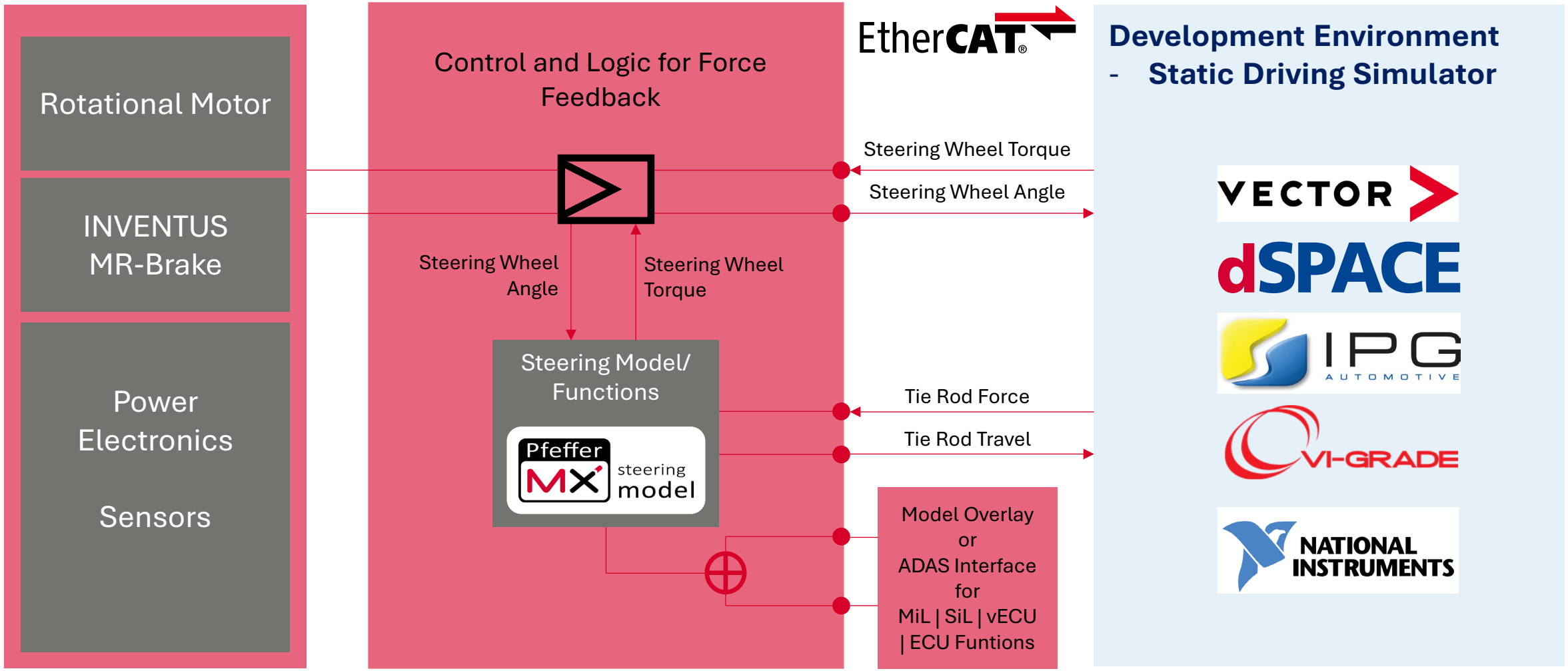
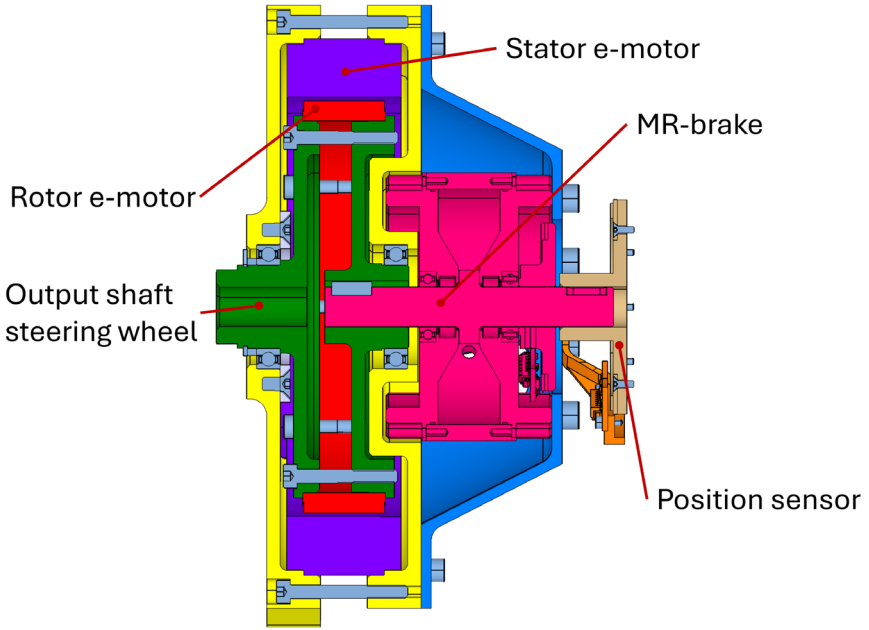
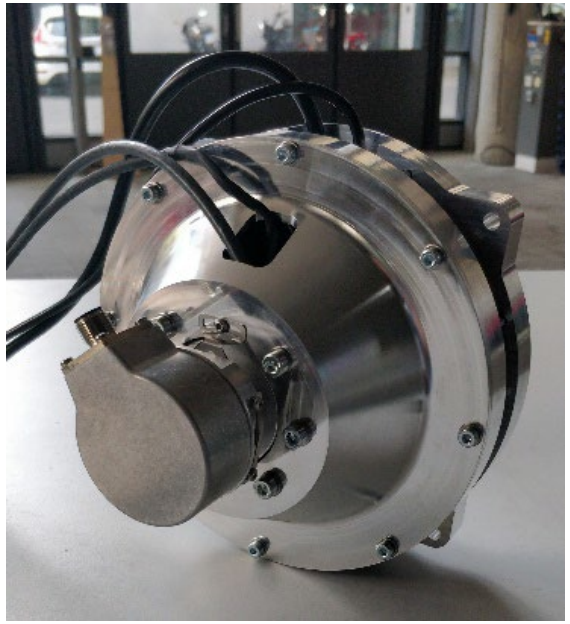
MX Rapid Prototyping Architecture



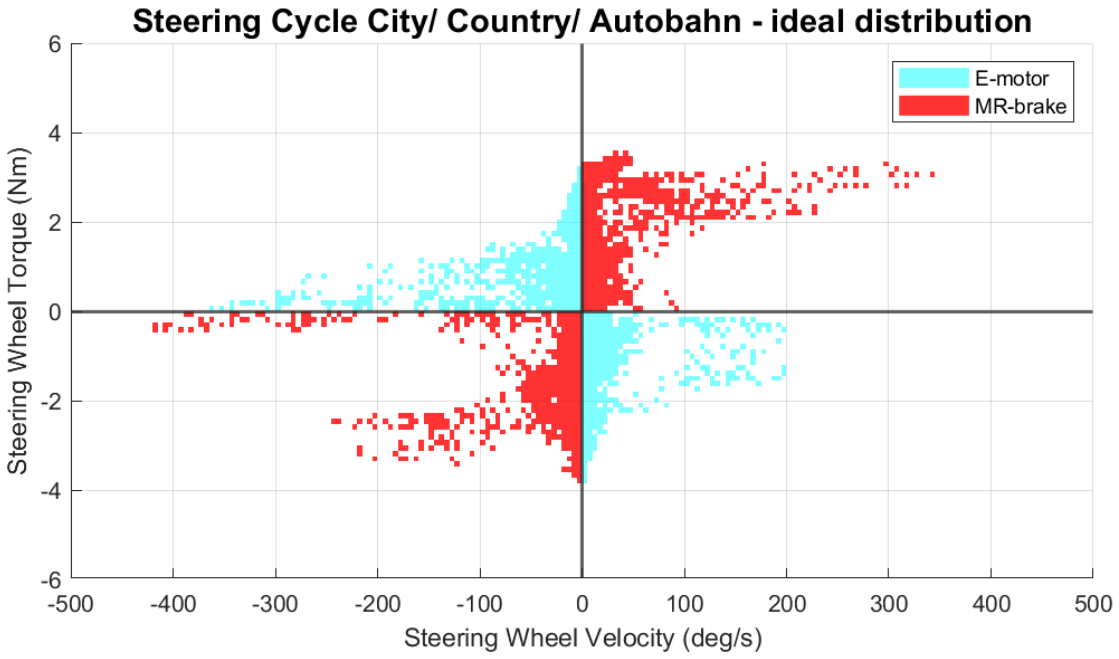
First Prototype of the Direct Drive E-Motor and MR-Brake

- No focus on size and packaging for series production
- Oversized 400V E-motor to analyse E-motor + MR-brake vs. standalone E-motor
- E-motor 15.7 Nm continuous torque/ 30.0 Nm peak torque
- INVENTUS MR-brake 8 Nm peak torque

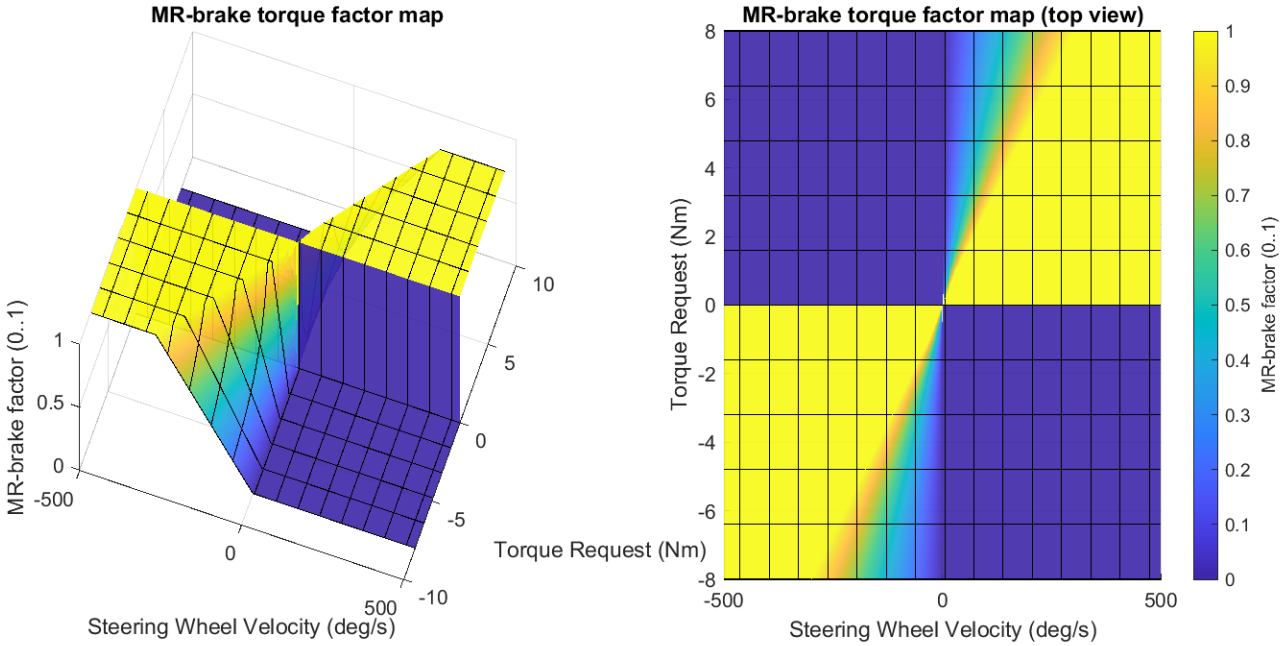




Controller and Torque Splitter Concept (Simulink)

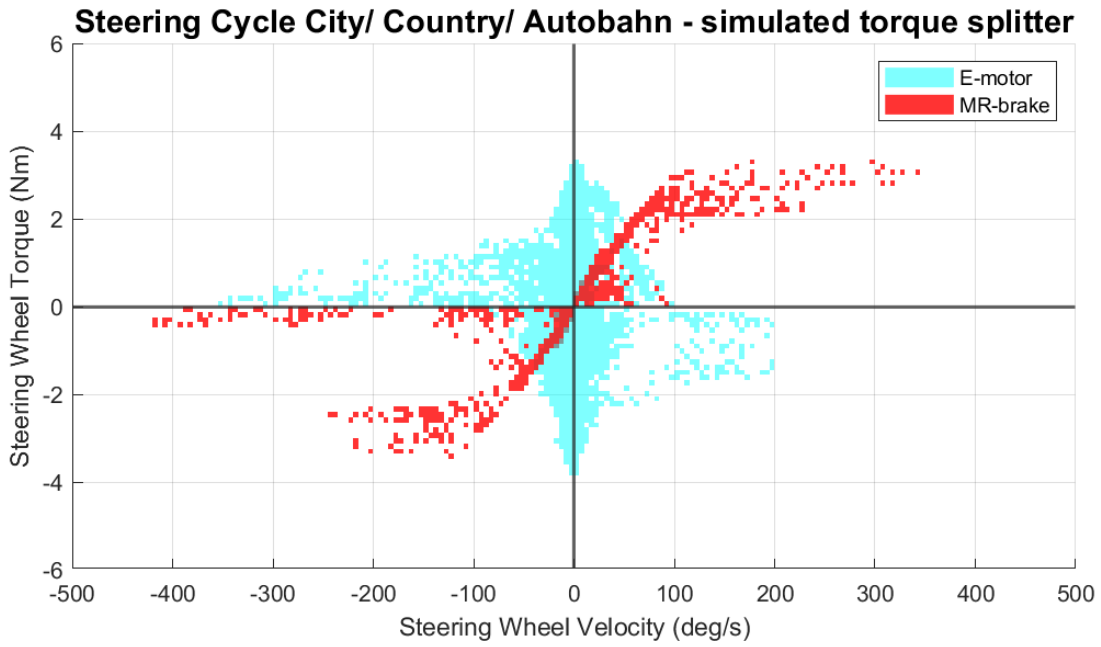


Ideal E-Motor MR-Brake Distribution

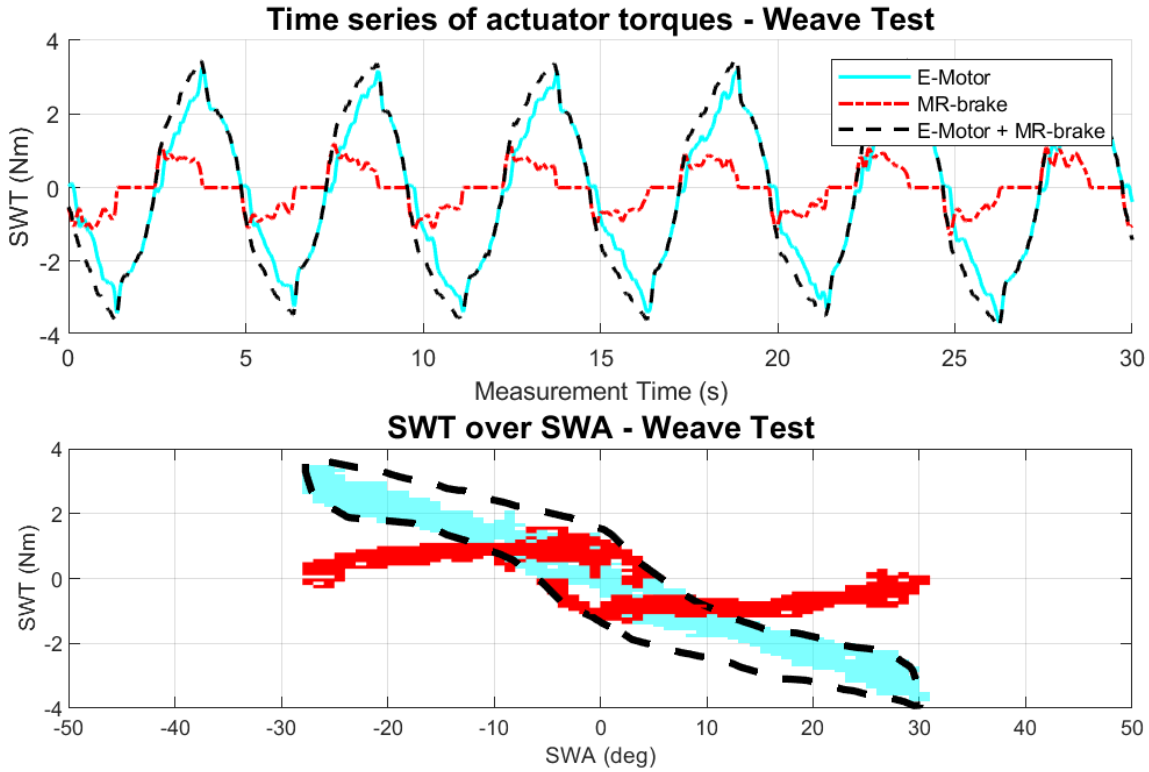


Torque Splitter Parametrization

Controller and Torque Splitter Results



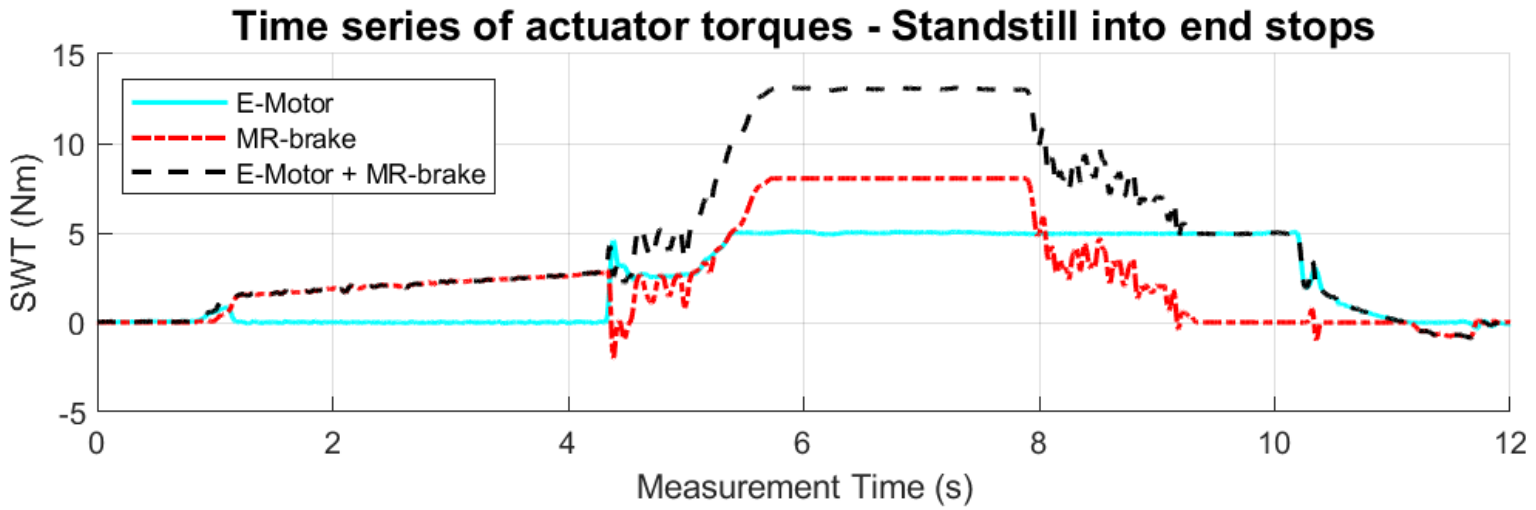
Distribution with Torque Splitter (Simulated)

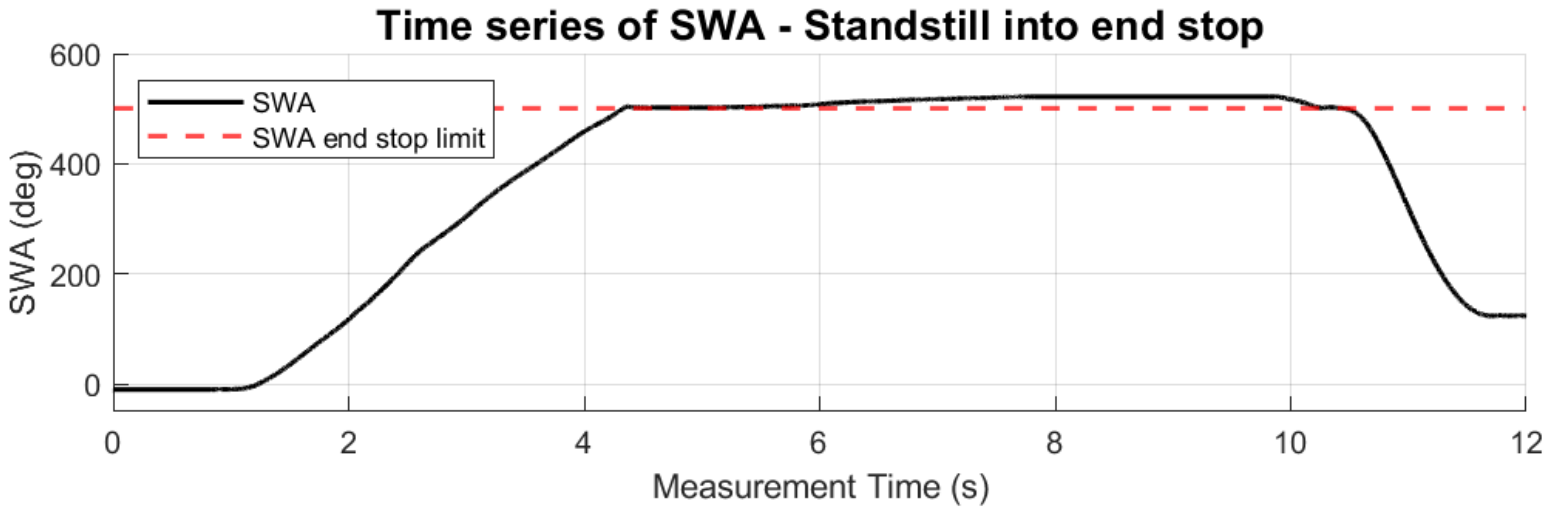


Weave Test Real Measurement

Controller and Torque Splitter – End Stops

- 1 s: MR-brake active during slowly turning/ E-motor is inactive.
- 4.5 s: E-motor and MR-brake at parametrized maximum
- 8 s to 10 s: steering slightly released -> MR-brake torque drops to 0 Nm
- 11 s: steering back to the center with reduced E-motor torque
- Good subjective steering feel
  - Smooth, harmonic
  - Sticky (sensor position)



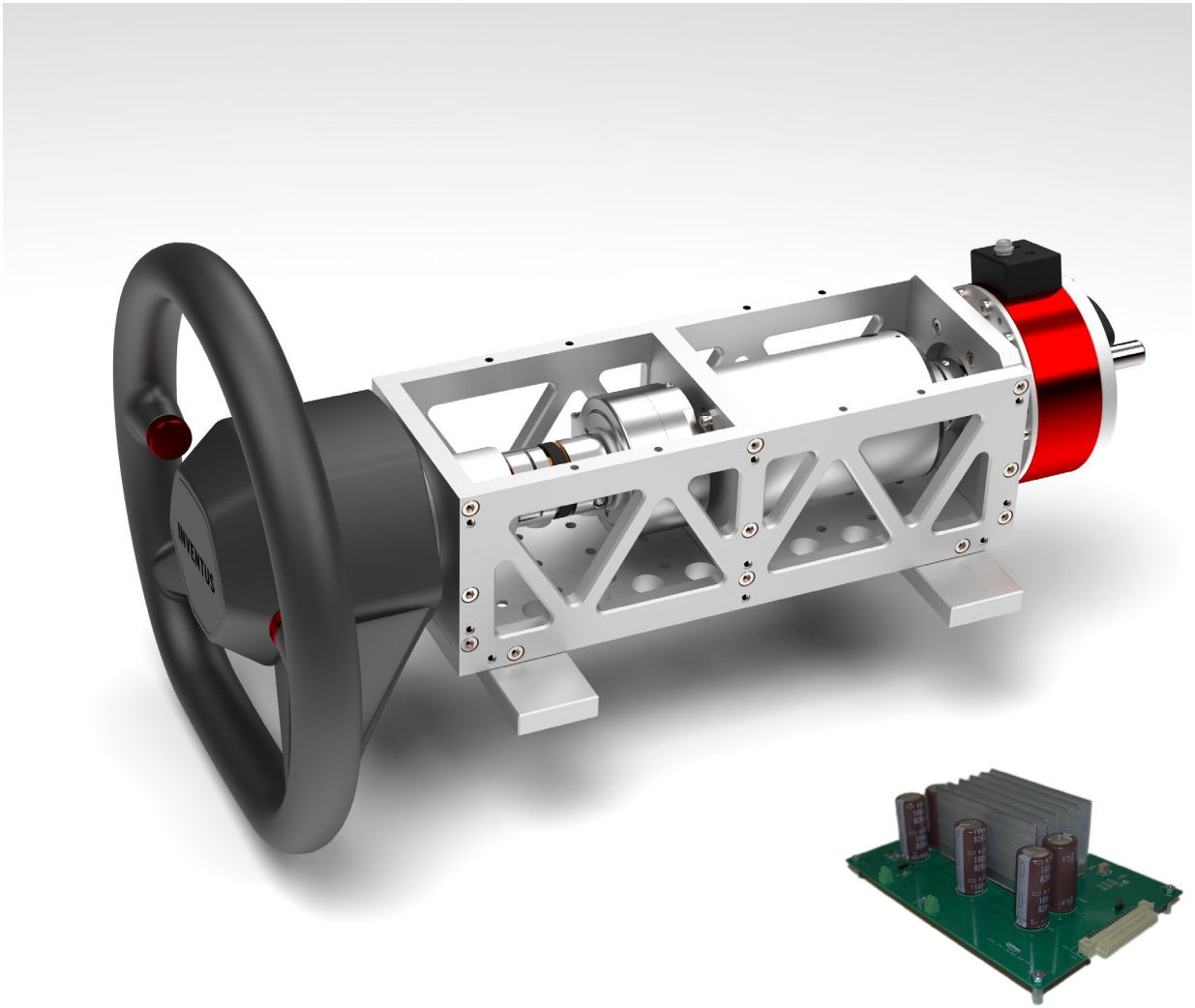


Redesign – Second Prototype

- No focus on size and packaging for series production
- Series production EPS-E-motor 6 Nm peak torque
- 12 Volt architecture with Infineon power electronics
- ECU on rapid prototyping platform

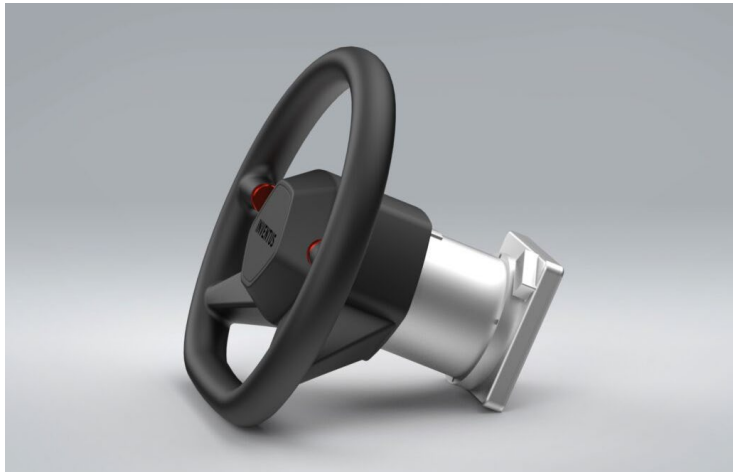
- Updated INVENTUS MR-brake
  - >25 Nm peak torque
  - Target < 0.1 Nm basic torque
  - (D 100 x 70 mm)

- Angle sensor position close to steering wheel
  - Motorshaft is used as torsion bar
  - High resolution sensor to find sensor requirements



Outlook – Next Steps

- Optimize second prototype and controller
- Driving simulator integration
- Evaluate series production potential
- Interreg milestones (model-based controller…)
- Find new development partners for Steer by Wire
- Evaluate semi-active approach for other chassis-systems
  - Antirollbar
  - Brake by Wire
  - Linear damper
  - Mounts
  - Crash absorber
  - …



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