E-motor Development: From Simulation to Real World and back

Giuseppe Volpe | Lead Advanced Engineering eMotor

18/01/2024

- **MAGNA and MAGNA Powertrain**
- **Automotive Solutions**
  - **Present and Future**
- **E-motor Design Workflow**
  - **From Design to Test Bench (and back)**
  - **Optimisation Example**

Our Vision

Advancing mobility for everyone and everything.

Our Mission

Our mission is to use our expertise to create a better world of mobility, responsibly.

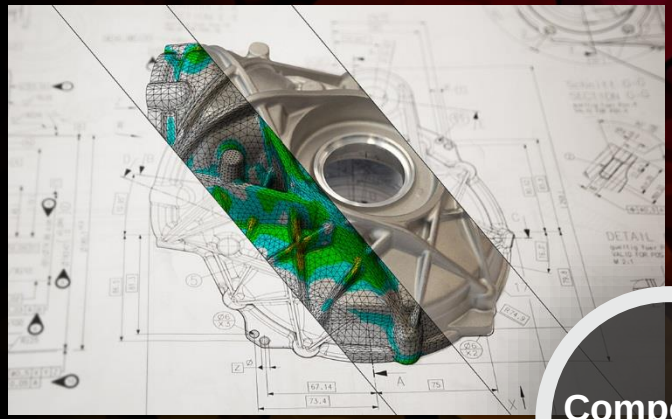
Committed to Making a Difference

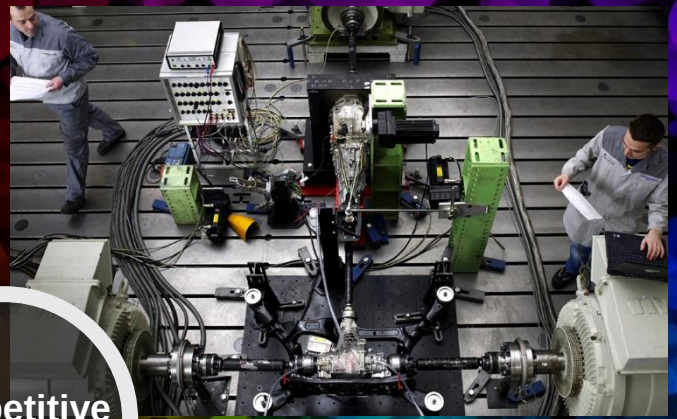
Targeting carbon neutrality in our European operations by 2025 and global operations by 2030.

$37.8B	Sales
341	Manufacturing Assembling Facilities
171,000+	Entrepreneurial Employees
#1	North America market position
#4	Global Market Position

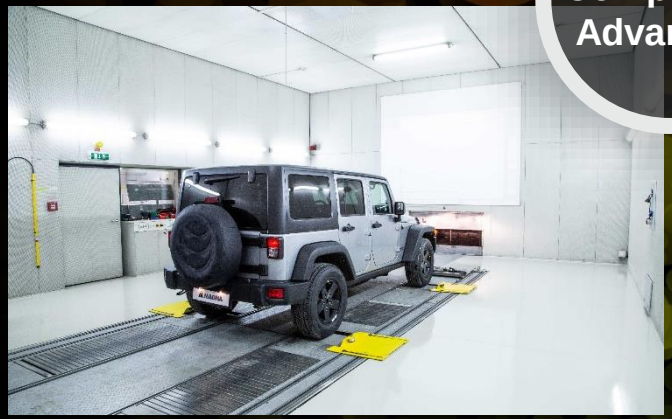
AS OF Q1 2023

Magna Powertrain Capabilities



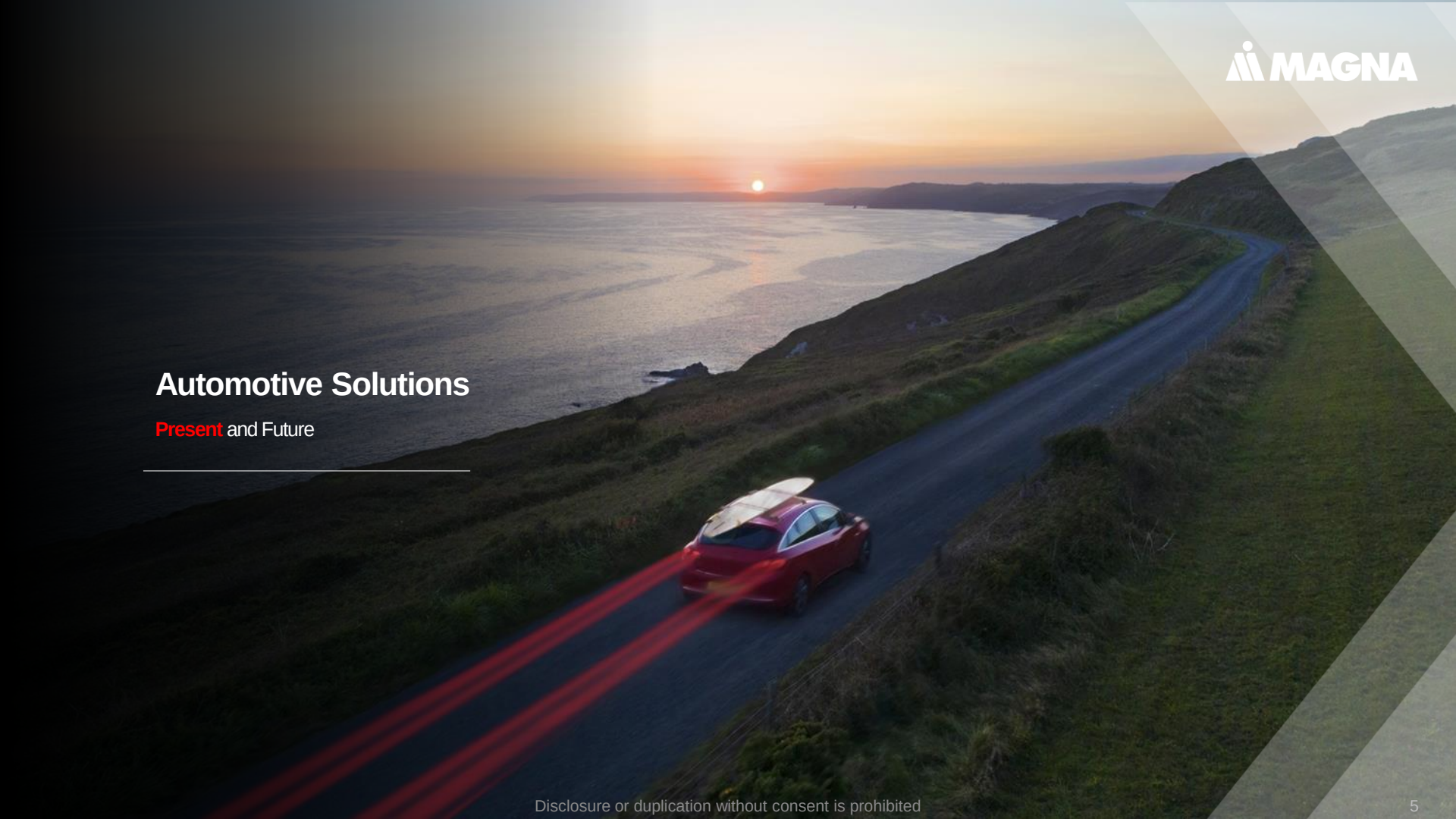


Competitive Advantage



We are a **reliable partner** and always **deliver on time**. We also have **full powertrain development** and **system integration capabilities** along the entire product life cycle.

Our services range from **concept, product development** & **testing** to **production** and **aftersales**.



Automotive Solutions

Present and Future

Latest Magna Powertrain Solutions

Magna EtelligentEco

PHEV Powertrain Solution

- Up to 38% emission reduction
- Unique cloud connectivity feature
- Smart cruise control and eco routing

Magna EtelligentReach

BEV Powertrain Solution

- 30% range extension
- Combination of Next-Gen eDrive, software and controls
- Improvement in efficiency and driving dynamics

Magna EtelligentForce

BEV Powertrain Solution

- Drop-in replacement retains pick-up truck capability
- Leverage existing OEM assembly processes and installed capital

Magna EtelligentCommand

PHEV Powertrain Solution

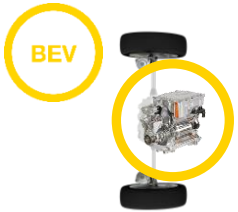
- Enables up to -38 % CO2 saving in real-world driving conditions and 110 km pure electric range (WLTP)
- Up to 15% safety margin

Magna EtelligentTerrain

BEV Powertrain Solution

- Uncompromised on- and off-road capabilities
- Up to 426 kW peak power
- Totally customizable w/o need for architectural changes

Magna eDS Low CE for VW MEB Platform



Compact secondary boost drive for midsize EVs with best-in-class drag torque and compact design. Dedicated design for EV platforms.

Package & Weight

- Compact coaxial design, especially in critical x-direction enabling maximum interior space

E-motor

- ASM w/ OD 200 mm

Vehicle Integration

- NVH jacket prevented

System Efficiency

- Best-in-class drag torque

Pre-Development | Released for Acquisition | Serial Development | **Serial Production**

Magna eDS Low CE

Efficiency
150 W @ 600 rpm best-in-class drag loss

Safety
1,570 Nm front axle torque

Convenience
Preventing secondary NVH measures

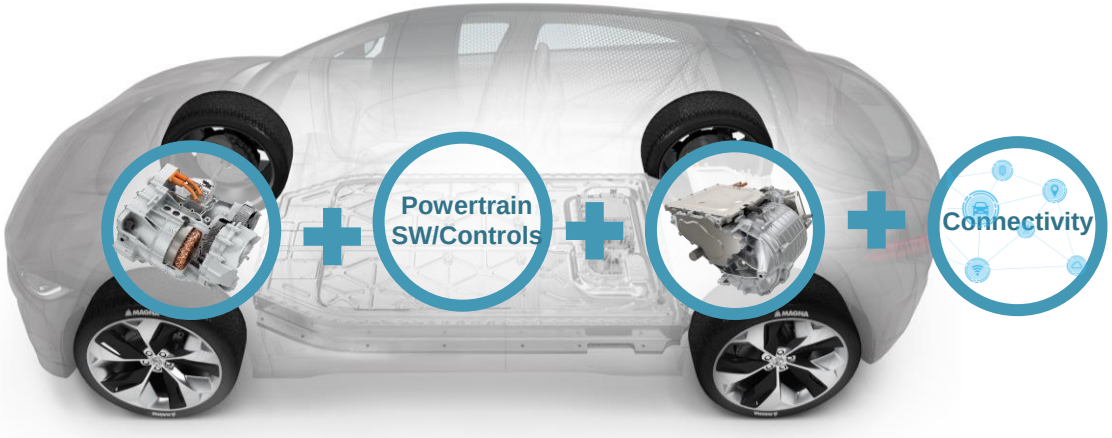
Dynamics
80 kW peak power on front axle up to maximum speed

Sustainability
Dedicated secondary ASM rare earth free

EtelligentReach Benchmark for Range and Dynamics

BEV

EtelligentReach is a BEV powertrain solution with highly integrated Magna eDrive systems on the front and rear axles, as well as an intelligent operating strategy that allows for outstanding drivability in any situation with the most efficient energy use and an extended range.



Front Electric Drive System
- eDS Mid+ w/ Decoupling+

Software/Controls
- Drive controller
- Integrated Brake

Rear Electric Drive System
- eDS Mid+ w/ torque vectoring

Connectivity
- Magna operating strategy

Pre-Development | Released for Acquisition | Serial Development | Serial Production

EtelligentReach
BEV solution

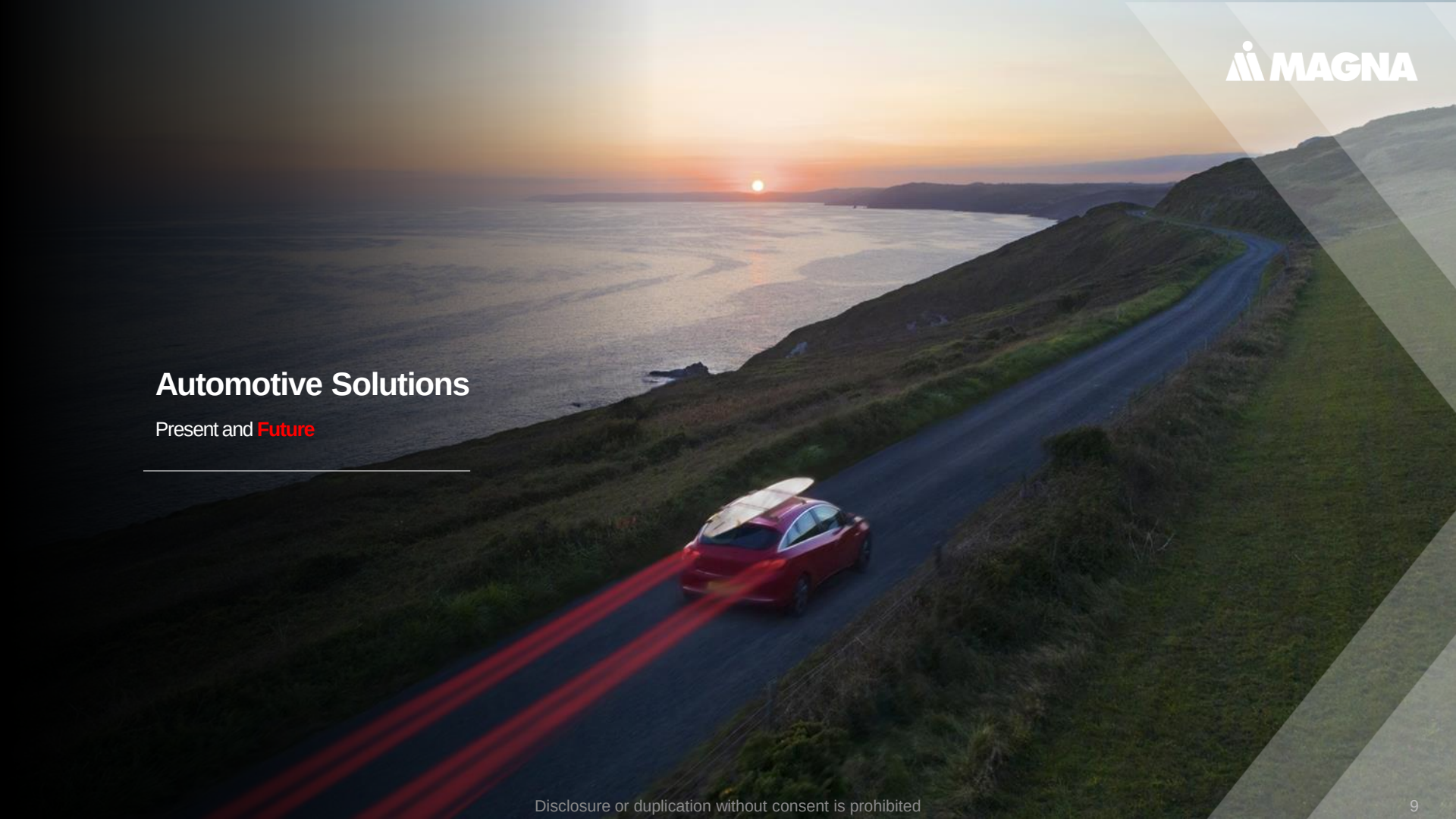
Efficiency
+ 16 % range through powertrain efficiency optimization

Safety
Up to 15 % safety margin

Convenience
- 50 % steering wheel angle demand

Dynamics
+ 0.1 g lateral acceleration

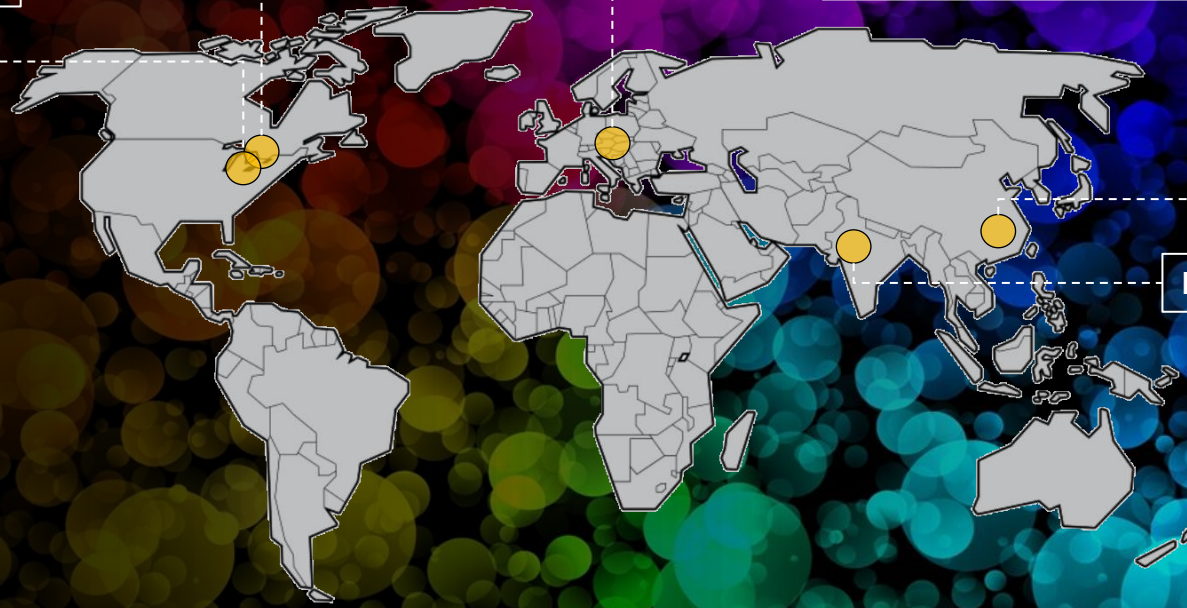
Range
+ 145 km / 90 miles through eDrive system optimization, intelligent operation strategy, vehicle optimization and battery energy density



Automotive Solutions

Present and Future

MAGNA Powertrain - Advanced Engineering
Global Network



CA: Concord

US: Troy

EU: Untergruppenbach / Munich/ Lannach / Traiskirchen / St. Valentin / Albersdorf

CN: Shanghai

IN: Bangalore / Pune

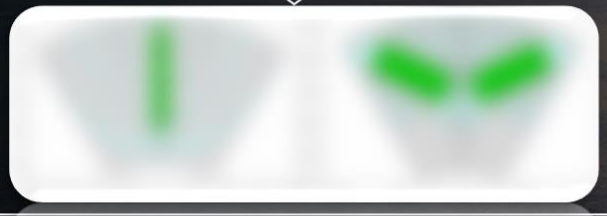
Our squad teams are functionally focused and engaged team members all around the globe. The teams are empowered to execute innovation programs in an agile development environment.

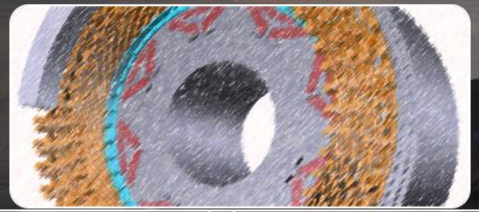
Advanced Engineering E-motor

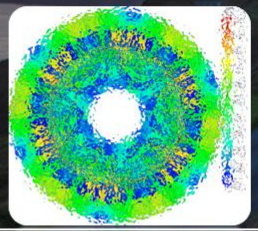
Novel PSM Topologies Implementation

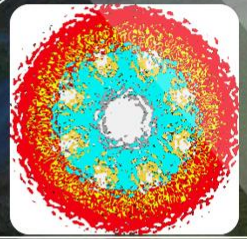
Reimagined Conventional Topologies

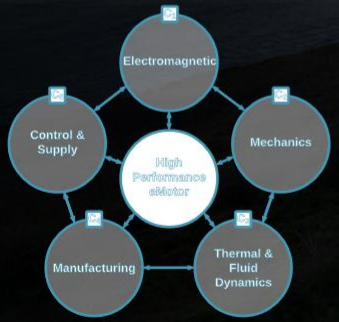
Rare Earth Free Solutions







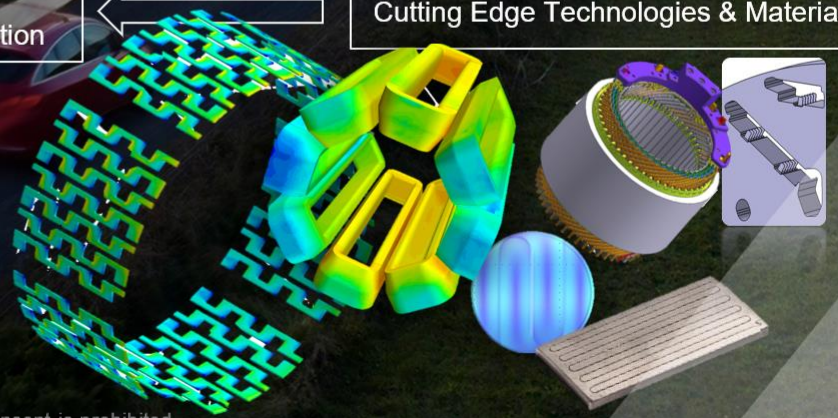




Concepts and Materials Parametrization / Implementation

Multiphysics integrated eMotor design optimisation

Cutting Edge Technologies & Materials



E-motor Design Workflow

From design to Test Bench

Multi physics workflow

MAGNA developed simulation framework based on:

Motor-CAD

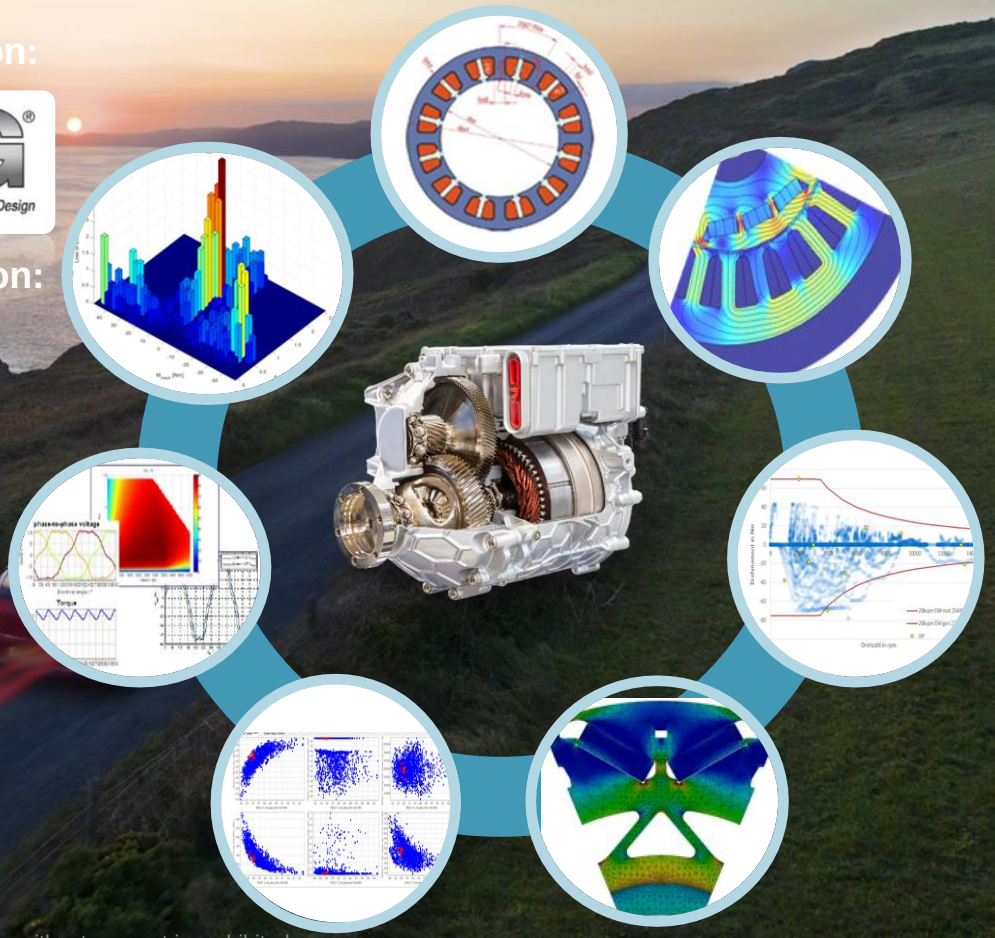
ANSYS Maxwell

SyM

JMAG Simulation Technology for Electromechanical Design

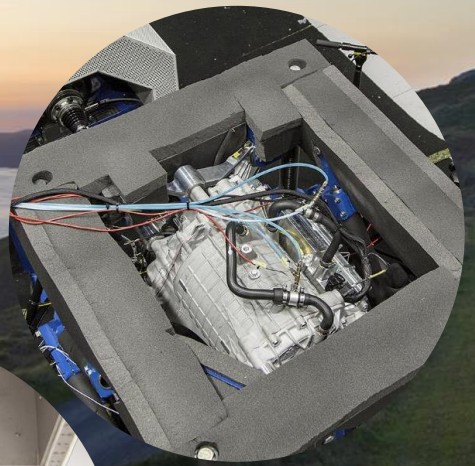
Multi-Objective / Multi-Physics Design Optimization:

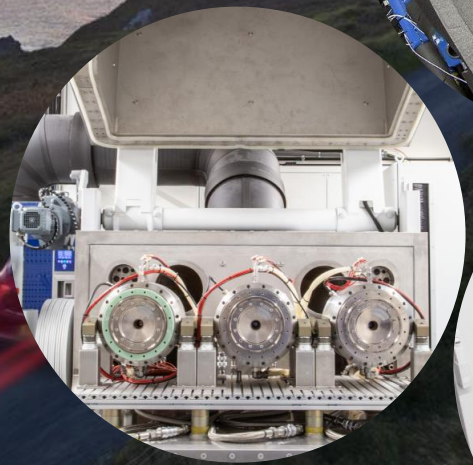
- Fully parametric motor design template
- Finite Element EMAG Simulation
- Loss Reduction and Driving Cycle Optimization
- Cost model / DMF
- Short circuit analysis / demagnetization
- Thermal simulation
- Torque ripple
- Mechanical strength / fatigue
- Tolerance Analysis
- High fidelity map generation
- Motor model (simultaneous engineering)

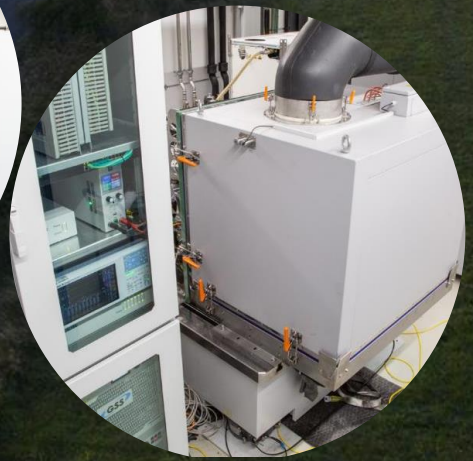


E-motor Testing

- Direct drive benches for eMotor development
  - Functional development
  - DVP testing
  - Efficiency Measurement
  - Parameter testing
- Sub System testing (48V)
  - B2B testing (HTOE / PTCE)
    - Environmental and lifetime testing
    - 6 Samples simultaneously
  - B2B testing (EoL / LPT)
    - delivery testing of 48V Motor, Inverter and System
    - large parameter tests
    - up to 4 samples simultaneously
- Voltage levels
  - 48 Volt
  - High Voltage
    - 400V
    - Update to 800V ongoing
- E-motor test rigs are partly / fully conditioned (oil, water, ambient)



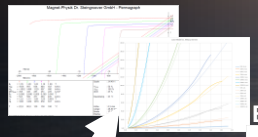




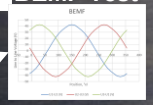
E-motor Testing

Static Tests

Material Measurements

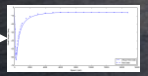


BEMF Test

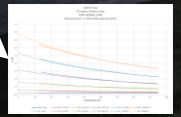


Motor and Material tests

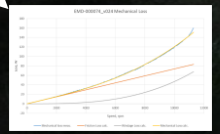
ASC Test



AC-Loss Test

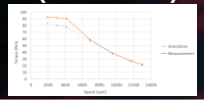


Coast-Down Test



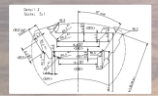
Efficiency Test

Performance Test (Peak/Cont.)



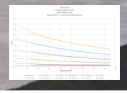
Calibrated Model

Updated Geometry Model



Electromagnetic Loss Model

k_AC

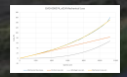


Updated Material Model

PM
Lamination

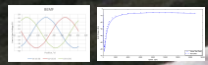
Mechanical Loss Model

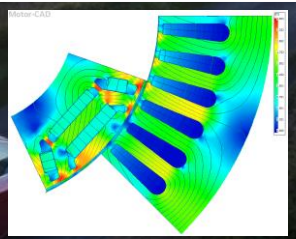
Windage
Friction



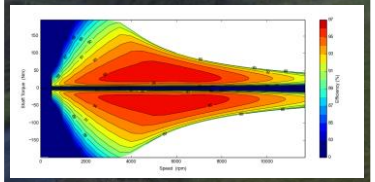
Model Parameters

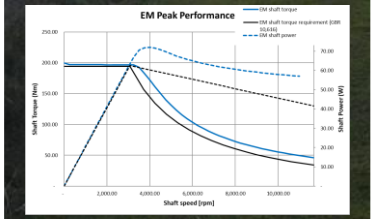
Br
Lσ
Rs





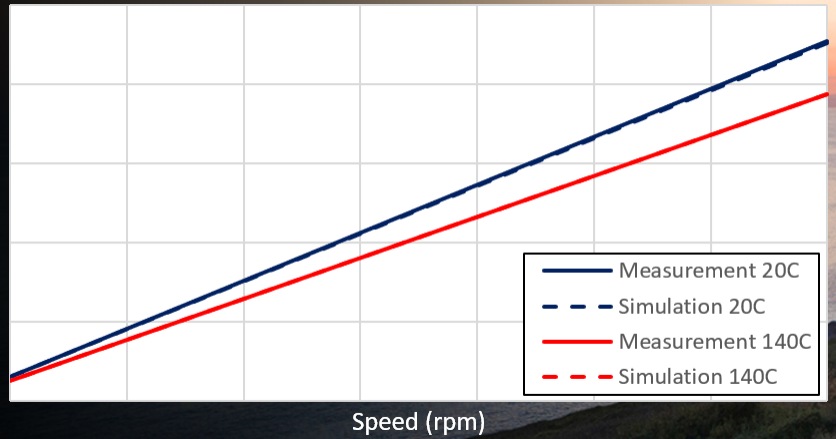
Calibrated Simulation Results

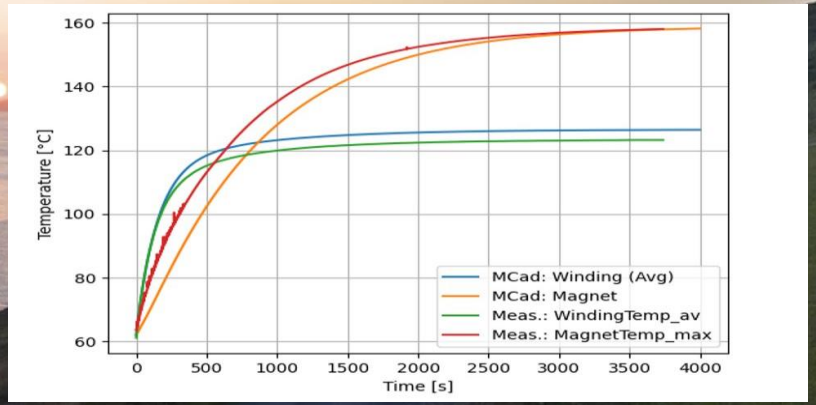


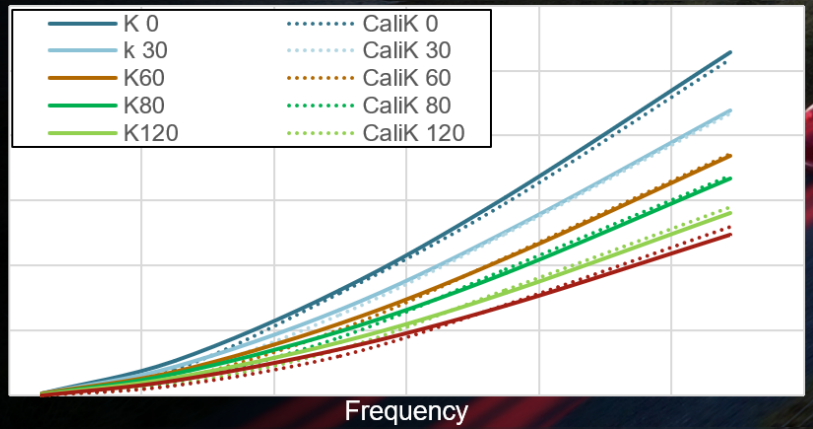


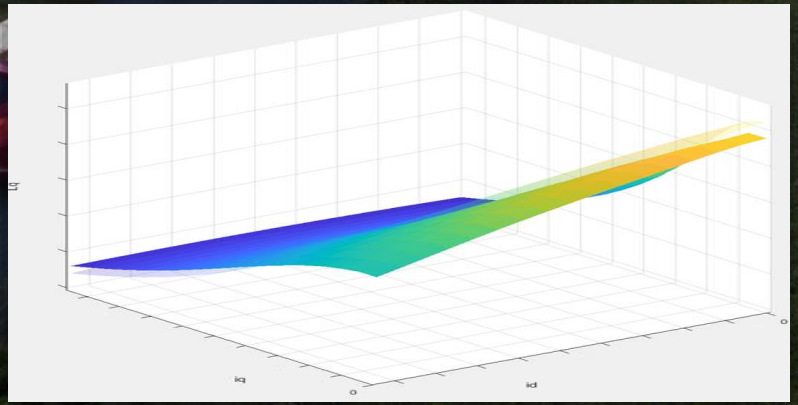
Comparison of Measurement and Calibrated Simulation

Calibration Example

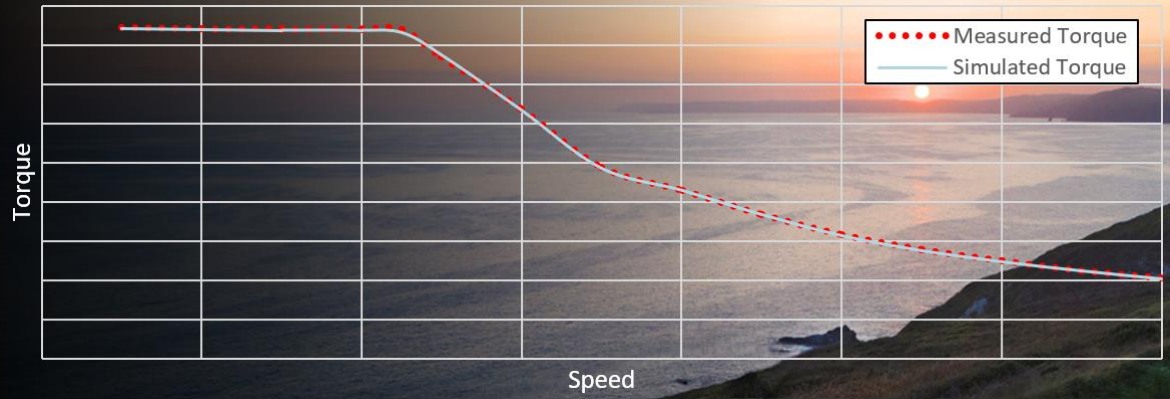


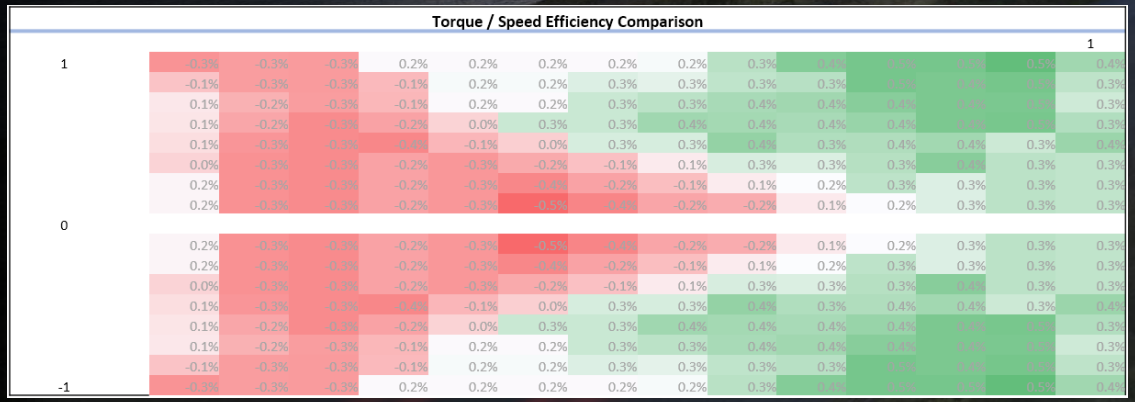






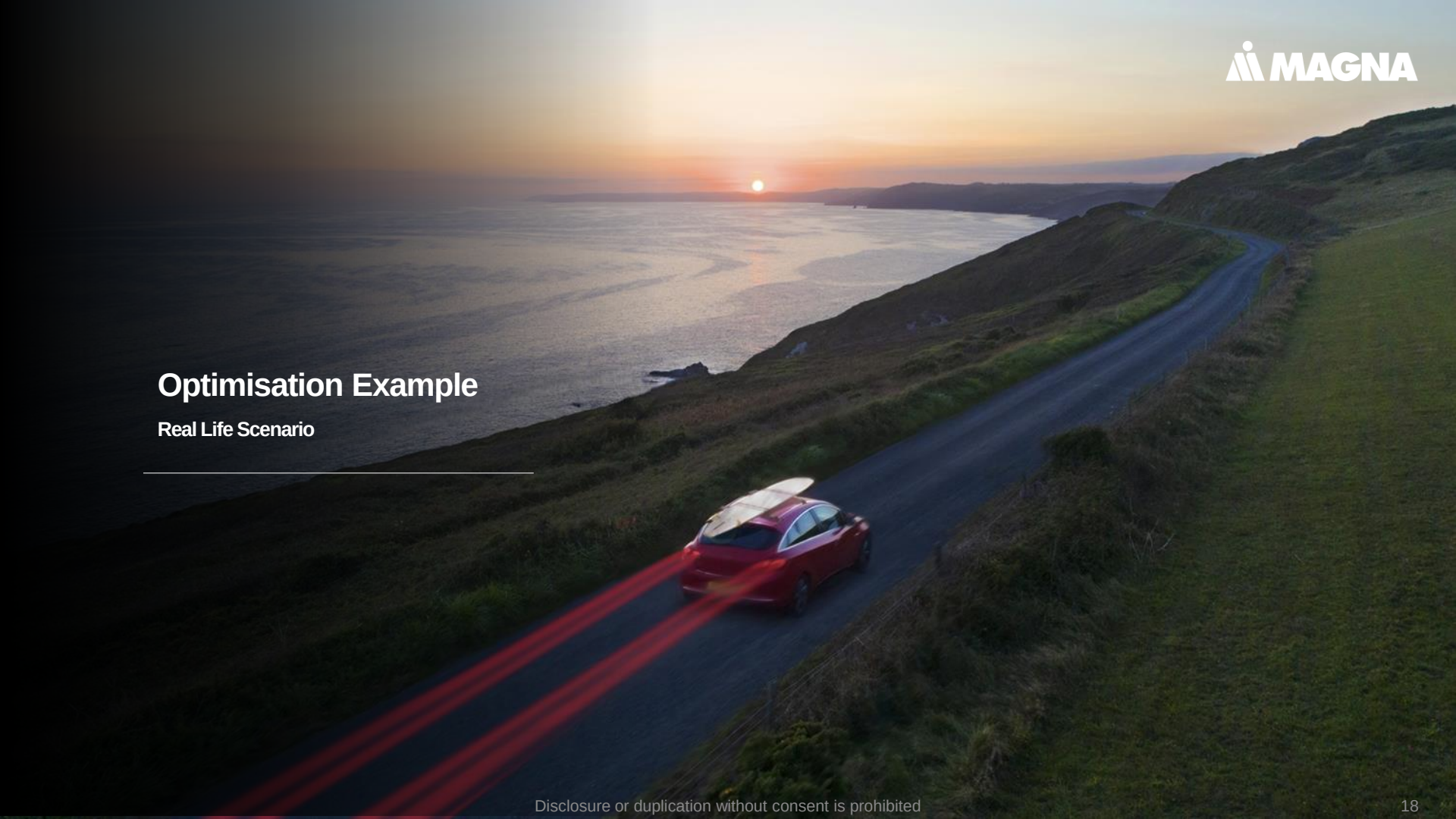
Calibration Example





Relative Torque to maximum torque deliverable per each speed

- Good Torque agreement
- Good Agreement between predicted and measured Efficiency



Optimisation Example

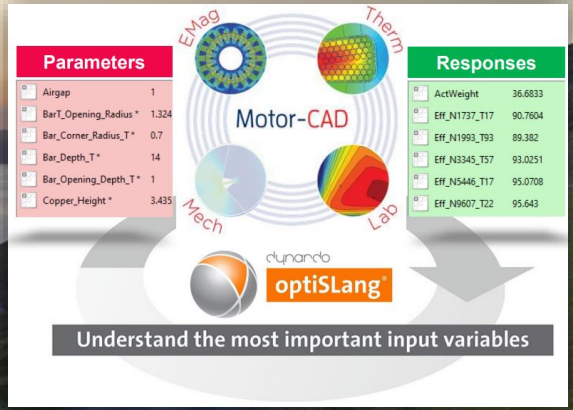
Real Life Scenario

Real Life Example

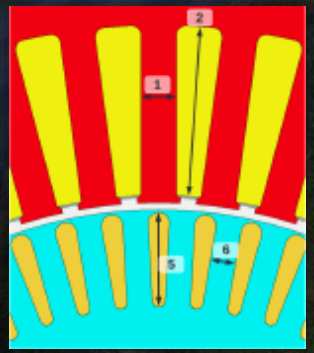
Study Objective

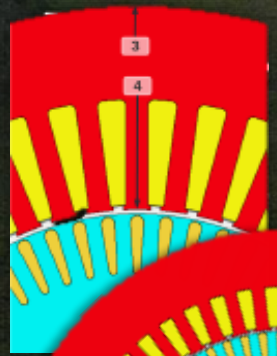
- **Primary Objective:**
  - Develop a low cost secondary eDrive
- **Secondary Objective**
  - Design and optimize two independent motor technologies
- The two motor technologies selected for comparison include:
  1. Permanent magnet machine (PM)
  2. **Induction machine (IM)**

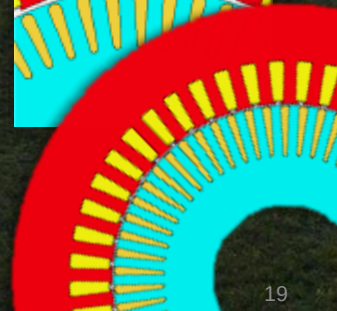
- **IM Initial Design**
  - 800VDC
  - Water/glycol ~10l/min
  - Winding hotspot limit : 180°C
  - Rotor cage temp. limit : 160°C
  - Ambient temperature : 65°C



Nr	Input Parameter
1	Stator Outside Diameter
2	Stator Inside Diameter
3	Stator Tooth Width
4	Stator Slot Depth
5	Stator Stack Length
6	Rotor Bar Height
6	Rotor Bar Width
7	Motor Active Stack Length



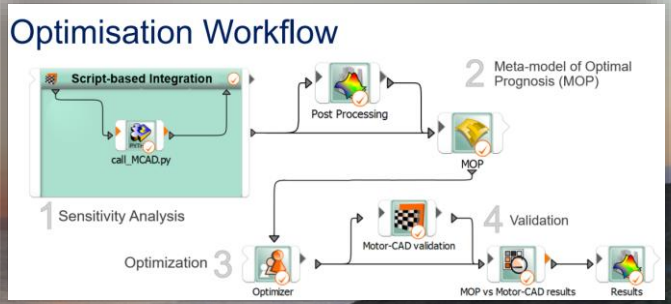




Credits to Eduan Howard

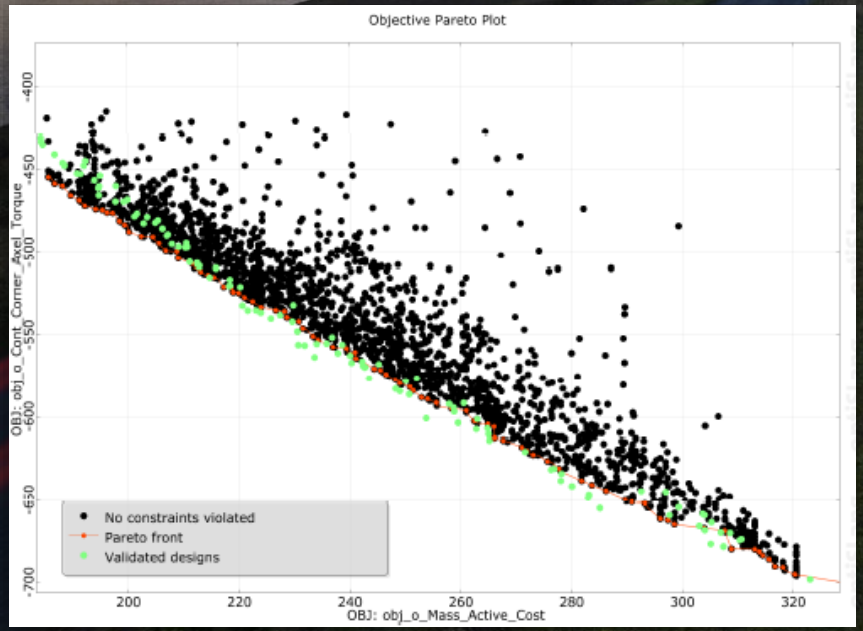
Real Life Example

Optimisation



- **Objective:**
  - **Maximize:**
    - **Corner Point Continuous Torque**
  - **Minimize :**
    - **Active Mass Cost**

- Optimization Results:
  - For the optimization on the AMOP, a generic algorithm was selected.
- Total Motor Evaluations = 28 900
- Total Feasible Designs = 2 437
- Results Validation:
  - Once the optimization converged on a pareto front, motors were selected for prediction validation that best represented the feasible pareto front
- Designs Selected for Validation = 143
- Total Feasible Designs = 70

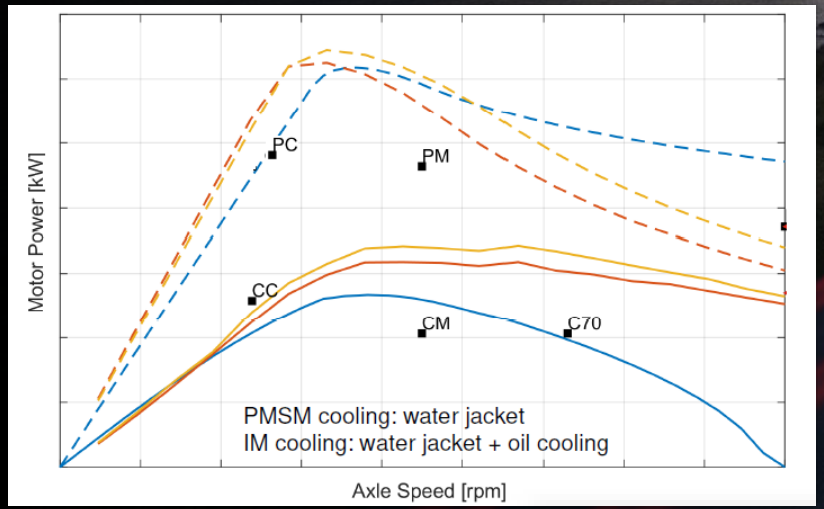


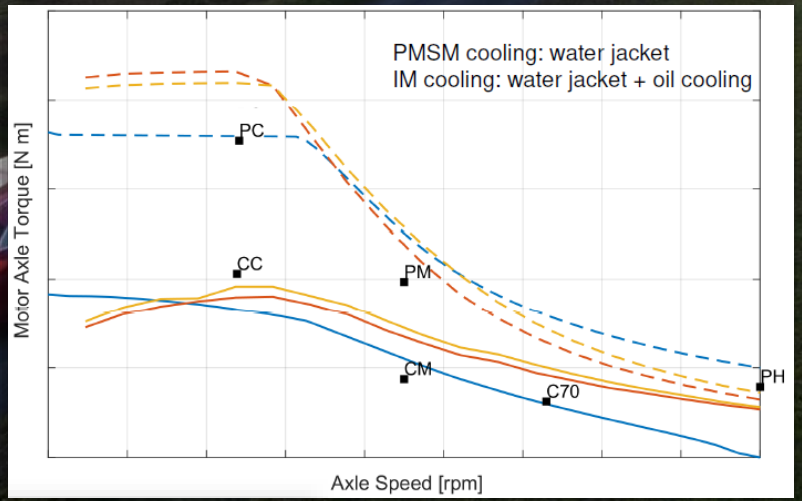
Credits to Eduan Howard

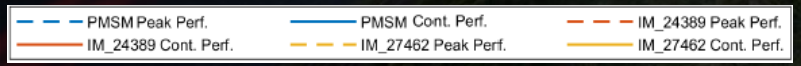
Real Life Example

Optimisation Outcome

- Peak Performance is only EMAG, Continuous Performance is from steady state thermal simulation
- Continuous performance curves were obtained with steady state thermal simulation in Motor-CAD, the requirements have a time duration for each load-point
  - Winding Limit: 180°C, Magnet Limit: 150°C, Cage Limit: 160°C
- Peak performance curves obtained with Motor-CAD Lab
  - Winding Temperature: 180°C, Magnet Temperature: 110°C, Cage Temperature: 160°C







Credits to Eduan Howard

Thank You!

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