MOTEUR ÉLECTRIQUE : DIMENSIONNEMENT PAR L'OPTIMISATION MULTIPHYSIQUE

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ALTAIR AT A GLANCE

Founded **1985**

Headquartered in Troy, MI US

69offices

in 24 countries

$313M

2016 Revenue

50+

ISV partners under our unique, patented licensing model

2000+

Engineers, scientists and creative thinkers

5000+

Customer installations globally

60,000+

Users

OUTLINE

- **Altair Simulation-Driven Design and Solutions for E-Motor Development**
- **The Porsche E-Motor Development Study**
  - **Overview**
  - **Phase 1 – Early Concept Design**
  - **Phase 2 – Multi-Disciplinary Development**
  - **Phase 3 – Consideration of Powertrain Components using Systems Modeling**
- **Summary / Conclusions**

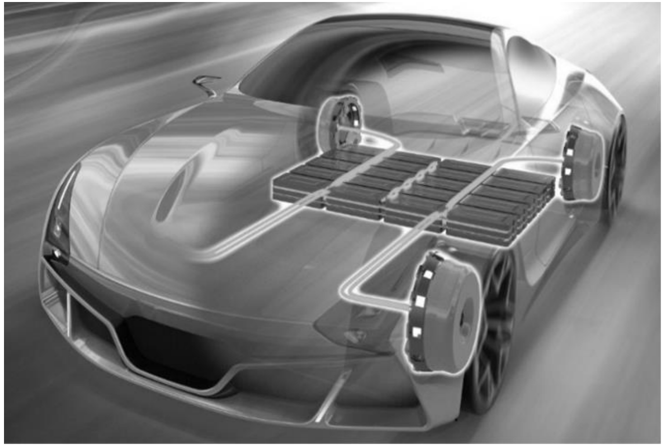
ALTAIR SIMULATION-DRIVEN DESIGN

- MULTI-PHYSICS E-MOTOR DESIGN -

SIMULATION-DRIVEN DEVELOPMENT FOR E-MOBILITY

E-Mobility creates opportunities to radically change the way components and systems are developed.

Packaging and integration are facilitators

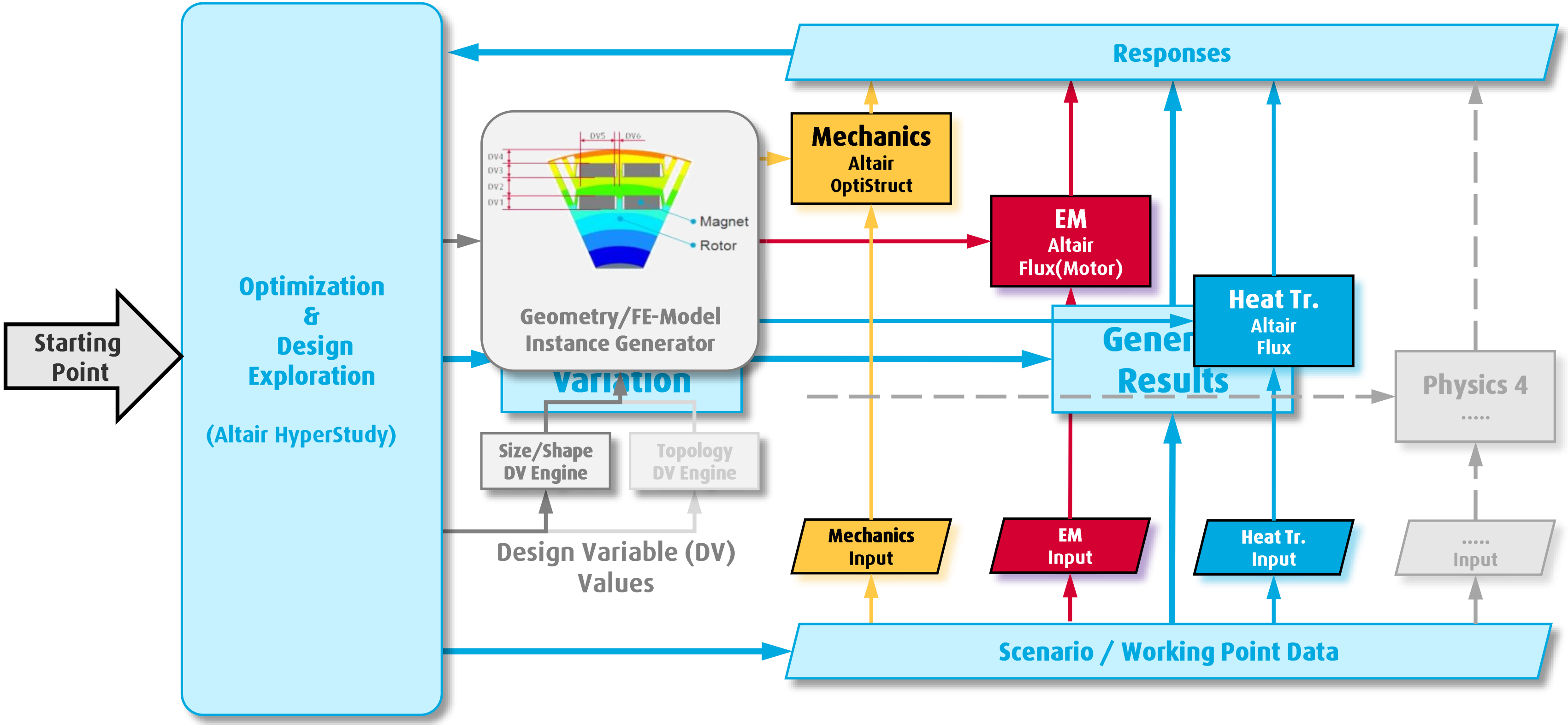


Simulation-Driven Design optimally supports the realization of design improvement opportunities arising from E-mobility

Altair E-Mobility Priorities

- **E-Motor Design:**
  Fulfilling more and higher requirements in shortened development cycles
- **Battery Development:**
  Efficient Integration of Battery Frame into Vehicle Structure
- **Powertrain Integration:**
  Dimensioning and Integration of E-Powertrain Subsystems into an optimal E-Powertrain
- **Cable Simulations:**
  Determining the optimum installation path for cable harnesses and their best shielding
- **EMC - Electromagnetic Compatibility:**
  Examining the influence of external and internal interference sources on installed devices and cables

GENERIC MULTI-PHYSICS E-MOTOR DESIGN ENVIRONMENT



THE PORSCHE E-MOTOR DEVELOPMENT STUDY

- OVERVIEW -

Altair Simulation Driven Design

Porsche E-Motor Development Study

Phase 1

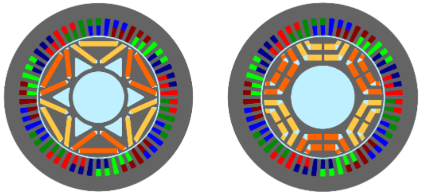
Phase 2

Phase 3

Summary & Conclusions

PORSCHE – E-MOTER DESIGN PILOT STUDY - PHASES

Phase 1
Baseline Concept

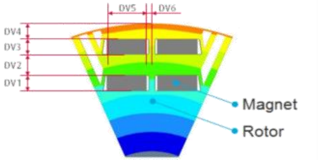


Optimization
Optimization of combinations of baseline rotor and stator concepts for given electromagnetic requirements.

Phase 2
Multi-Physics

Physics
EM, Structural, Thermal

Design Space
Magnet Shapes

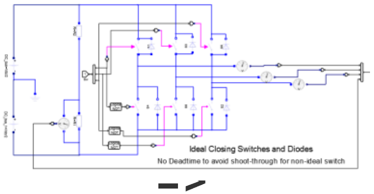


Responses
Power, Torque, Torque Ripples, Max Speed, Losses, Temperatures, Demagnetization, Stress

Scenarios
Individual Working Points

Phase 3
Systems Approach

Addition of Inverter Model



more realistic
Torques and Efficiencies

Altair Activate

PORSCHE DEVELOPMENT REQUIREMENTS

Porsche Design Challenge

Objectives:

- Maximum power (base point)
- Minimize torque ripples

Constraints:

- Demagnetization at base point
- Mechanical strength
- Temperature of winding lower than 200°C

The stator is imposed. The rotor design is open in any direction, meeting the requirements

Requirements:

- Iron fill factor: 0,92
- Magnet: Br 1,15
- T_{max} winding: 200°C
- T_{max} rotor: 180°C
- Minimum power: 170kW
- Max phase voltage: 241V
- Max phase current: 300A
- DC-link voltage : 650V, 800V

PHASE 1

- EARLY CONCEPT DEVELOPMENT -

Altair Simulation Driven Design

Porsche E-Motor Development Study

Phase 1

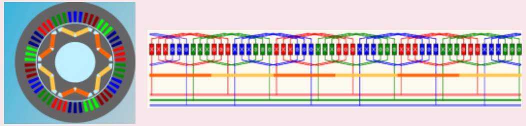
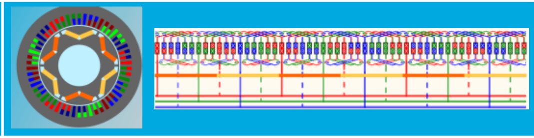
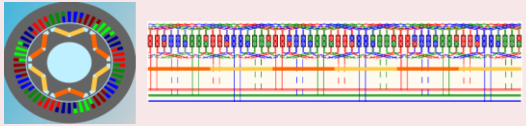
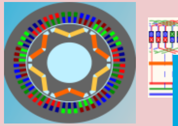
Phase 2

Phase 3

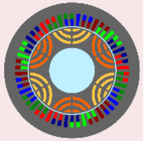
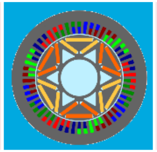
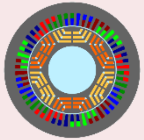
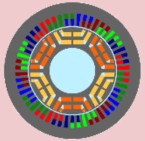
Summary & Conclusions

MOTOR BASELINE CONCEPT PROCESS

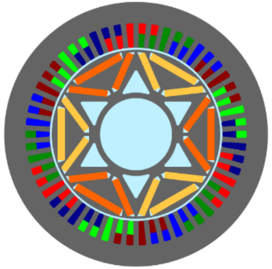
Winding Selection

Winding A	
Winding B	
Winding C	
Winding D	

Rotor Selection

	Rotor A	Rotor B	Rotor C	Rotor D
				
Current den (A/mm2)	31,1	31,1	31,1	31,1
Torque (Nm)	181	164	165	162
Power (kW)	195	186	185	180
Base speed (rpm)	10.290	10.830	10.670	10.610
Efficiency (%)	96,0	95,9	95,9	95,7
Magnet weight (Kg)	2,54	2,48	2,48	2,53

Final Baseline Concept

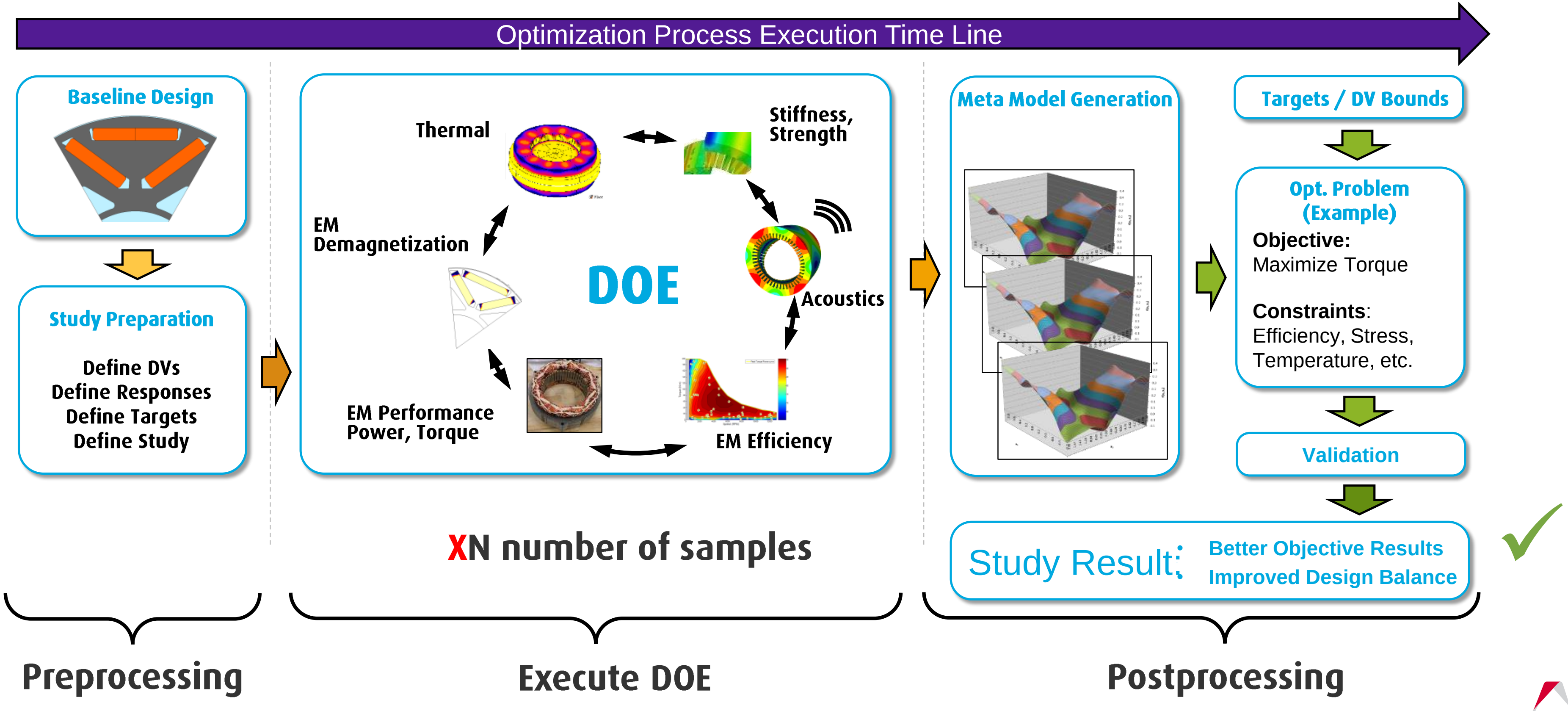


PHASE 2

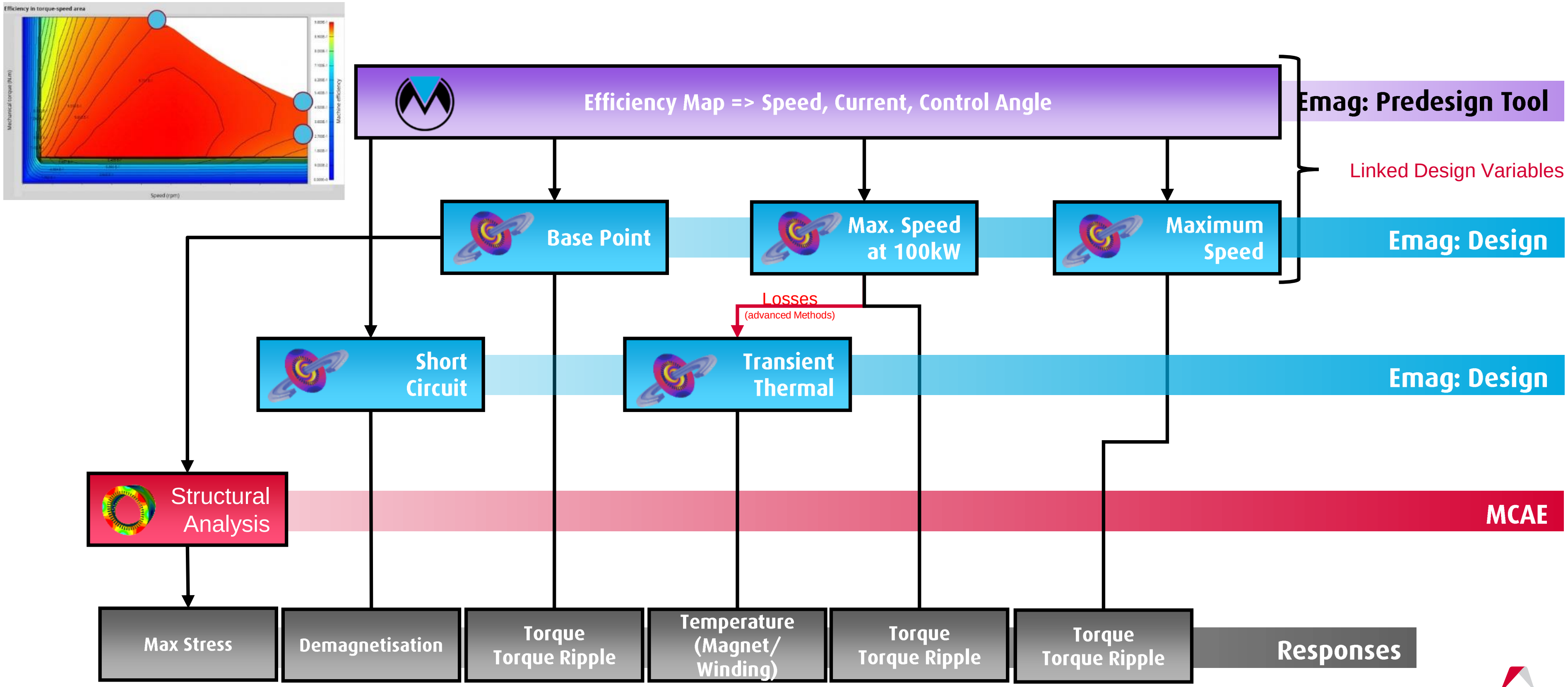
- MULTI-PHYSICS DEVELOPMENT -

Altair Simulation Driven Design	Porsche E-Motor Development Study			Summary & Conclusions
	Phase 1	Phase 2	Phase 3	

MULTI-DISCIPLINARY/PHYSICS OPTIMIZATION – GENERIC OVERVIEW



SIMULATIONS TO EXTRACT RESPONSES FOR ONE SINGLE DESIGN



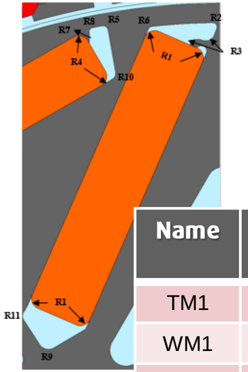
OPTIMIZATION OUTLINE

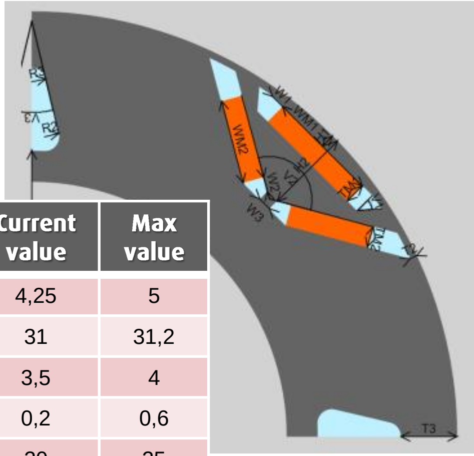
Summary of Optimization Problem in HyperStudy

Add Model | Remove Model | Model Resources

	Active	Label	Varname	Model Type	Solving time	
1	☑	FluxMotor	m_1	FluxMotor	2,5	minutes
2	☑	base_speed	m_2	Flux	4	minutes
3	☑	Max_Speed	m_3	Flux	4	minutes
4	☑	Short_circuit	m_4	Flux	6	minutes
5	☑	100_kW_MAx_S...	m_5	Flux	4	minutes
6	☑	Thermal	m_6	Flux	6	minutes
7	☑	HyperMesh	m_7	Operator	10	seconds
8	☑	OptiStruct	m_8	Operator	2	minutes
					29	**minutes**

Design Space



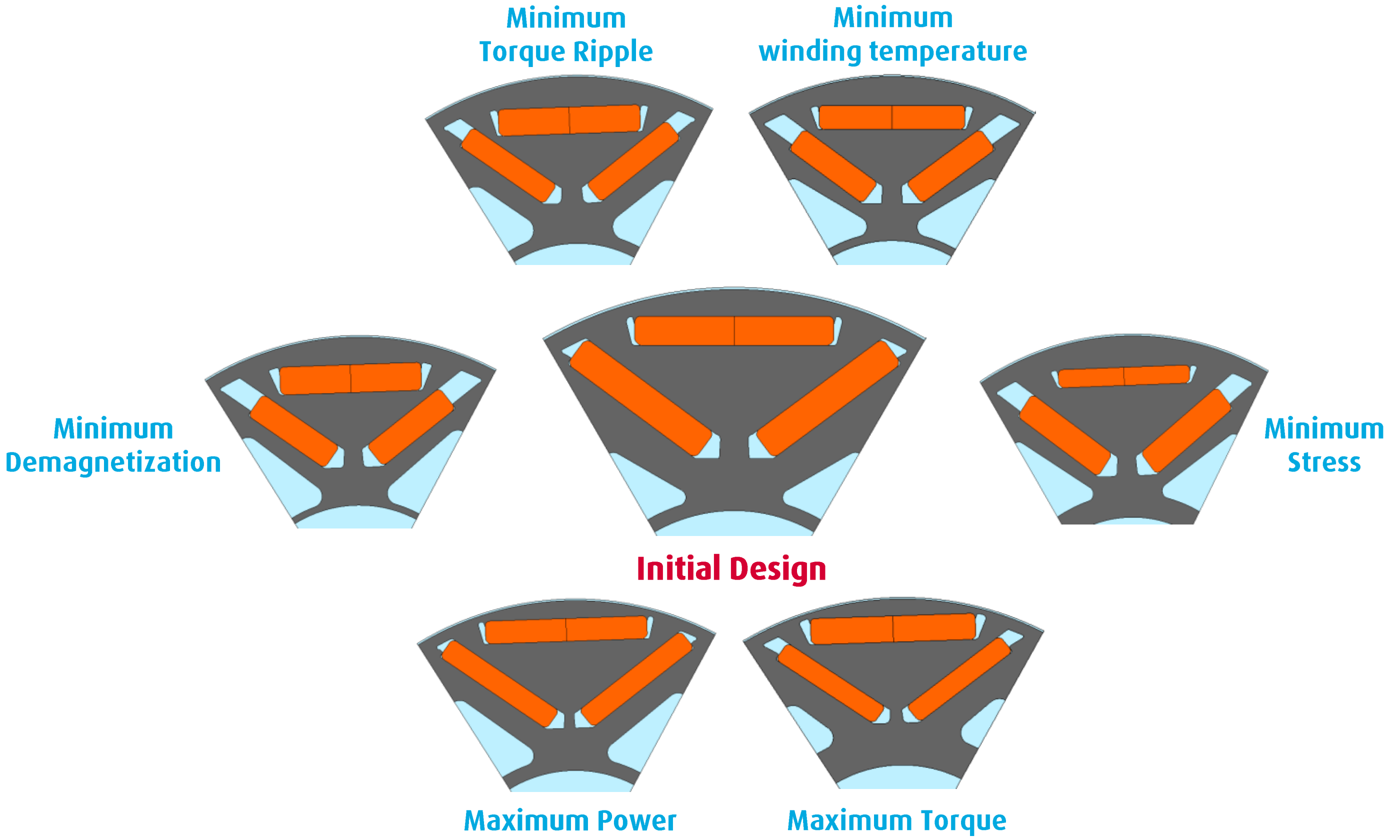


Name	Min Value	Current value	Max value
TM1	3	4,25	5
WM1	29	31	31,2
H1	3	3,5	4
W1	0,2	0,2	0,6
V1	15	20	25
TM2	3,5	4,75	4,75
WM2	16	23	23
H2	20	20	20
W2	0,5	0,6	0,7
T2	1,1	1,5	1,6
V2	106,7	107	107,1

DOE Study

- 18 Design Variables
- Approximately 400 runs
- 18h with 15 cores in parallel

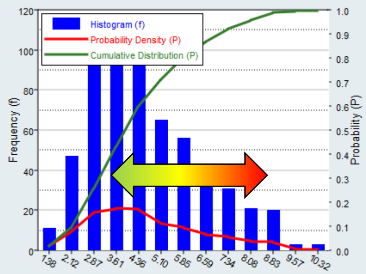
DESIGN EXPLORATION ON DOE RESULTS



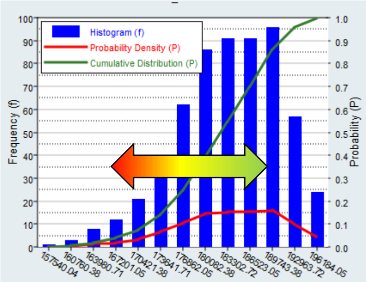
GLOBAL OPTIMIZATION

2 Objectives

- Min Torque Ripples
- Max Power



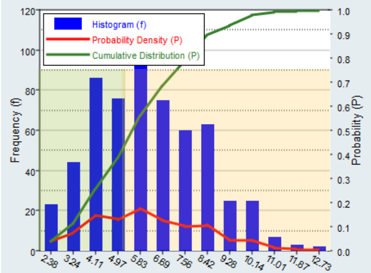
Torque Ripples



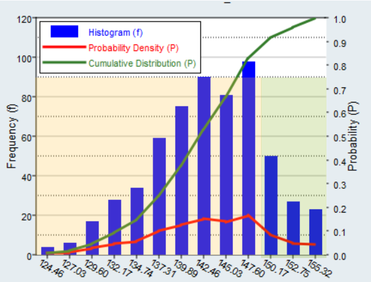
Mechanical Power

4 Constraints

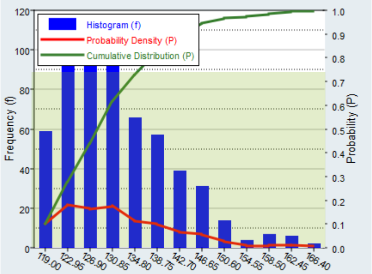
- Demagnetization < 5 %
- Base torque >= 150 Nm
- Temperature winding <180°C
- Max stress <= 500 Mpa



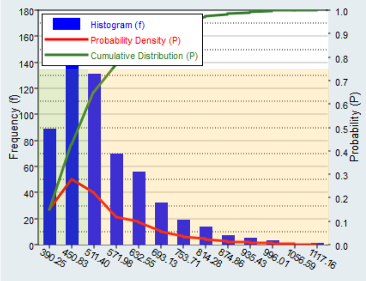
Demagnetization



Mechanical Torque

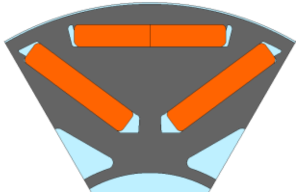


Temp Winding

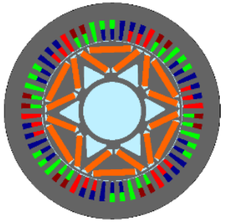


Max Stress

E-MOTOR OPTIMIZATION PROBLEM – FINAL RESULTS



	Initial
Base torque [Nm]	155
Base torque Ripple [Nm]	8,5
Stress [Mpa]	2.316
Winding Temp. [°C]	171
Demagnetization Factor	6,6



- **Optimization Objective:**
  - **Maximize base output Power**
  - **Minimize base Torque Ripple**
- **Constraints:**
  - **Stress lower than 500 MPa**
  - **Winding Temperature lower than 180°C**
  - **Demagnetization lower than 5%**
  - **Base Torque greater than 150 Nm**

Magnet Weight Reduction of 40 %

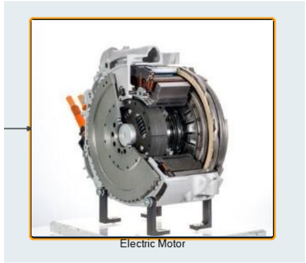
PHASE 3

- CONSIDERATION OF POWERTRAIN COMPONENTS USING SYSTEMS MODELING -

PROCESS: ACTIVATE INVERTER INPUTS TO FLUX

Flux

Motor Parameters



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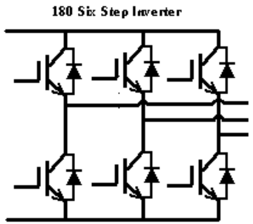

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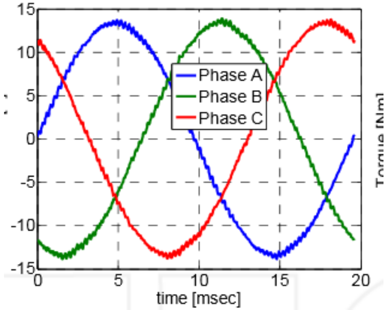


Current Waveforms

Flux

More Accurate Motor Results: Losses, Torque Ripple, etc.

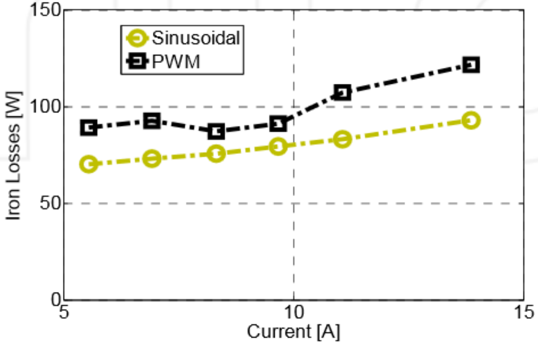


*Image Source: https://cdn.intechopen.com/pdfs-wm/39370.pdf
See notes, next slide for details

Faster process than direct co-sim:
Use simplified motor model in Activate to generate steady-state current

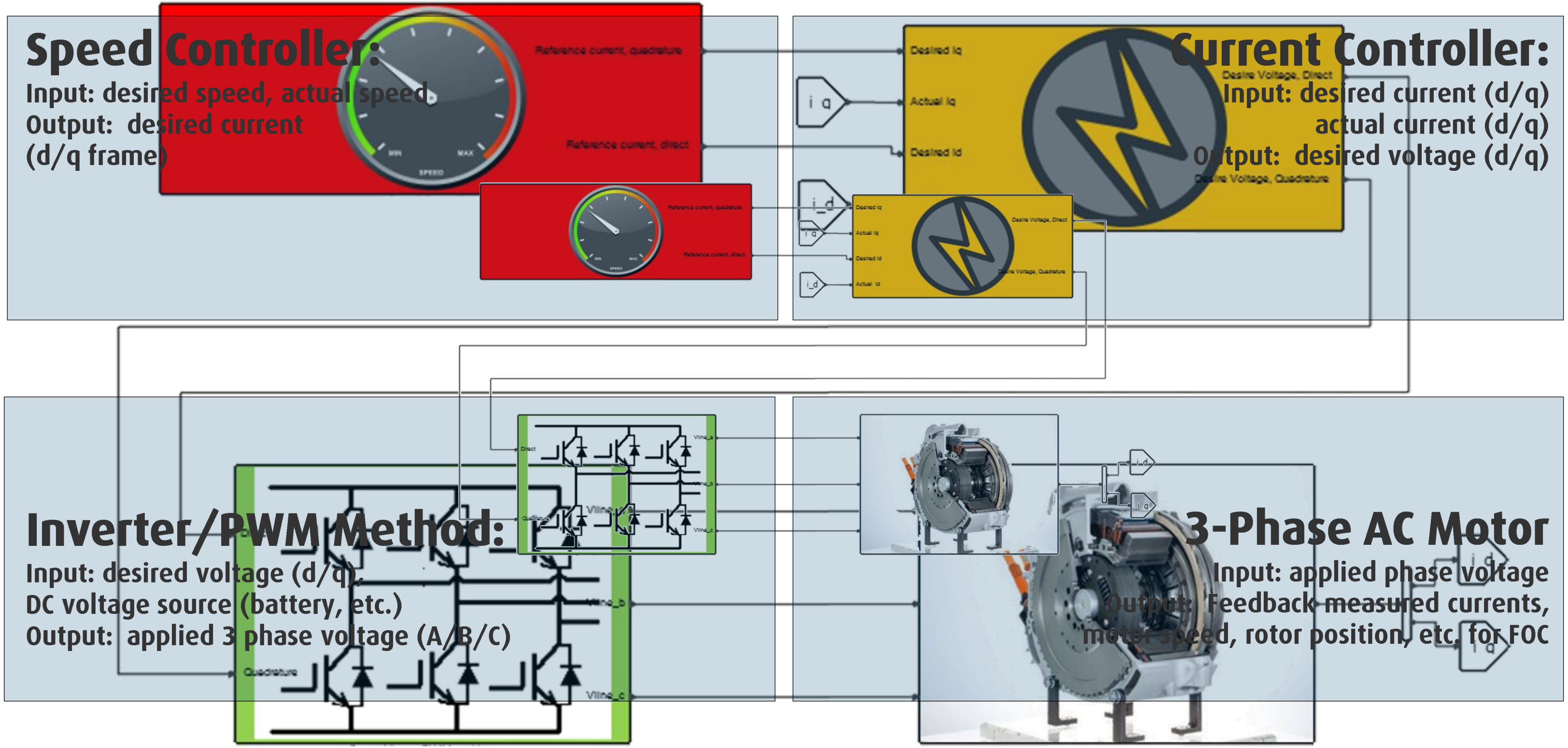
FIELD ORIENTED CONTROL STEPS: OVERVIEW

Speed Controller:
Input: desired speed, actual speed
Output: desired current
(d/q frame)

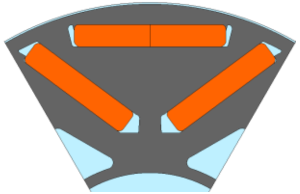
Current Controller:
Input: desired current (d/q)
actual current (d/q)
Output: desired voltage (d/q)

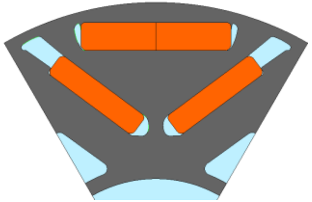
Inverter/PWM Method:
Input: desired voltage (d/q),
DC voltage source (battery, etc.)
Output: applied 3 phase voltage (A/B/C)

3-Phase AC Motor
Input: applied phase voltage
Output: Feedback measured currents,
motor speed, rotor position, etc. for FOC

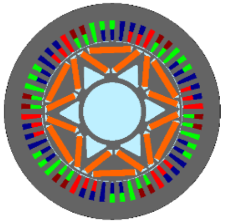


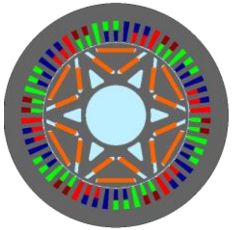
E-MOTOR OPTIMIZATION PROBLEM – FINAL RESULTS WITH PWM





	Initial	Current Optimum With Sine Current
Base torque [Nm]	155	150
Base torque Ripple [Nm]	8,5	5,4
Stress [Mpa]	2.316	500
Winding Temp. [°C]	171	139
Demagnetization Factor	6,6	5,2

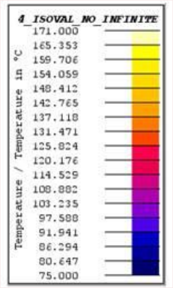




Magnet Weight Reduction of 40 %

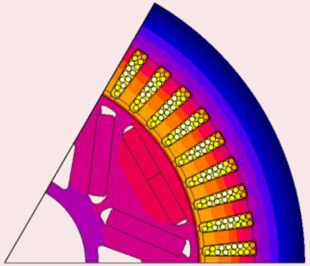
(*) TEMPERATURES USING PWM CURRENT

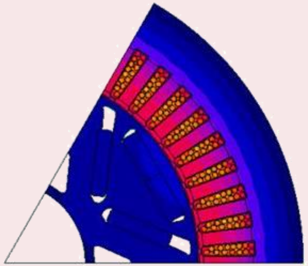
	Initial	Current Optimum With Sine Current	Current Optimum with PWM Current (620V – 800V)
Joule losses (W)	4.220	2.266	2.272 – 2.278
Magnet losses (W)	143,6	58	141 - 164
Iron losses stator (W)	1.157	1.096	1.173 – 1.206
Iron losses rotor (W)	230	159	196 - 208
Temp. Rotor [°C]	Tmax 118	Tmax 87	Tmax 103 - 108

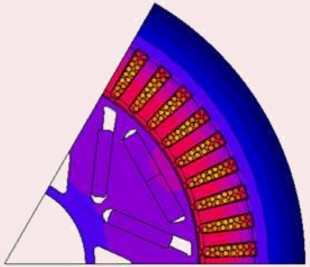


High

Low







Added losses leads to 20 % higher temperatures in magnets and rotor yoke

SUMMARY & CONCLUSIONS

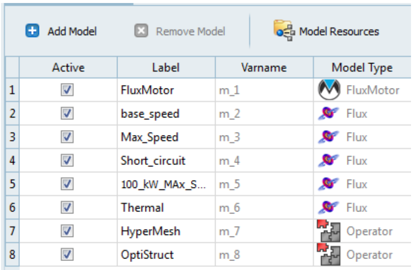
SUMMARY

Multi-physics design optimization of an E-motor has been demonstrated including:

- **Predesign of motor**
- **Electromagnetic analysis**
- **Thermal analysis**
- **Structural analysis**

Processes have been demonstrated to support early development, to support later multi-physics development and to support the integration with systems modeling approaches to consider the complete powertrain.

The tools and the open APIs provide a very large flexibility to provide design processes which can be adapted to local customer requirements and suitable for integration into the customer design process.



	Active	Label	Varname	Model Type
1	☑	FluxMotor	m_1	FluxMotor
2	☑	base_speed	m_2	Flux
3	☑	Max_Speed	m_3	Flux
4	☑	Short_circuit	m_4	Flux
5	☑	100_kW_MAx_S...	m_5	Flux
6	☑	Thermal	m_6	Flux
7	☑	HyperMesh	m_7	Operator
8	☑	OptiStruct	m_8	Operator