Altair Technology Conference 2018

Efficient Design Workflow for Optimizing Electric Vehicles Including Fast Predesign, Magnetic, Thermal and Structural Analysis

Dr Patrick Lombard – Lead Application Specialist Manager

ATC 2018

OUTLINE

- Introduction
- Requirements
- Multi-physics analysis
  - Predesign
  - Magnetic analysis
  - Thermal analysis
  - Structural analysis
- Optimisation
- Conclusion

INTRODUCTION

- How to design an Electric motor for automobile ?
- Taking into account of different constraints
  - Cheap
  - Light
  - Efficient
  - Not too hot
  - Silent

BMW i3 and i8

Jaguar I-Pace

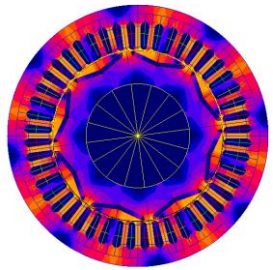
- Run multi-Physics analysis
- And Optimize

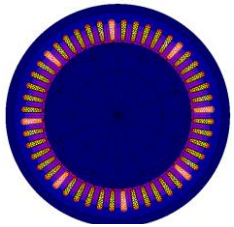
Electric motors already designed with Altair tools !

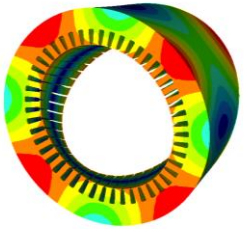
- Proposal : have a look at how to achieve this on an example

- Define requirements from PORSCHE

- Define a design strategy
  - For fast predesign with FluxMotor
  - For magnetic analysis with Flux 2D
  - For thermal analysis with Flux 2D
  - For structural analysis with OptiStruct
  - For optimization with HyperStudy







- Apply it !

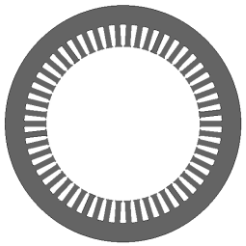
© 2018 Altair Engineering, Inc. Proprietary and Confidential. All rights reserved.

Requirements

REQUIREMENTS

PORSCHE

- Objectives
  - Maximum power (base point)
  - Minimize torque ripple
- 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

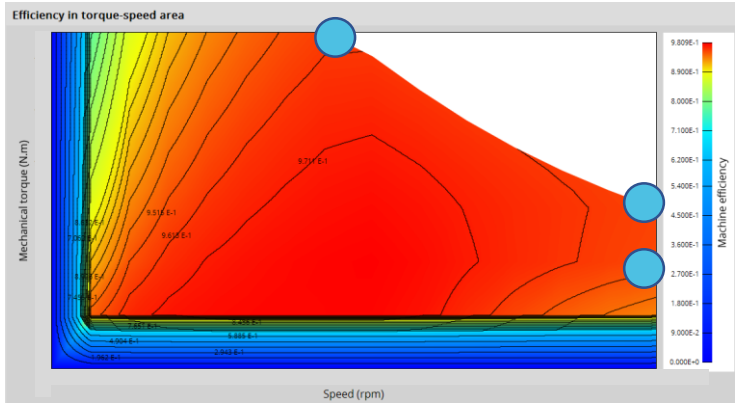


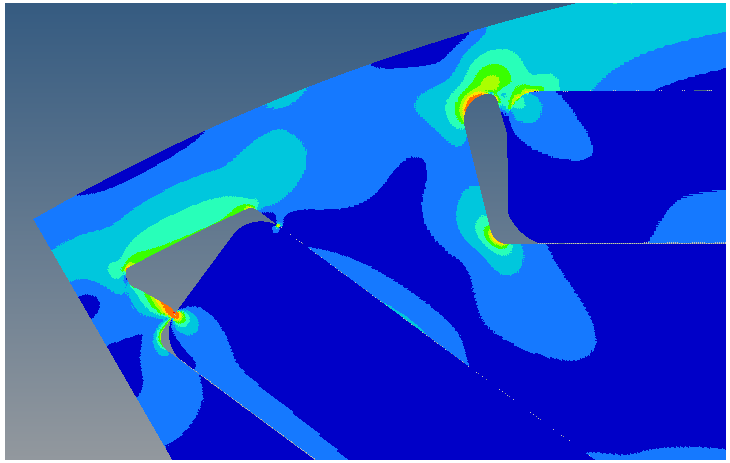
- Requirements
  - Stator diameter : DIAM
  - Active length : LENGTH
  - Iron fill factor : 0,92
  - Magnet : Br 1,15 T
  - Tmax winding 200°C
  - Tmax rotor : 180°C
  - Maximum speed : MAXS rpm
  - Minimum power : 170kW
  - Max phase voltage : 241V
  - Max phase current : 300A
  - DC-link voltage : 650V, 800V

Some data are missing for confidentiality reasons

METHOD

- Base point
  - Determine it
  - Extract average torque and torque ripple
  - Run short-circuit test and check risk of demagnetization
- Max speed max torque
  - Extract average torque and torque ripple + losses
- Max speed 100 kW : check temperature after 2 hours
  - Run magnetic analysis in order to know the losses
  - Run thermal 2D analysis to check temperature after 2 hours
- Stress : check stress at MAXS rpm on rotor only



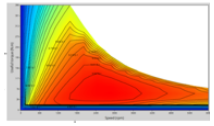


OPTIMIZATION LOOP

ATC 2018

Rotor parameters

HyperStudy



Objective:
- Max power
- Min torque ripple

Constraints
- Demagnetisation < 5%
- Stress < 500 MPa
- Temperature < 200°C
- base torque >150 Nm

FluxMotor
- SineWave test

Results
- Base point : speed, angle
- Max speed : current, angle
- Max speed 100kW : current, angle

Flux
- Base point
- Max speed
- Short-circuit at base point
- Max speed 100 kW
- Thermal 2D analysis

Results
- base speed : torque ripple, efficiency, mean torque
- Max speed: losses, torque ripples, mean torque
- Check demagnetization
- Max speed 100kW : losses
- Temperature after 2 hours at max speed (100 kW)

OptiStruct
- Structural analysis at maximum speed

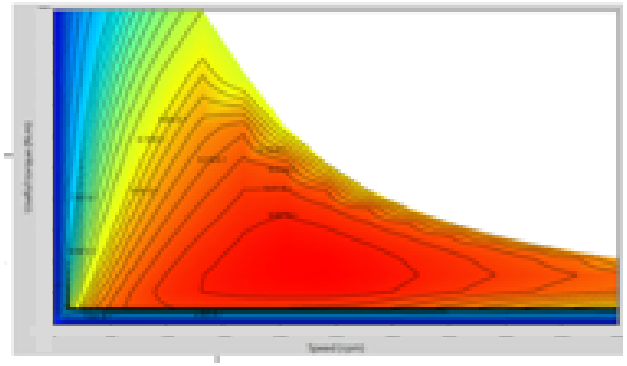
- Max constraints around magnets

© 2018 Altair Engineering, Inc. Proprietary and Confidential. All rights reserved.

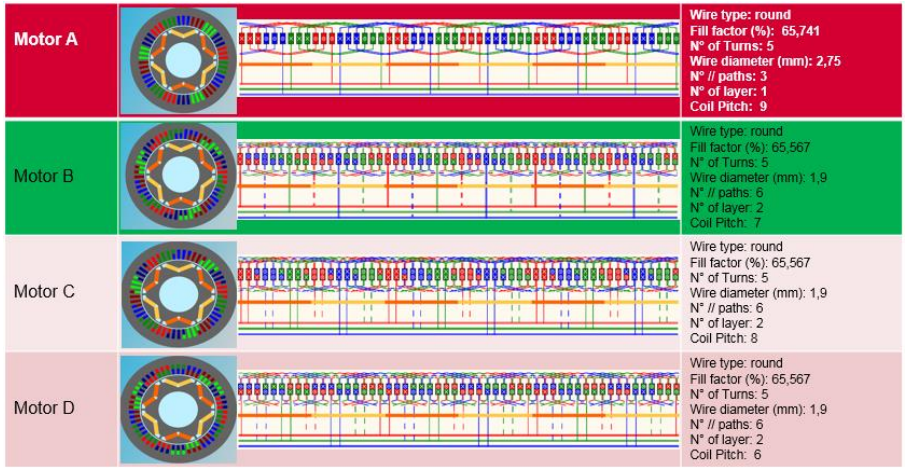
Multi-Physics Analysis

FAST PREDESIGN WITH FLUXMOTOR :

- Input
  - Rotor geometric parameters
- Ouput
  - Base speed : speed, current, angle, torque ripple
  - Max speed : speed, current, angle, losses
  - 100 kW: current, angle
- Method : efficiency test

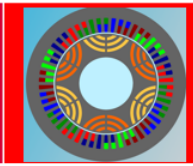
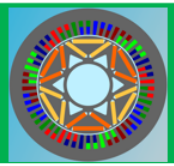
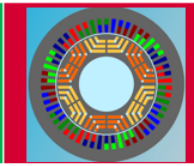
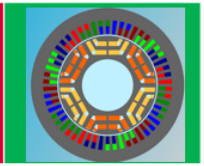


First step : analysis on winding



Second step : try 4 different topologies

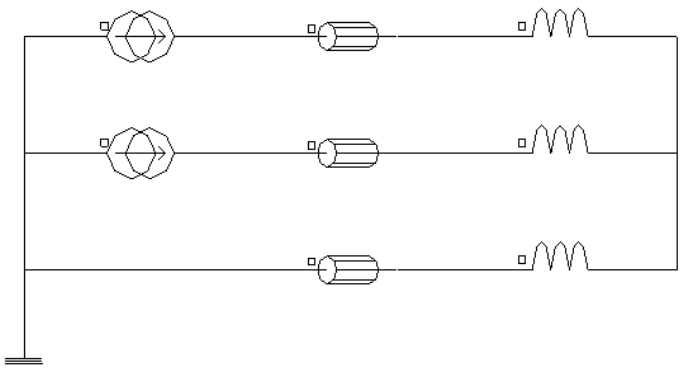
- Results base speed :

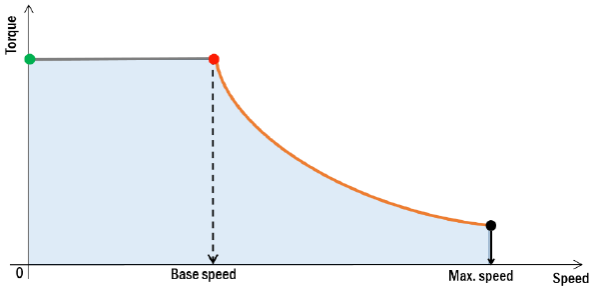
	Rotor A	Rotor B	Rotor C	Rotor D
				
Current density (A/mm2)	31,132	31,132	31,132	31,132
Torque (N.m)	180,54	163,78	165,47	167,7
Power (KW)	194,6	185,7	184,8	177,7
Base speed (rpm)	10291,2	10826,55	10665,8	10116
Efficiency (%)	96,05	95,87	95,8	95,15
Magnet weight (Kg)	2,543	2,479	2,485	2,533

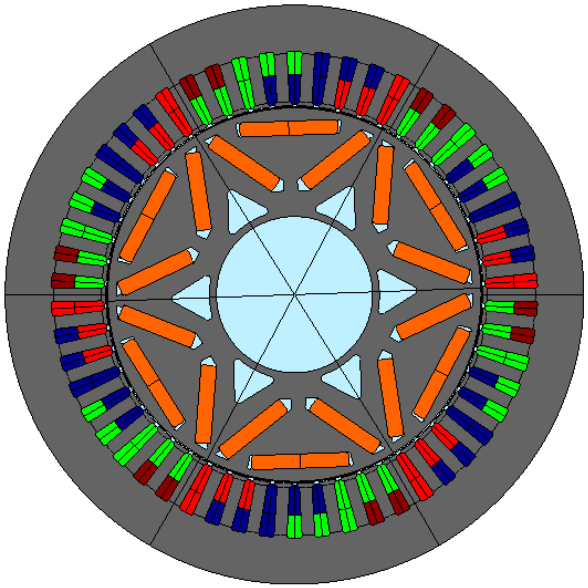
we keep motor B and D (A more costly to build)

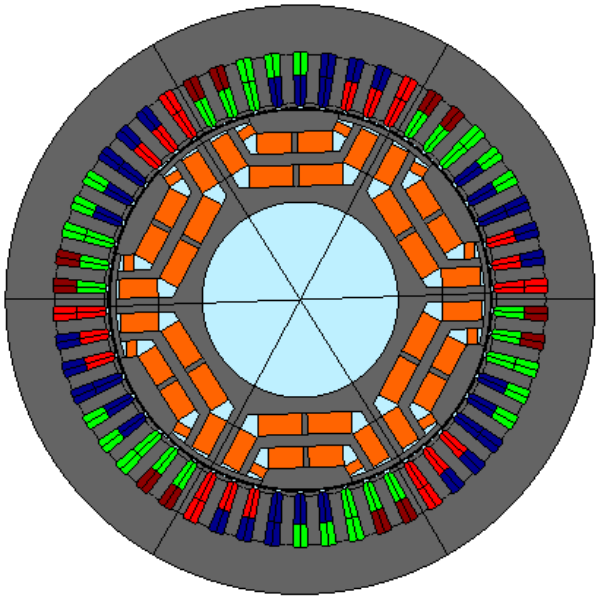
FLUX : BASE POINT

- Input
  - Rotor geometric parameters
  - Base speed,
  - Base line current,
  - Base control angle
- Output
  - Base Torque,
  - Base torque ripple,
  - Base efficiency
  - Generate *.STEP file (for OptiStruct analysis)



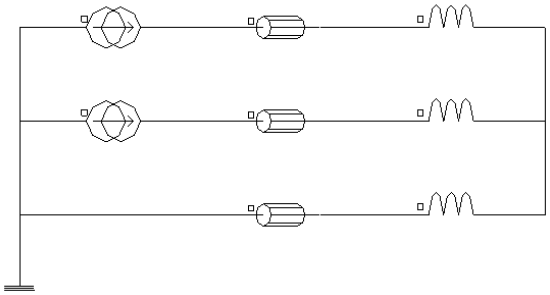


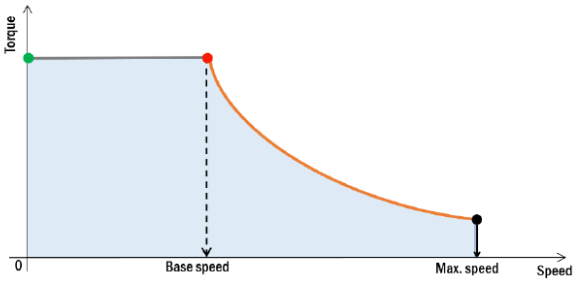




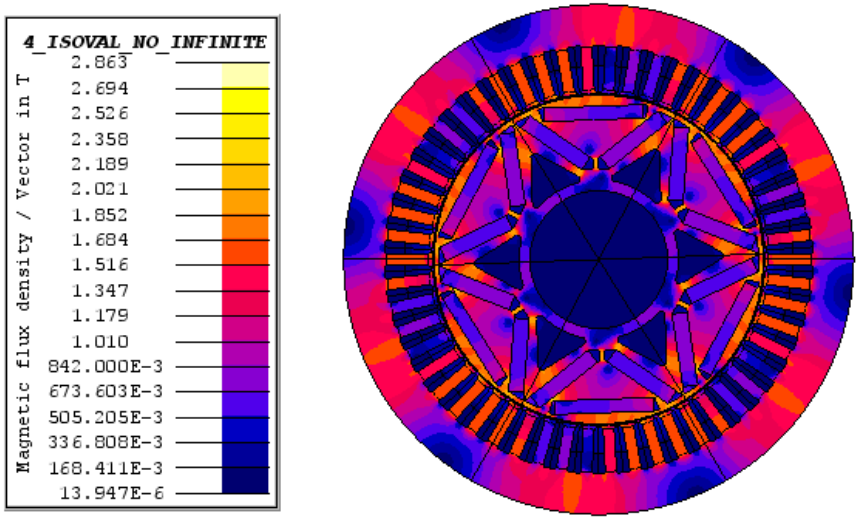
FLUX : MAX SPEED

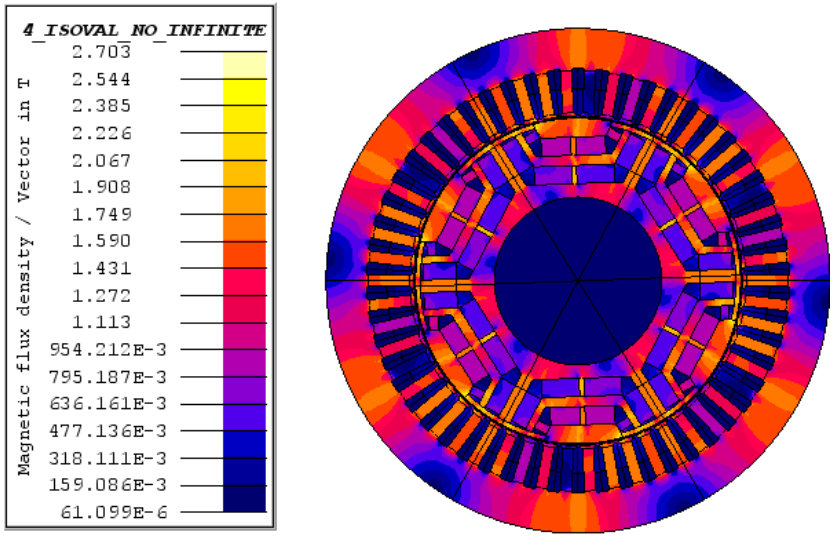
- Input
  - Rotor geometric parameters
  - Current, angle





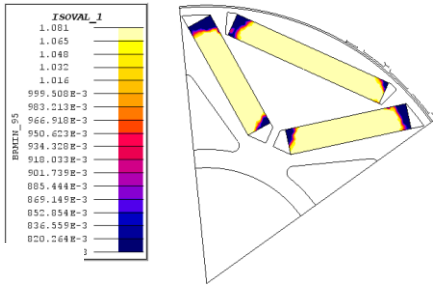
- Output
  - Torque, losses, efficiency



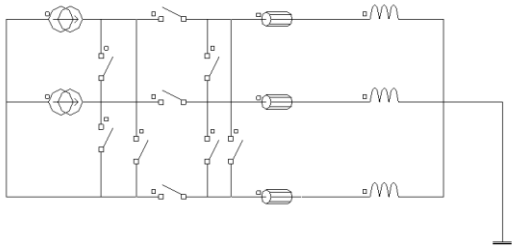


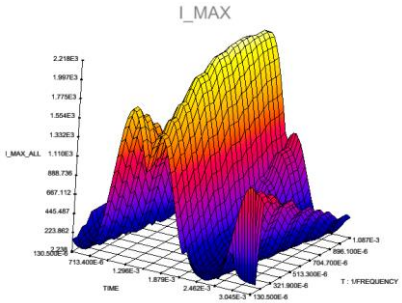
FLUX : SHORT-CIRCUIT AT BASE SPEED

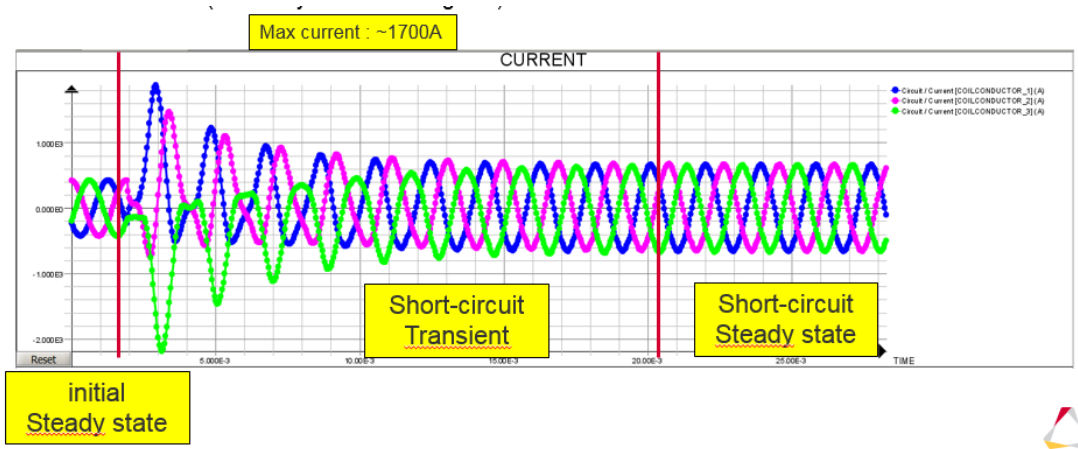
- Input
  - Rotor geometric parameters
  - Current, angle
- Output
  - Demagnetization factor at 95%

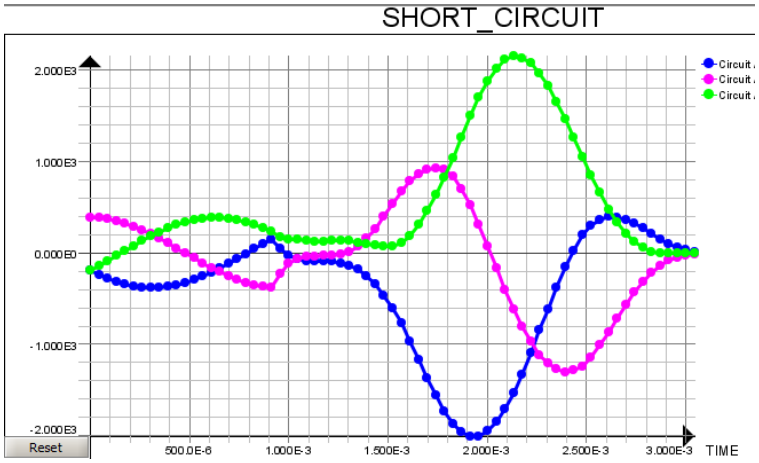


Select right starting time for short-circuit





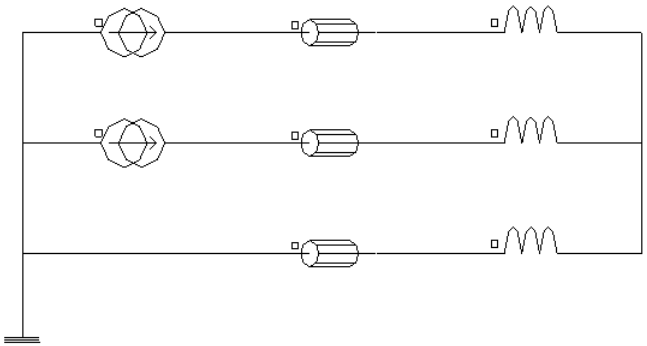


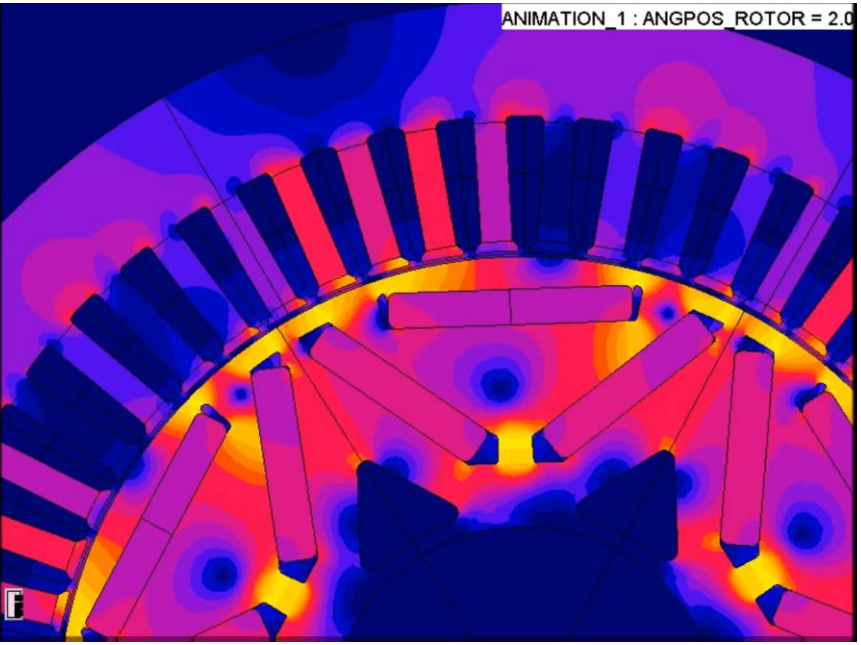


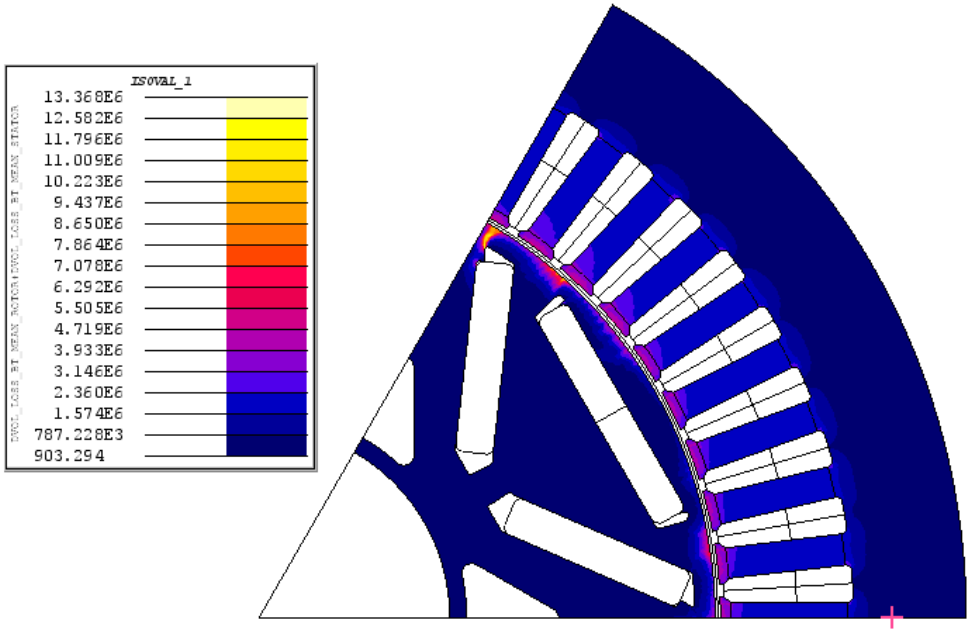
Light analysis for optimization

FLUX 100 kW AT MAX SPEED

- Input
  - Rotor geometric parameters
  - Current, angle
- Output
  - Losses (iron rotor and stator, Joule, magnet)

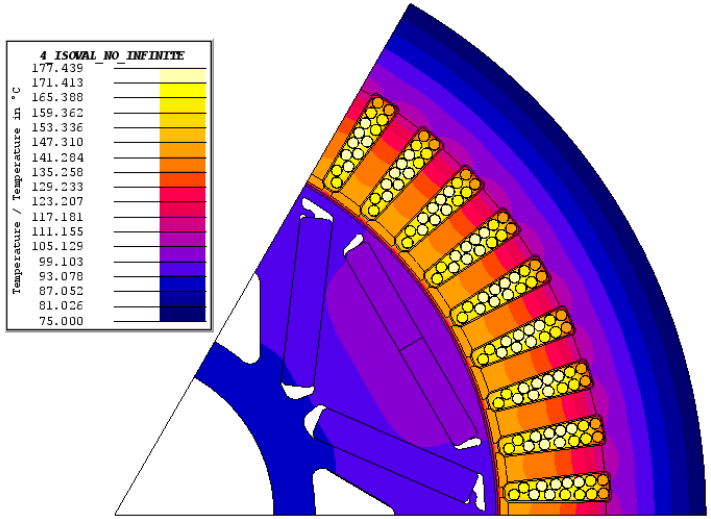


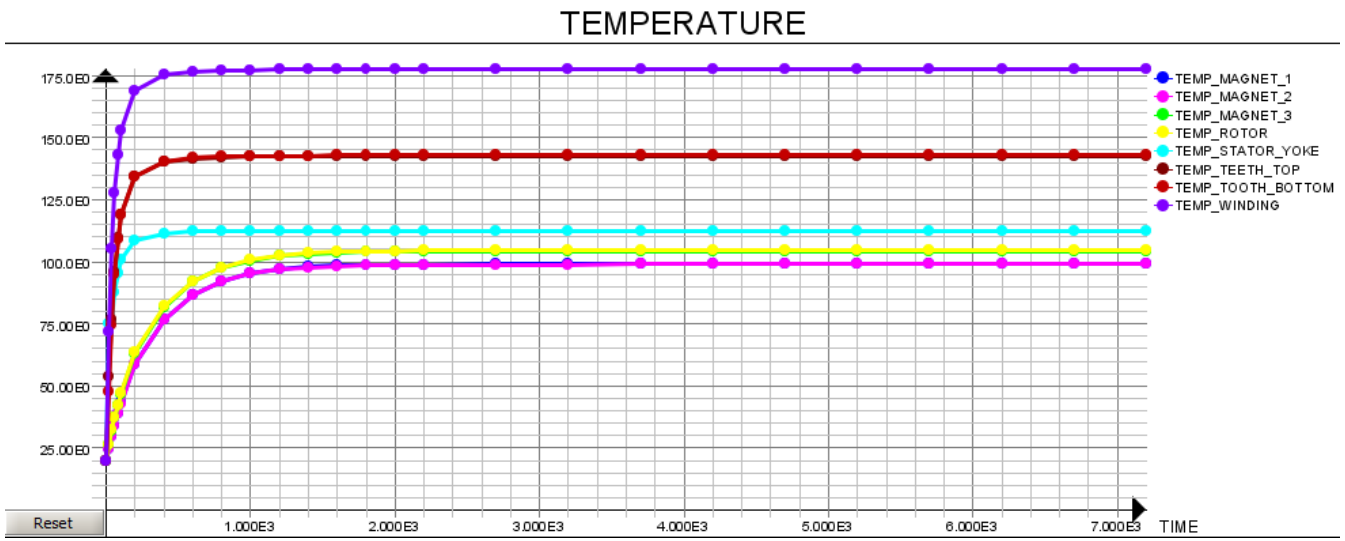




FLUX : 2D THERMAL ANALYSIS

- Test after 2 hours
- Input :
  - Rotor geometric parameters
  - Losses
- Output
  - Temperature in magnets (max)
  - Temperature in winding (T < 180°C)

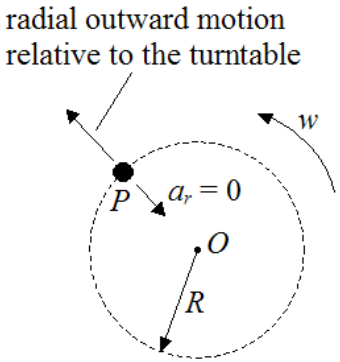




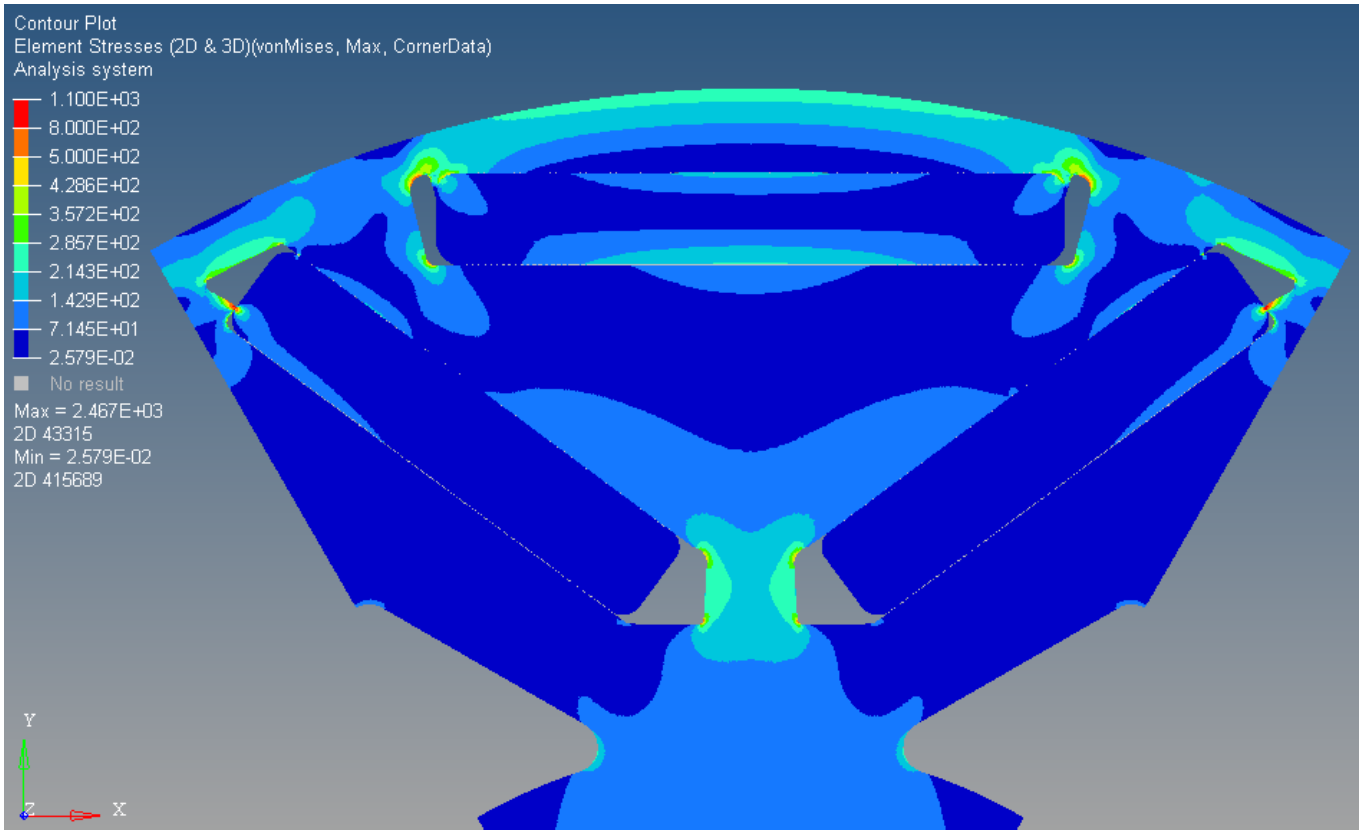
Light analysis
for optimization

STRUCTURAL ANALYSIS WITH OPTISTRUCT

- Starting from geometry in step file
- Input
  - STEP file
- Output
  - Max value of stress (should be lower than 500 MPa)



How to keep the magnet inside the rotor frame at high speed ?



© 2018 Altair Engineering, Inc. Proprietary and Confidential. All rights reserved.

Optimization

INTRODUCTION

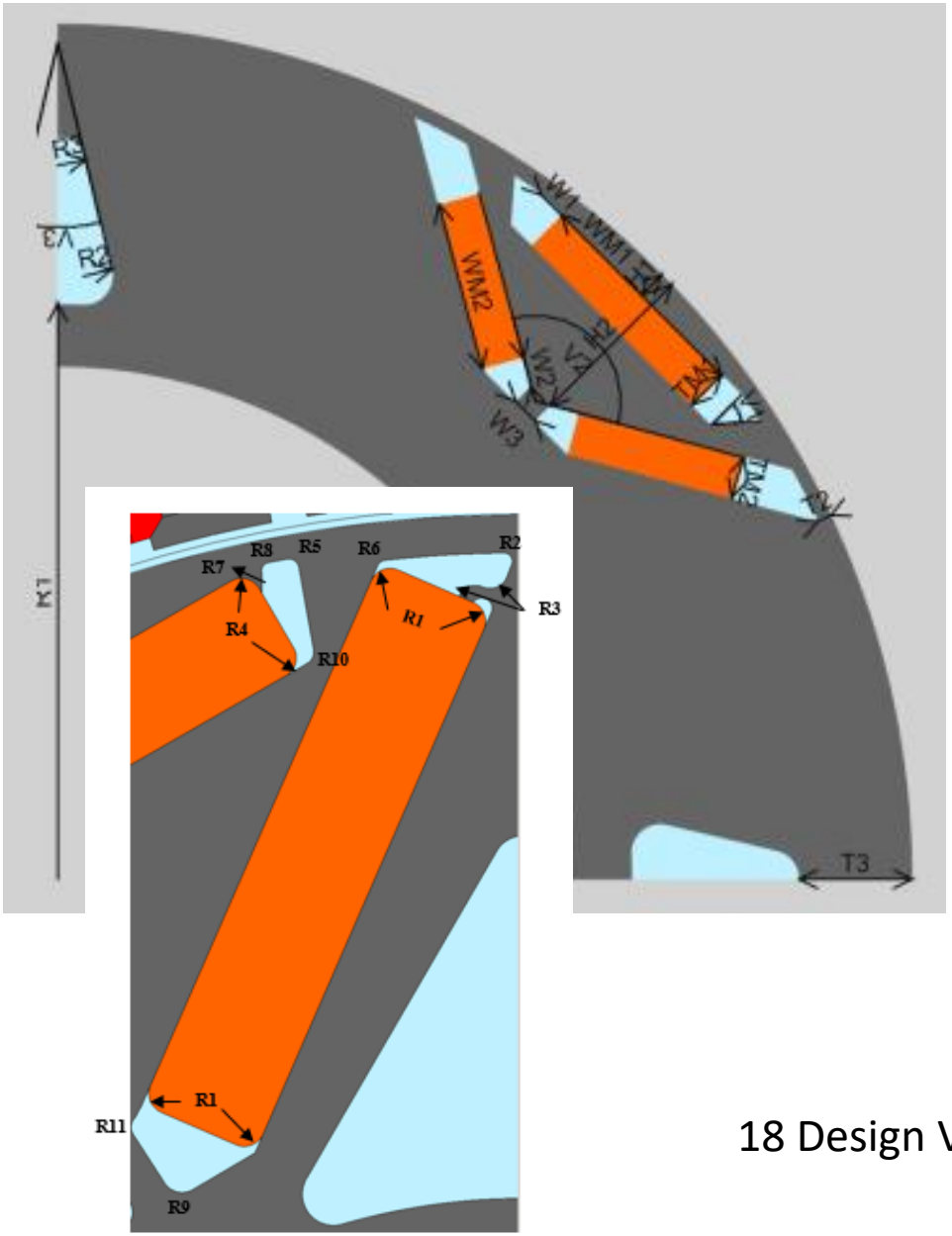
- Define project in HyperStudy with various models
- Run DOE to check influencial parameter
- Run Optimization

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

Full solving time 39 minutes

SELECTING INTERVALS FOR VARYING PARAMETERS

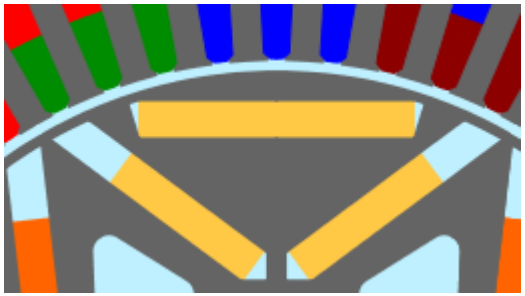


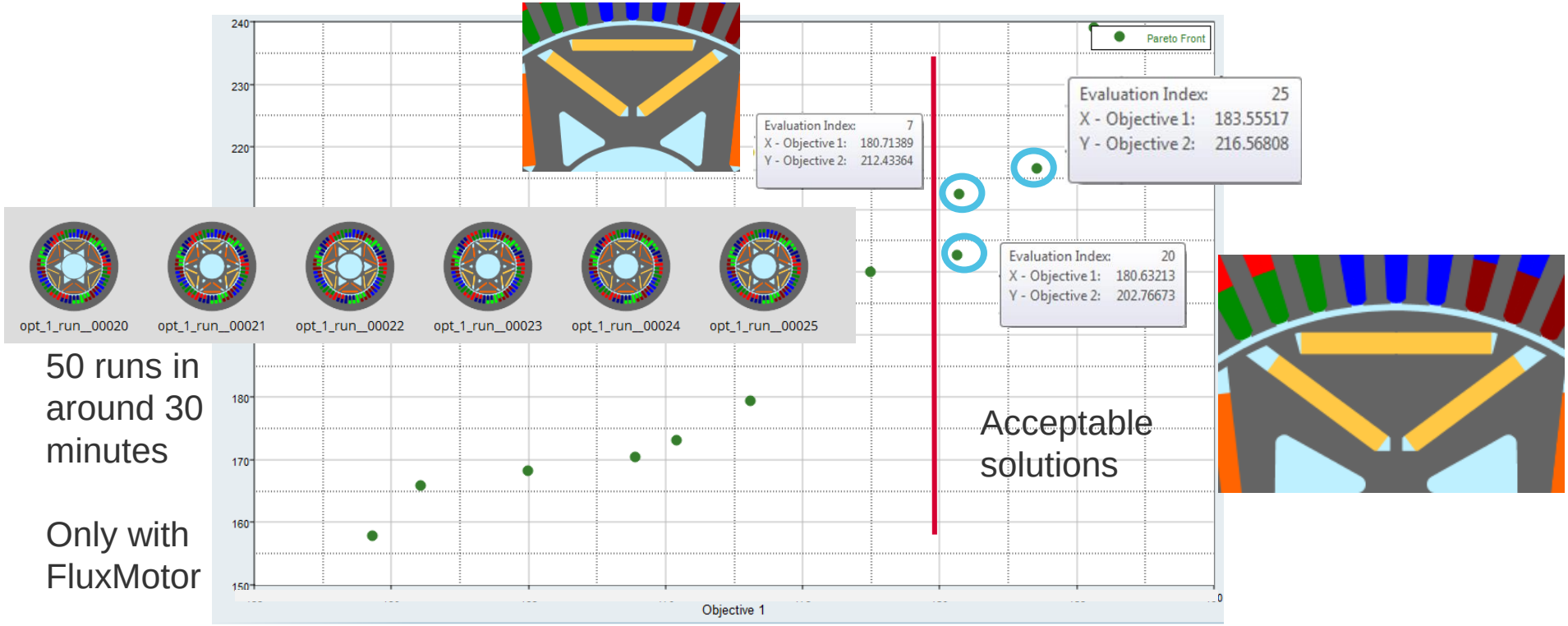
Name	Min Value	Current value	Max value
TM1	3	4,25	5
WM1	29	31	31,2
H1	3	3,5	4
W1	0,2	0,2	0,6
V1	15	20	25
TM2	3,5	4,75	4,75
WM2	16	23	23
H2	20	20	20
W2	0,5	0,6	0,7
T2	1,1	1,5	1,6
V2	106,7	107	107,1

18 Design Variables

OPTIMIZATION FOR THERMAL PURPOSE

- Goal:
  - Maximize base torque
  - Minimize current at 100 kW (initial value 266 A)





50 runs in around 30 minutes

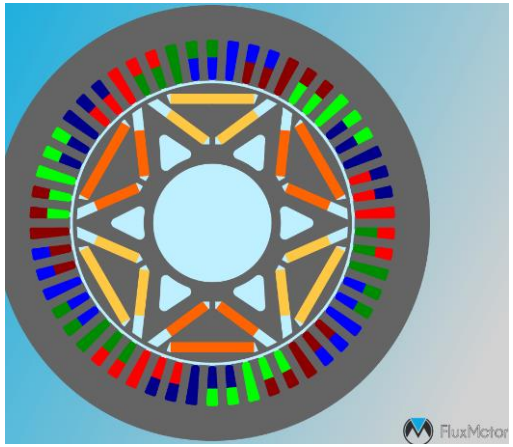
Only with FluxMotor

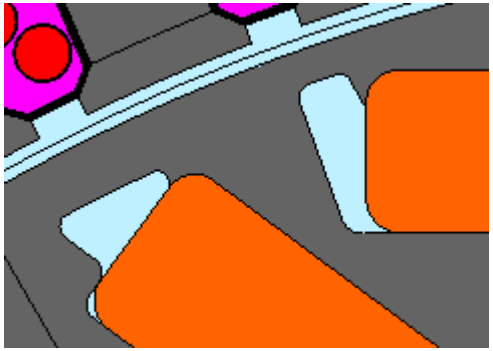
Acceptable solutions

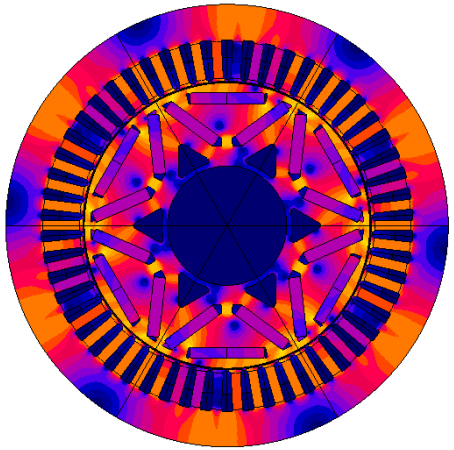
Display of Pareto front

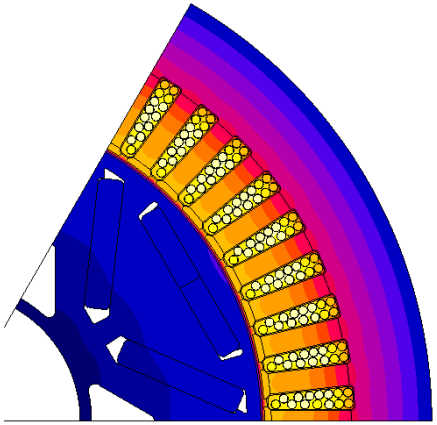
GLOBAL OPTIMIZATION

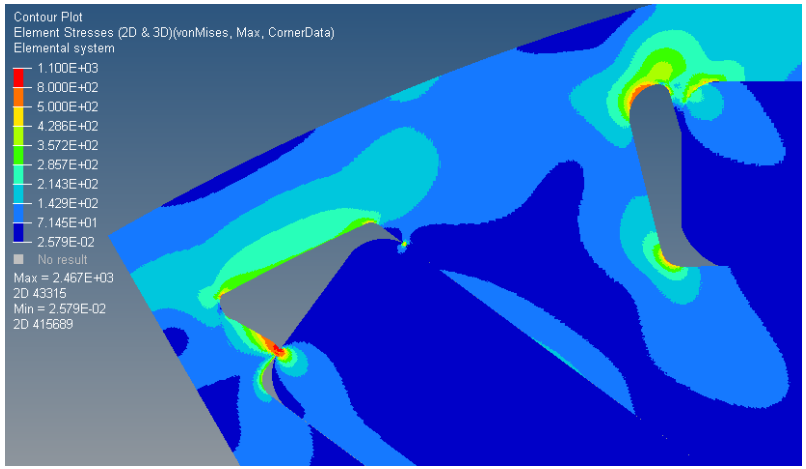
- Goal:
  - Maximize base output power
  - Minimize base torque ripple
- Constraint:
  - Stress lower than 500 MPa
  - Winding temperature lower than 180°C
  - Demagnetization lower than 5%
  - Base torque greater than 150Nm





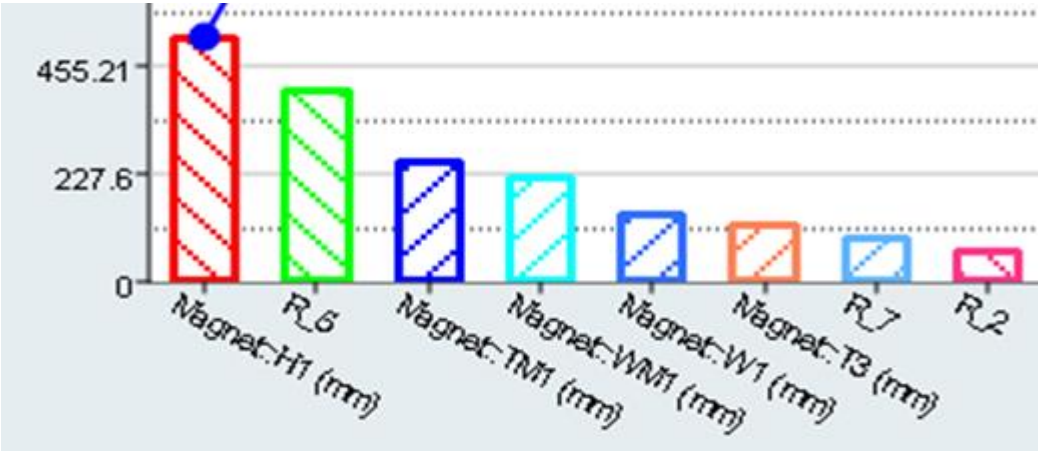


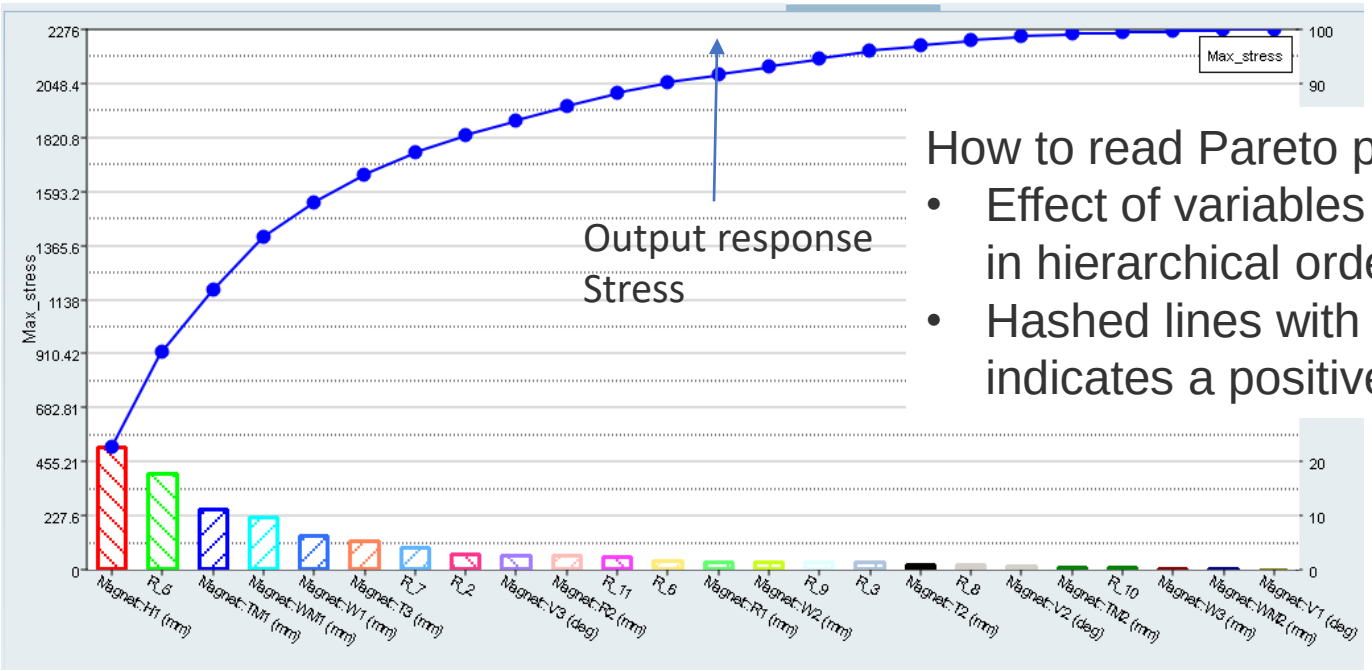




GLOBAL OPTIMIZATION : Design Of Experiments

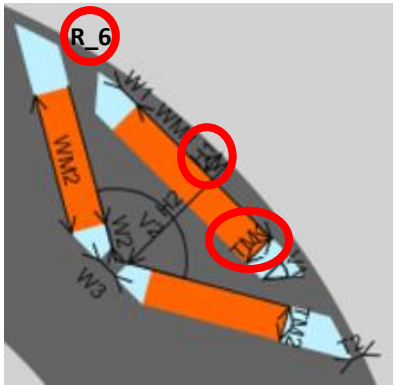
- Based on 358 Run
- 64026s= 17H 47’
- 15 multi-execution





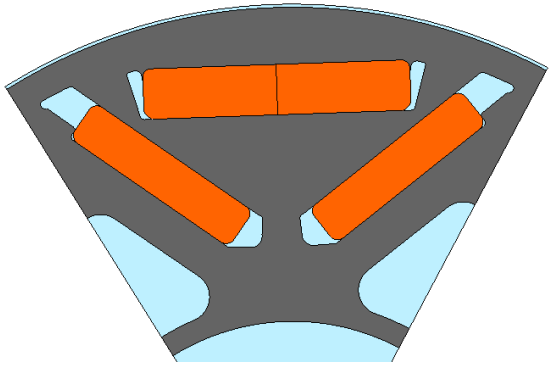
How to read Pareto plot ?

- Effect of variables on output responses in hierarchical order (highest to lowest)
- Hashed lines with a positive slope indicates a positive effect

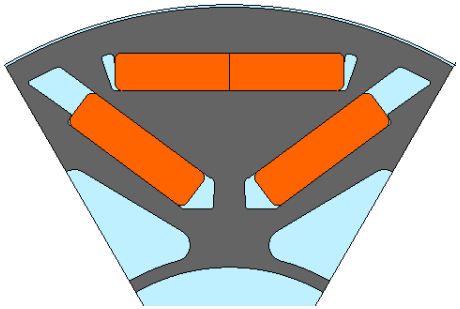


GLOBAL OPTIMIZATION : Design Of Experiments

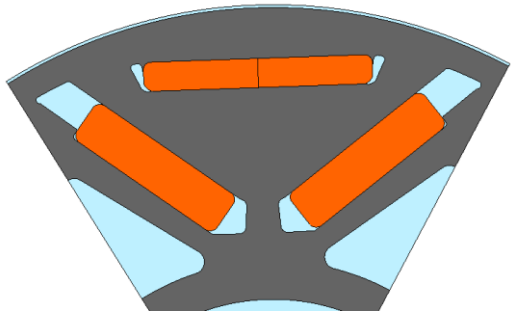
- Understand trends from DOE



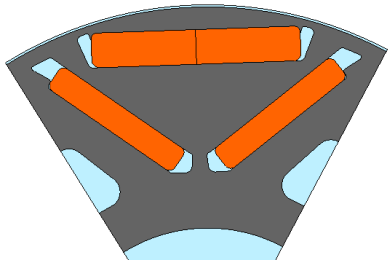
Minimum torque ripple



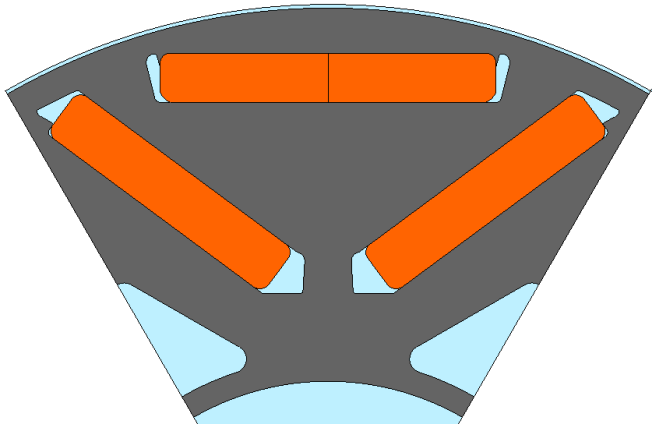
Minimum winding temperature



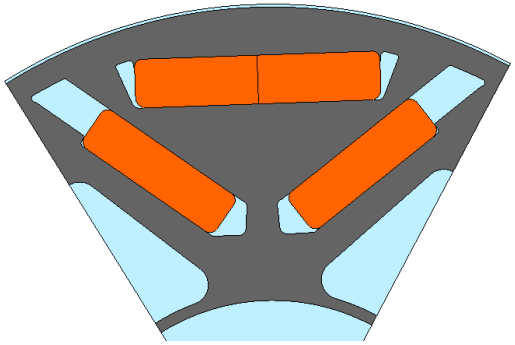
Minimum stress



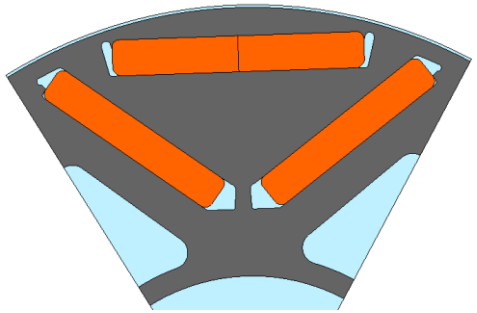
Maximum torque



initial



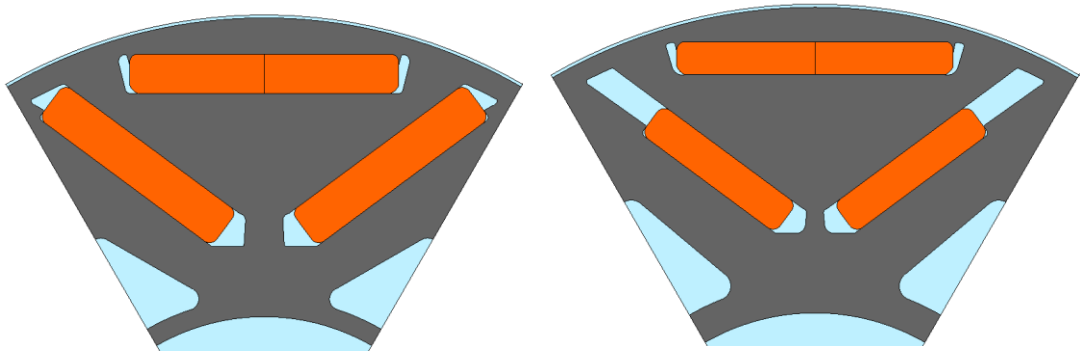
Minimum demagnetization

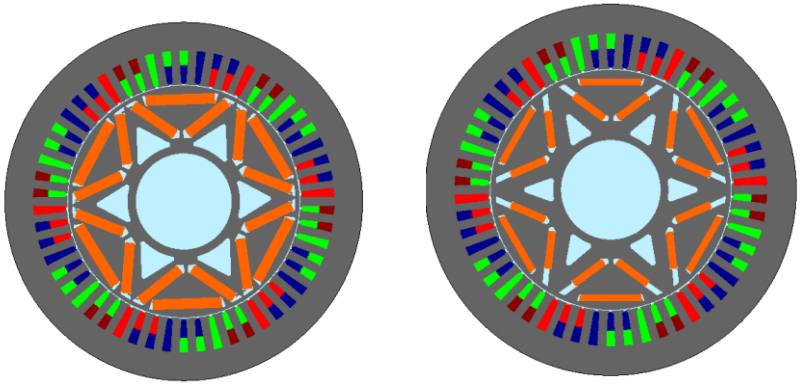


Maximum power

GLOBAL OPTIMIZATION

- Goal:
  - Maximize base output power
  - Minimize base torque ripple
- Constraint:
  - Stress lower than 500 MPa
  - Winding temperature lower than 180°C
  - Demagnetization lower than 5%
  - Base torque greater than 150 Nm





	Initial	Current Optimum
Base torque (Nm)	155,3	151,2
Base torque ripple (Nm)	8,46	4,51
Stress (MPa)	2316	**646**
Winding temperature (°C)	199,6	144,6
Demagnetization factor at 95%	6,61	4,98

© 2018 Altair Engineering, Inc. Proprietary and Confidential. All rights reserved.

Conclusion

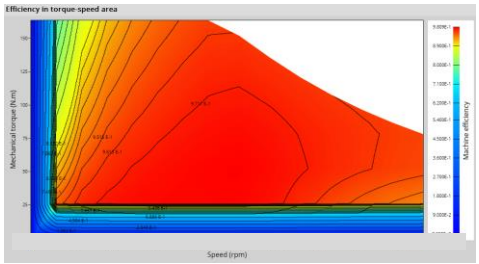
CONCLUSION

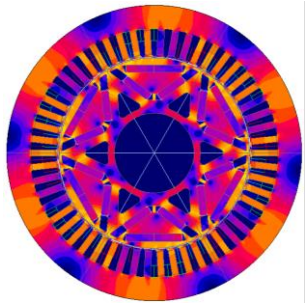
- Multi-physics optimization for motor is available mixing
  - Predesign of motor
  - Magnetic analysis
  - Thermal analysis
  - Structural analysis

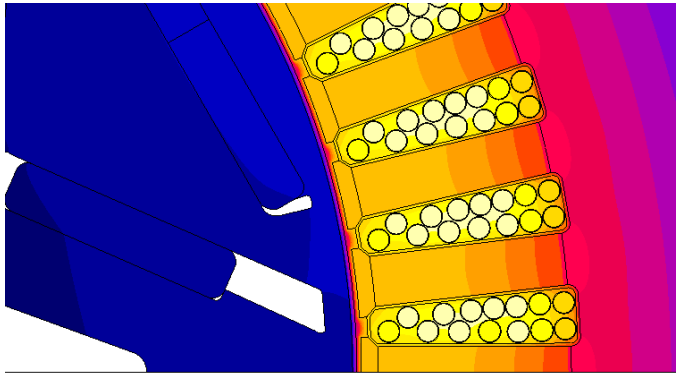
- Note: the strong coupling between HyperStudy and FluxMotor is really interesting
  - Easy to set up
  - Fast for providing efficient solutions

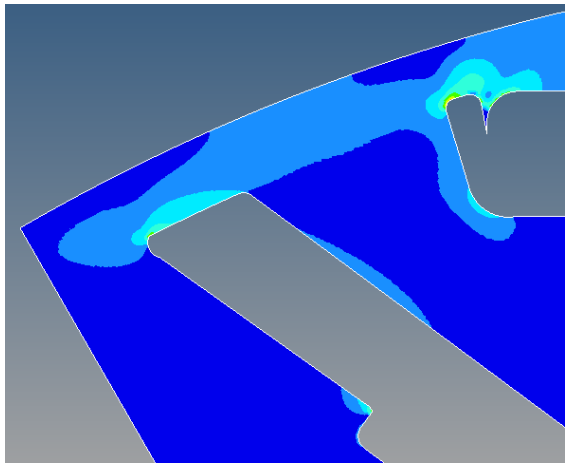
Add Model | Remove Model | Model Resources

	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









- Many thanks to the Altair Team for this collaborative work
  - FluxMotor : Erwan Galli
  - Flux : Abdessamed Soualmi
  - OptiStruct : Thomas Lehman
  - HyperStudy : Diana Mavrudieva, Stephan Koerner

- Thanks to Porsche and Sven Luthardt

- Thank you for your Attention !