FPA-13

Multiphysics modeling and optimization of PMSM for high speed operation

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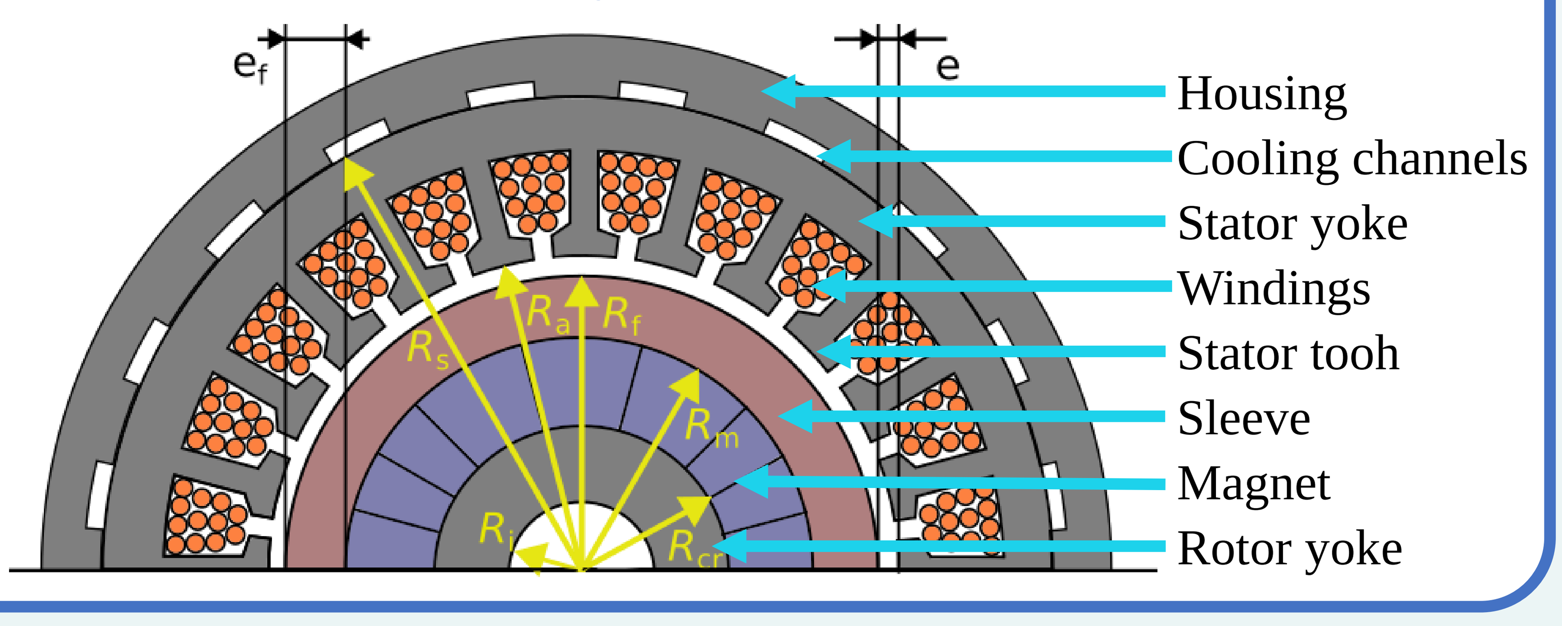
Introduction and goals

- ❖ Growing interest in high-speed machines
  - ↳ Higher power density
  - ↳ Lighter systems
- ❖ Application example :
  - ↳ PMSM (200 kW, 30000 rpm), cooled by oil jacket and spraying oil on endwindings
- ❖ Goals
  - ↳ Develop a multiphysics model of a PMSM
    - ↳ Electromagnetic, Mechanical, Thermal
  - ↳ Use these models in an optimisation approach
    - ↳ Genetic algorithm « ga » in Matlab

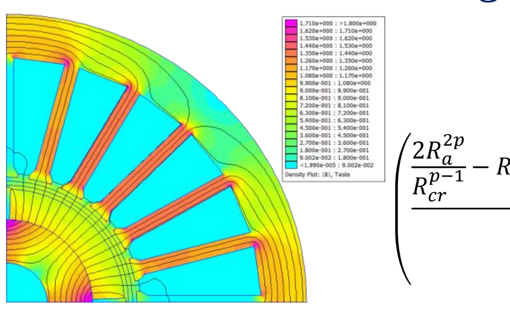
Geometry of the PMSM considered



Analytical models and coupling

Specifications (200 kW, 30 000 rpm)
Optimization variables

Electromagnetic model



$$P_t = 2\Omega . k_w . \cos(\psi) . (BH) . \pi R_a^2 L$$

$$B = \frac{4B_r}{\pi\sqrt{2}} . \sin\left(\frac{\beta\pi}{2}\right) . \frac{p}{1-p^2} . R_a^{-p-1} . \left(\frac{\frac{2R_a^{2p}}{R_{cr}^{p-1}} - R_m^{p+1}\left(1 - p + \frac{R_m^{-2p}}{R_a^{-2p}} . (1+p)\right)}{\left(1 - \left(\frac{R_a}{R_{cr}}\right)^{2p}\right)} + (1-p) . R_m^{p+1} \right)$$

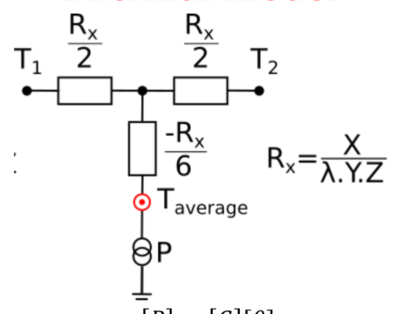
Von Mises stress
Dimensions
Properties

Losses
Dimensions
Temperature
Properties

Mechanical model

$$\begin{cases} \sigma_{rr} = -p_s \\ \sigma_{\theta\theta} = \frac{\rho\Omega^2(3+\vartheta)}{8}\left[\frac{-(1+3\vartheta)}{(3+\vartheta)} R_m^2 + 2R_f^2\right] \\ \quad + p_s\left[-1 - \frac{2R_f^2}{(R_m^2 - R_f^2)}\right] \end{cases}$$

Thermal model



$$[P] = [G][\theta]$$

Optimization variables

Variable	Lower boundary	Upper boundary
Active length/pole pitch	0,6	3
Rms air gap flux density [T]	0,2	0,8
Current density [A/mm²]	1	20
Electric loading (kA/m]	30	200
Slots/pole/phase	2	4
Pole pairs	1	4
Sleeve thickness [mm]	1	5
Mean winding temperature [°C]	50	150

Optimization constraints

Variable	Lower boundary
Tooth width [mm]	> 4
Efficiency [%]	> 95
External radius [cm]	< 20
Sleeve thickness [mm]	> 1
Length [cm]	< 30
Stress in sleeve [Mpa]	< 1000
Winding temperature [°C]	< 150
ΔB/B [%]	< 1
ΔT/T [%]	< 1

Application 1 : Different lamination materials

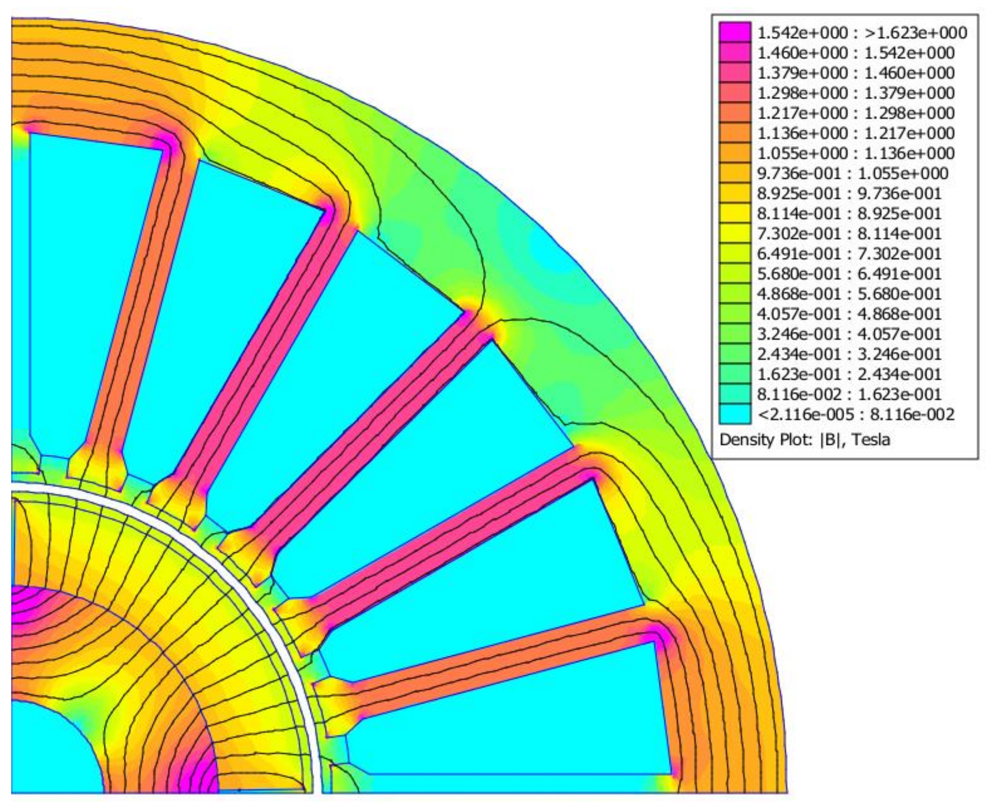
- ❖ FeCo sheets :
  Mass : 18,5 kg ➡ Power density : 10,8 kW/kg

	Analytical	FE	Error [%]
Torque [N.m]	63,7	61	4,4
Mean winding temperature [°C]	150	163,4	8,2
Max stress on sleeve [Mpa]	400	409	2,2

- ❖ FeSi sheets :
  Mass : 21,3 kg ➡ Power density : 9,4 kW/kg

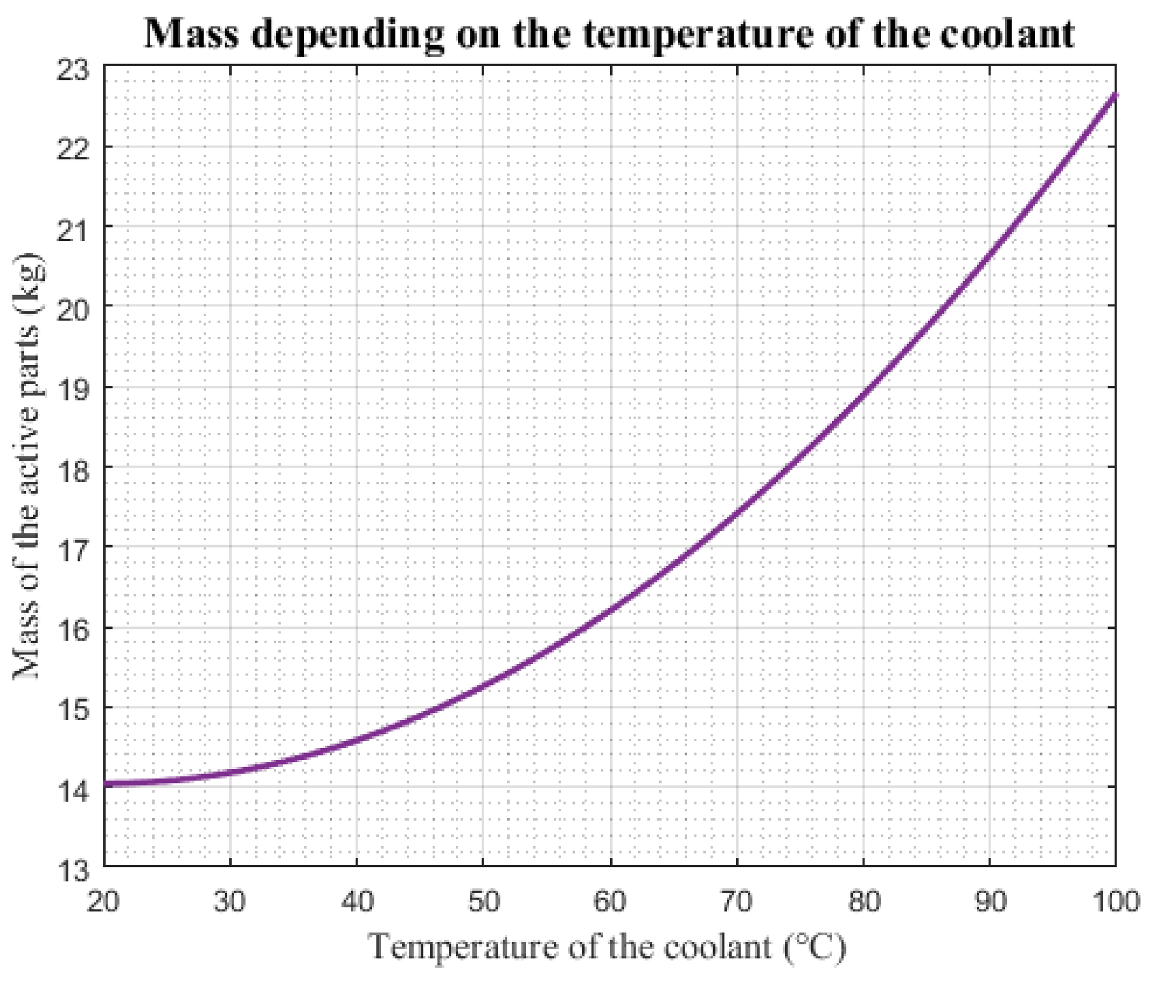
	Analytical	FE	Error [%]
Torque [N.m]	63,7		
Mean winding temperature [°C]	150		
Max stress on sleeve [Mpa]	219		

- ❖ Verification of the flux density in the core (FeCo)
  Max allowable flux density : 1,8 T
  Max no load flux density : 1,54 T



Application 2 : Temperature's coolant evolution

- ❖ Variation of the temperature of the coolant (20°C-100°C)



- ❖ 8.5 kg gain by using oil at 20°C instead of 100°C
  - ↳ High thermal constraints
  - ↳ Possibility to increase the power density by improving the cooling
    - ↳ Other method
    - ↳ Other coolant
- ❖ Warning
  - ↳ Repercussion on the mass of the heat exchanger
    - ↳ Keeping the temperature of the liquid lower will require a more efficient exchanger

Conclusion

- ❖ FeCo laminations leads obviously to the lightest machine, with FeSi laminations, the mass is 15 % higher than the FeCo machine
- ❖ Mass of the machine is nearly divided by two using oil at 20 °C instead of 100 °C (warning, repercussion on the mass of the exchanger)
- ❖ Gain in calculation time (example : analytical thermal model : 0,06 s and FE : 15 s for a single computation)
- ❖ Optimization approach takes nearly 1800 s

Acknowledgments

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