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Galileo Ferraris' Contest contest

April 9, 2024

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why electrical machine design as a contest?

- among *challenging* problems in design, the one of traction motors is emerging as a multi-physical one
- always more stringent and demanding constraints are driving the structure to new and unforeseen limits and a need for *pre-design tools* is emerging
- new interactions and couplings between different physical domains, electromagnetic, thermal, structural, acoustic, etc., have surfaced, creating the need for *multi-physical* analysis of the structure.
- At the same time, different criteria must be considered in the design process, and most often, these are contrasting each other as for example:
  - torque vs temperature
  - rotating speed vs mechanical stresses in the rotor
  - . . .

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an *open* environment

- As it is apparent, the design process has become, at least, twofold computationally intensive: one in the analysis phase (*multi-physical*) and one in the optimization one (*multi-objective*)
- a cooperation among research groups requires an *open* databases of results on a technically sound *test-case*
- for these reasons, the electrical machine design seems to be a good candidate problem for assessing *data-driven methodologies* mainly but non only in the COMPUMAG community
- the availability of *open* datasets will allow different research groups to assess their procedures without the need to have the analysis capabilities of the whole multi-physics problem

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why electrical machine design as a contest?

- Among different possible motor configurations, *V-shaped* Internal Permanent Magnet (IPM) configurations are chosen as a reference.
- the motor geometry is described in a unique way by well-defined rules, as well as its material characteristics in all the physical domains involved. Supply conditions and circuit data are provided.
- The structure will be modelled starting from its two dimensional cross section containing the main *factors* that can influence performance.
- The two-dimensional mesh is created having a sufficient number of elements and a distribution able to return an adequate degree of accuracy in all physical domains involved.

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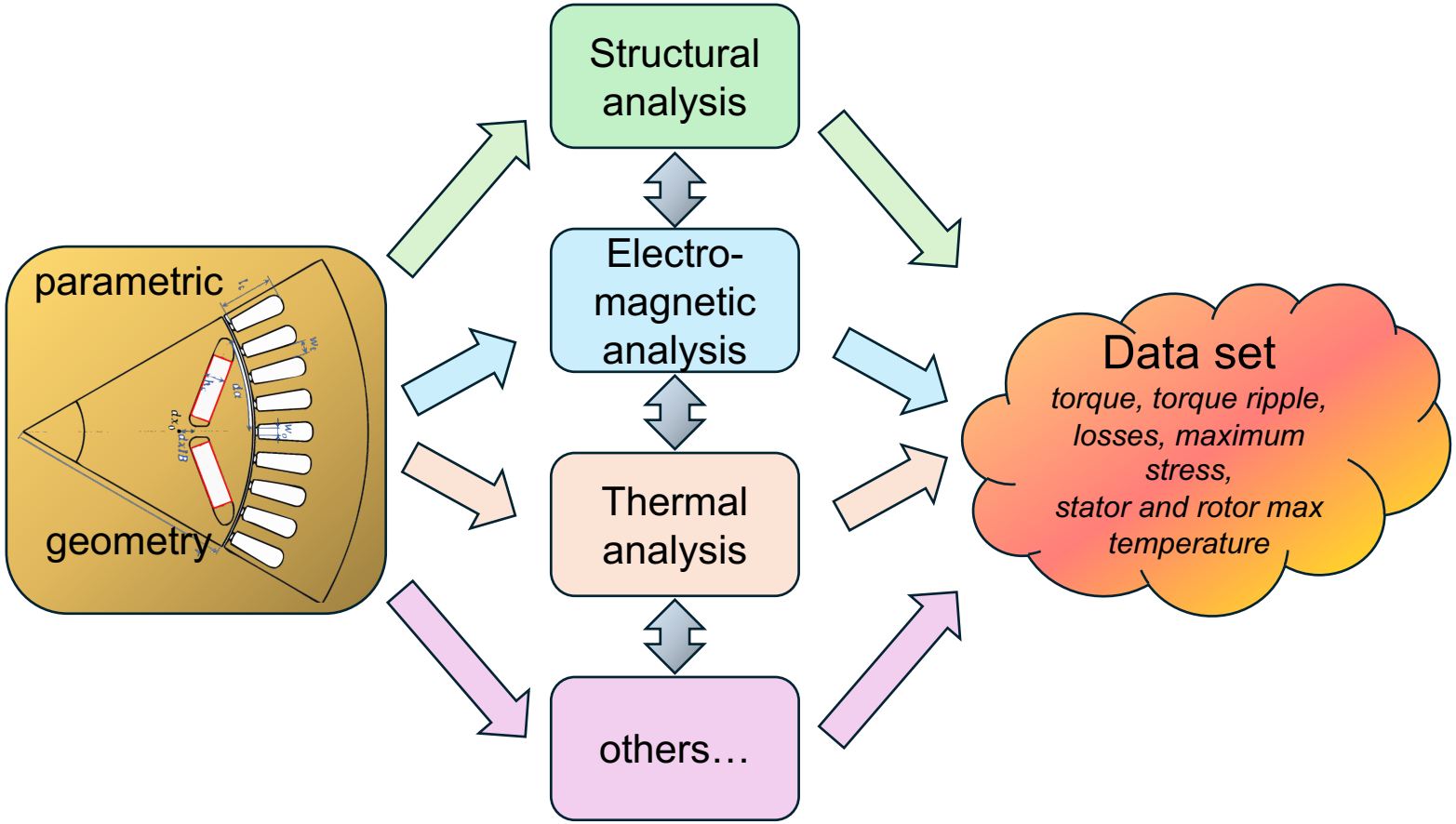
Test case structure

Multi-phisics model, from geometry to results



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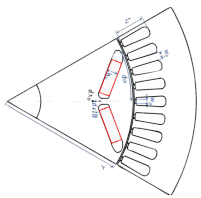
Test case structure

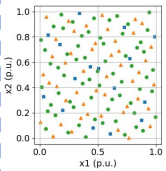
- breakdown of different steps $\mathbf{x} \in \mathcal{R}^p \rightarrow \mathbf{y} \in \mathcal{R}^m$
- all procedures linked in a single `Matlab`® procedure
- available under the Apache Version 2.0 license
- geometric rules to build mesh are controlled to suppress possible *unfeasible* solutions

Step 1
definition of parametric geometry by *p* real valued arrays

$\mathbf{x} \in \mathcal{R}^p$



Step 2
hierarchical generation of *N* points



Step 3
creation of motor structure

$\mathbf{x}_k,$

$k = 1, \ldots, N$

syre

Step 4
creation of the 2D triangular mesh

FEMM

Lua

Step 5
Multi-physics analysis based on 2D and 3D models

electromagnetic

thermal

structural

Step 6
collection of *m* results for each configuration

$\mathbf{y} \in \mathcal{R}^m$

results dataset

Workflow

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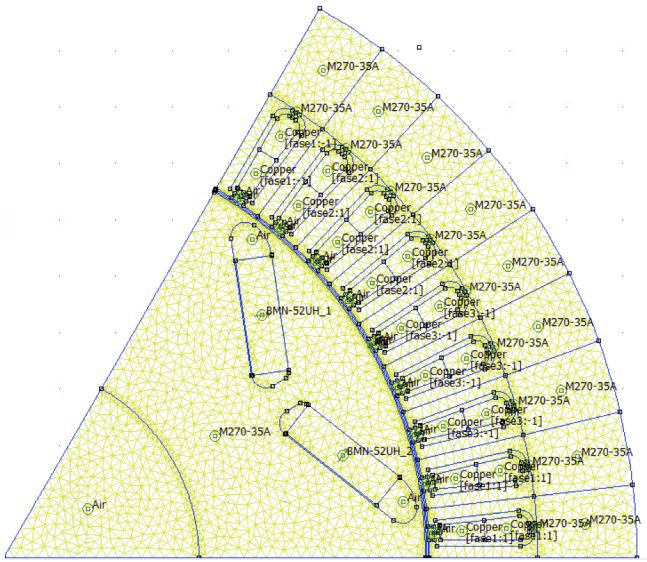
Building of *multi-physics* model

2D mesh

- all physical domains will be analysed starting from the $2D$ mesh created from parameters $\mathbf{x}_k \in \mathcal{R}$
- all results are evaluated by finite element method so that no other model is set between parameters and results



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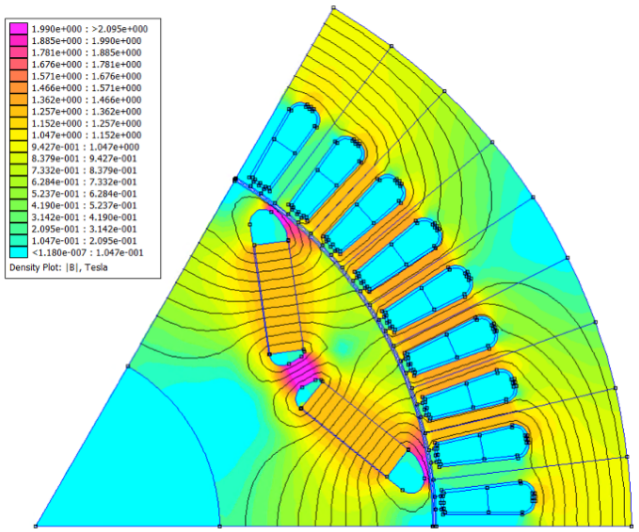
Test case structure

electromagnetic

- nonlinear magneto-static analysis is based on the two-dimensional mesh
- several relative positions between rotor and stator (*snapshots*) will be considered, enabling the evaluation of quantities like torque ripple, magnetic induction waveforms within iron, etc.
- in a first instance a number of positions (≈ 12), sufficient for the correct evaluation of the torque ripple, will be run.



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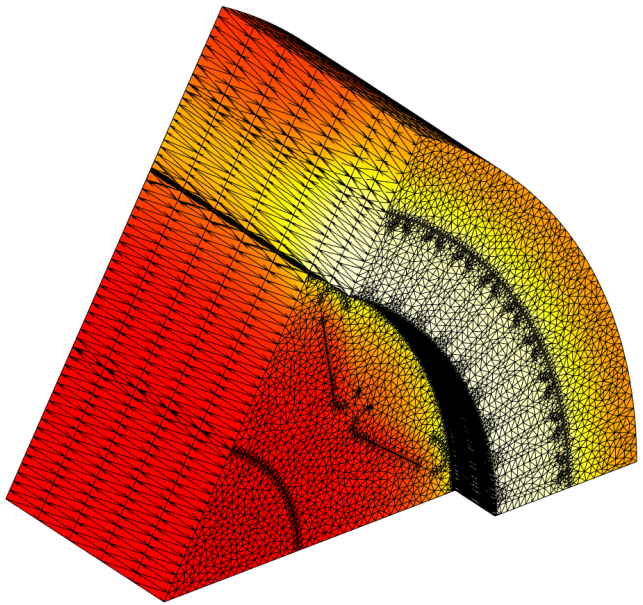
Test case structure

thermal

- $2D \rightarrow 3D$ model compatible with cooling water jacket and potted end windings
- thermal in overload (*peak performance*) thermal transient on $T = 10$ s (dominance of copper losses)
- wire winding $\rightarrow$ homogenized material (copper + slot liner)
- heat transfer at the air gap will be considered at the *base* rotational speed *(corner speed)*
- comparison with *state of the art* tools will be provided



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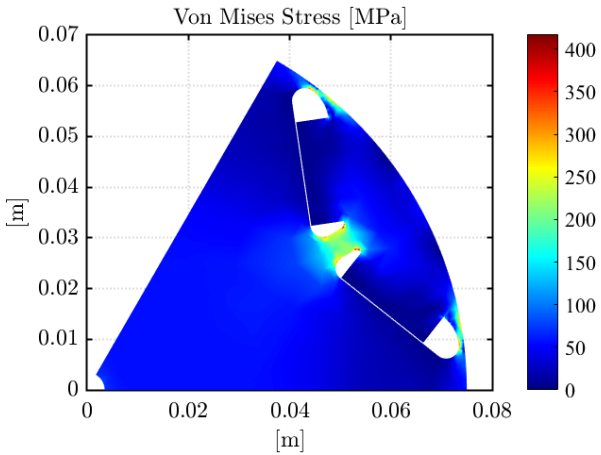
Test case structure

structural

- rotor structure considering the maximum rotational speed at a given reference temperature
- the permanent magnet is constrained on the external contact with the slot while it is free on the internal one
- no relative movement between parts is allowed (no sliding between slot and magnet)
- stresses related to the interference between the rotor core and the shaft are neglected



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