2014 Flux Conference

Reluctance Synchronous Motor Optimization

a parametrical and topological approach using Flux®

CEDRAT
design solutions for
electrical engineering

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Reluctance Synchronous Motor (RSM) Optimization

a parametrical and topological approach using Flux®

Objectives → Parametrical approach → Topological approach → Experimental validation

Structure of the presentation

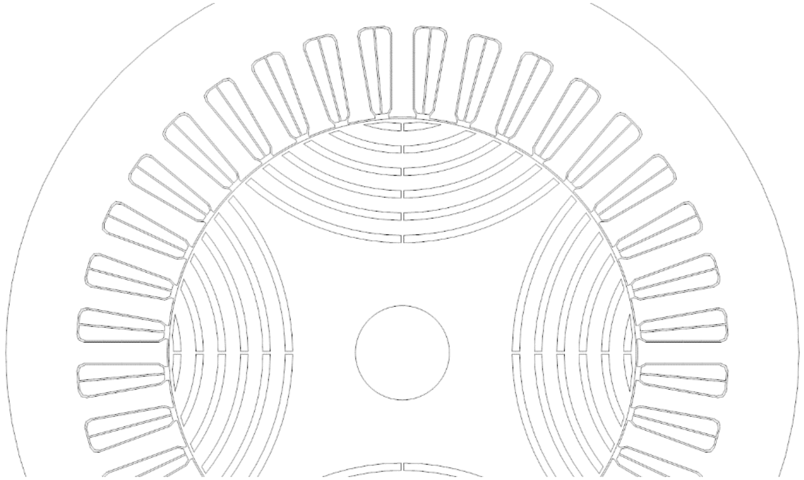
1. Objectives
   - The Reluctance Synchronous Motor; an alternative for the induction motor?
   - How can maximum rotor saliency by achieved?
2. Parametrical approach
   - Which parameters influence the characteristic of a RSM?
   - What about cogging torque?
3. Topological approach
   - Are there strategies of topological optimization?
   - What about genetic algorithms?
4. Experimental validation
   - Can the solutions keep up at real conditions?

Objectives

Parametrical approach → Topological approach → Experimental validation

Objectives

- The Reluctance Synchronous Motor (RSM): an alternative for the induction motor?
- Maximal rotor saliency leads to maximum reluctance torque and thus maximum torque per volume
- How can maximum rotor saliency by achieved?



Approach

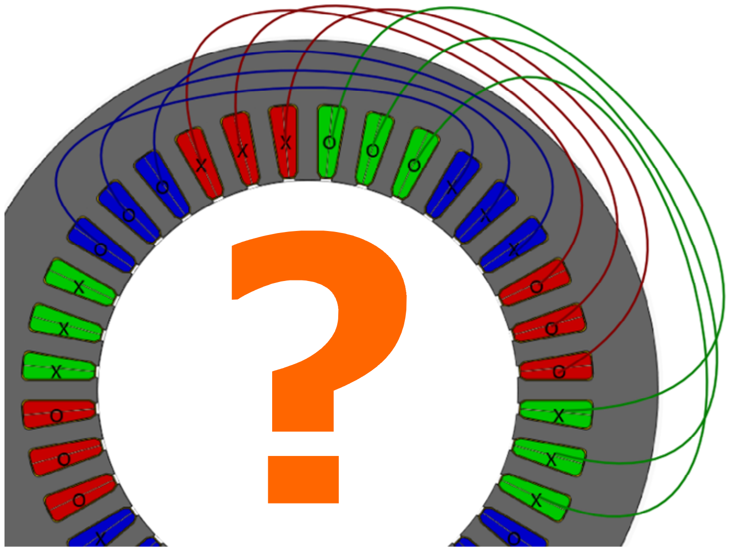
- Parametrical optimization
- Topological optimization
- Experimental validation

Bildnachweis:

Objectives: RSM – an alternative to the induction motor?

Aim: replace an existing induction rotor by a reluctance-rotor

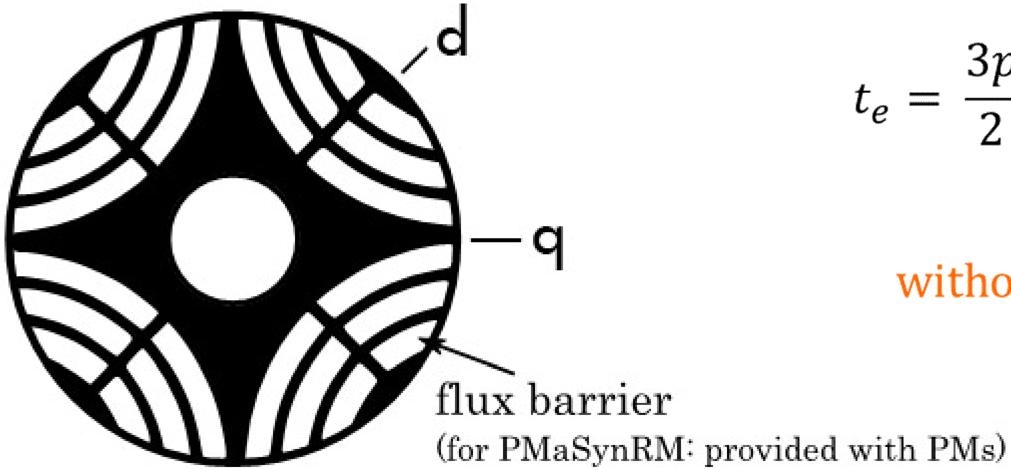
Boundary conditions: Standardized stator with overlapped winding scheme



IEC 90/4 Stator (36 slots)

Best RSM-Rotor?

Objectives: theoretical background



$$t_e = \frac{3p}{2}\left(\underbrace{\psi_{PM} i_q}_{} + \left(L_d - L_q\right) i_d i_q\right)$$

without magnets $\psi_{PM} = 0$

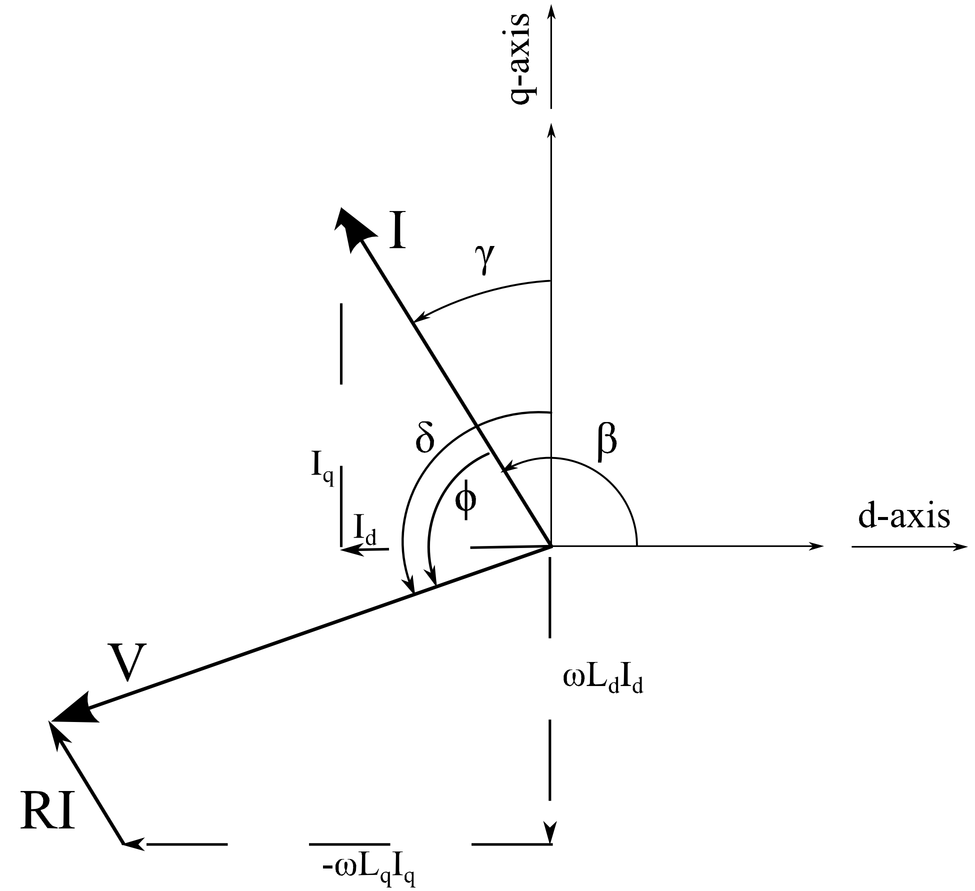
$$t_e = \frac{3}{2} p i_d i_q \left(L_d - L_q\right)$$

1. L_q must be maximized (absolute value)
2. Rotor saliency must be maximized (L_q relatively to L_d)

I. Boldea, Reluctance Synchronous Machines and Drives, Clarendon Press, Oxford 1996
T. J. E. Miller, Design of a Synchronus Reluctance Motor Drive, IEEE 1991

Objectives: theoretical background

Phasor diagram



I. Boldea, Reluctance Synchronous Machines and Drives, Clarendon Press, Oxford 1996
T. J. E. Miller, Design of a Synchronus Reluctance Motor Drive, IEEE 1991

Objectives

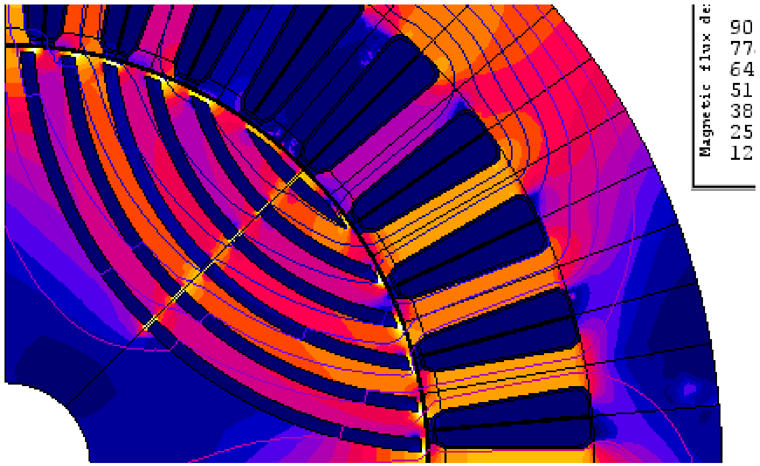
Parametrical approach

Topological approach

Experimental validation

Approach

1. Select Design an identify parameters
   - ✓ C-Shape flux barriers
2. Identify the influence of each single parameter on the performance
   - ➢ Number of barriers?
   - ➢ Ratio air/iron
3. Identify the correlation of every parameter
4. Global optimisation
5. Select best design based on selection-criteria



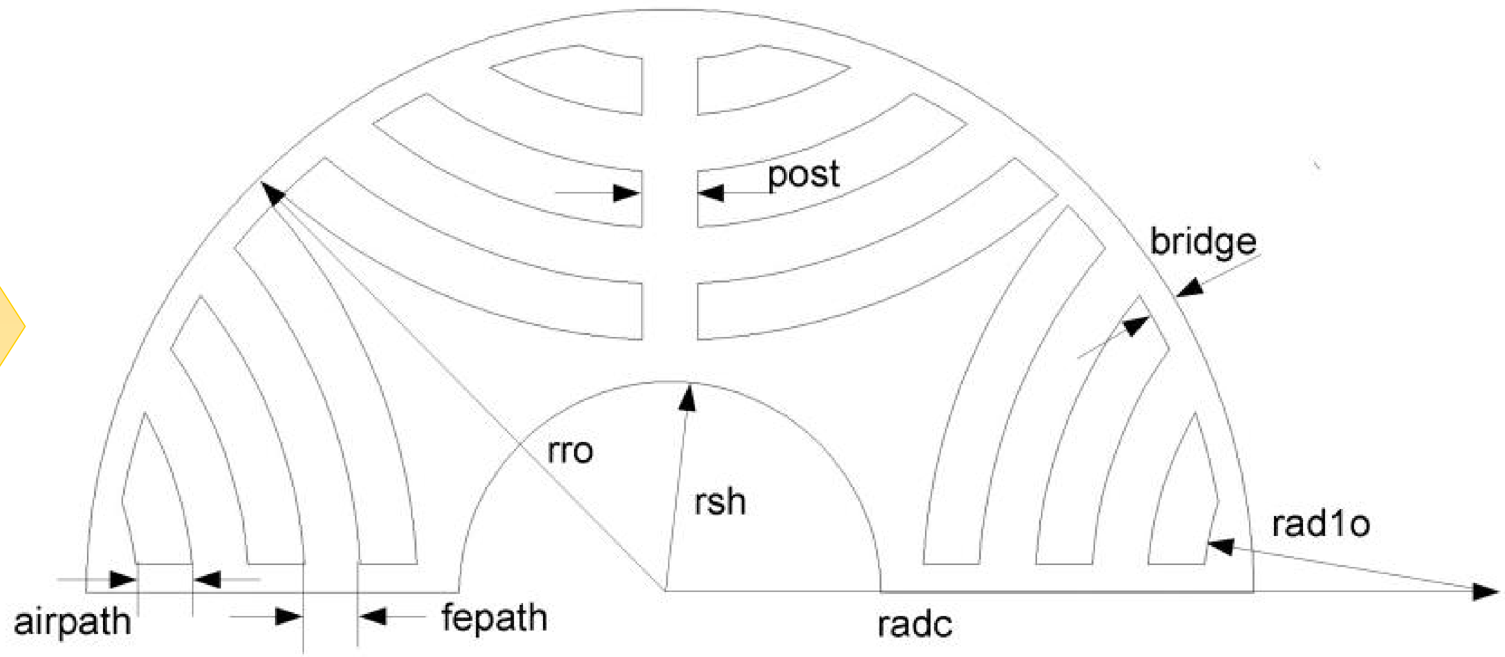
objectives

- Maximize rotor saliency
- Identify influence of parameter
- Optimize motor performance

Bildnachweis:

Parametrical approach

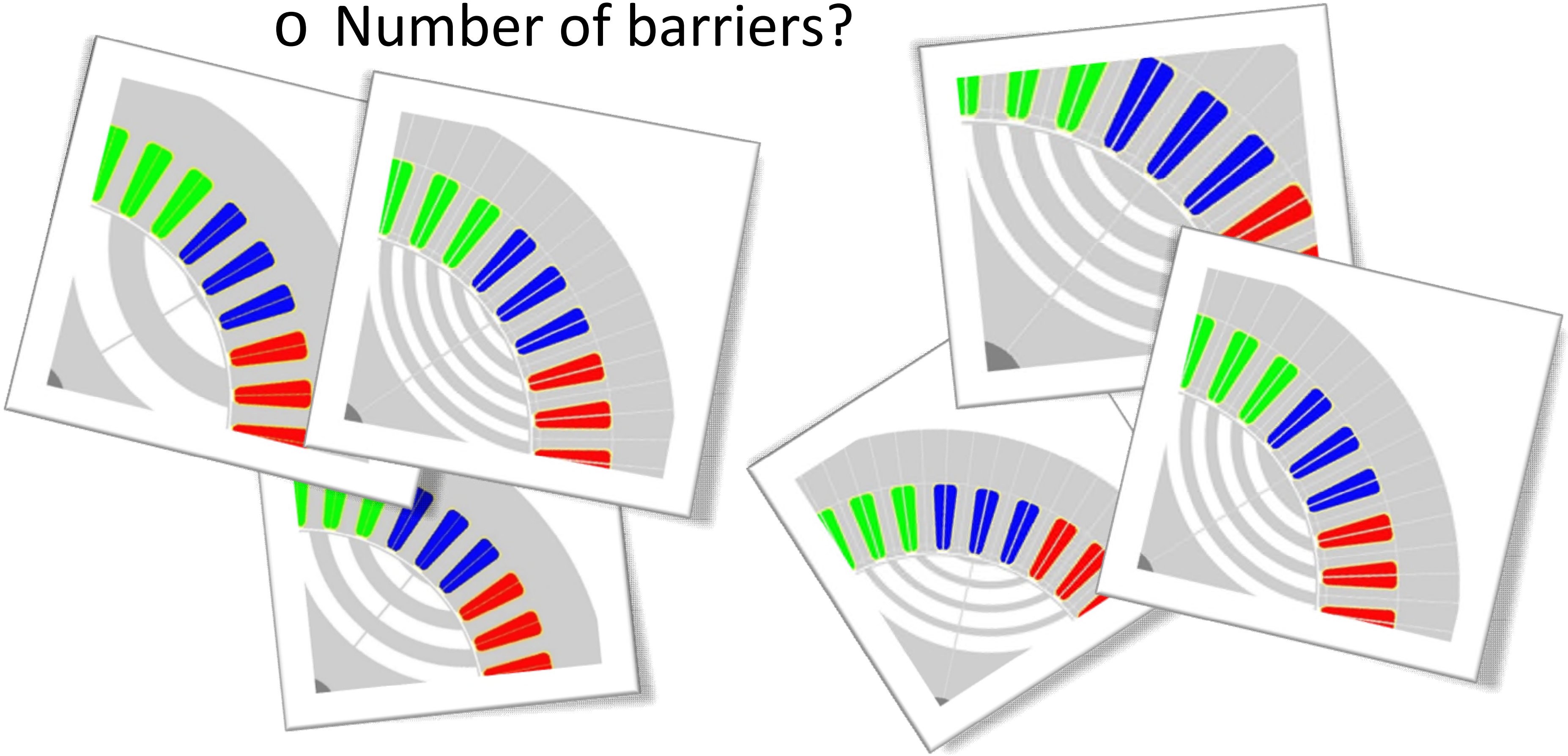
Parameterisation → Evaluation of some crucial parameter → Definition of global optimisation grid → Global optimisation (Grid Search)



Parametrical approach - Evaluation of some crucial parameter

Which parameter influences rotor saliency?

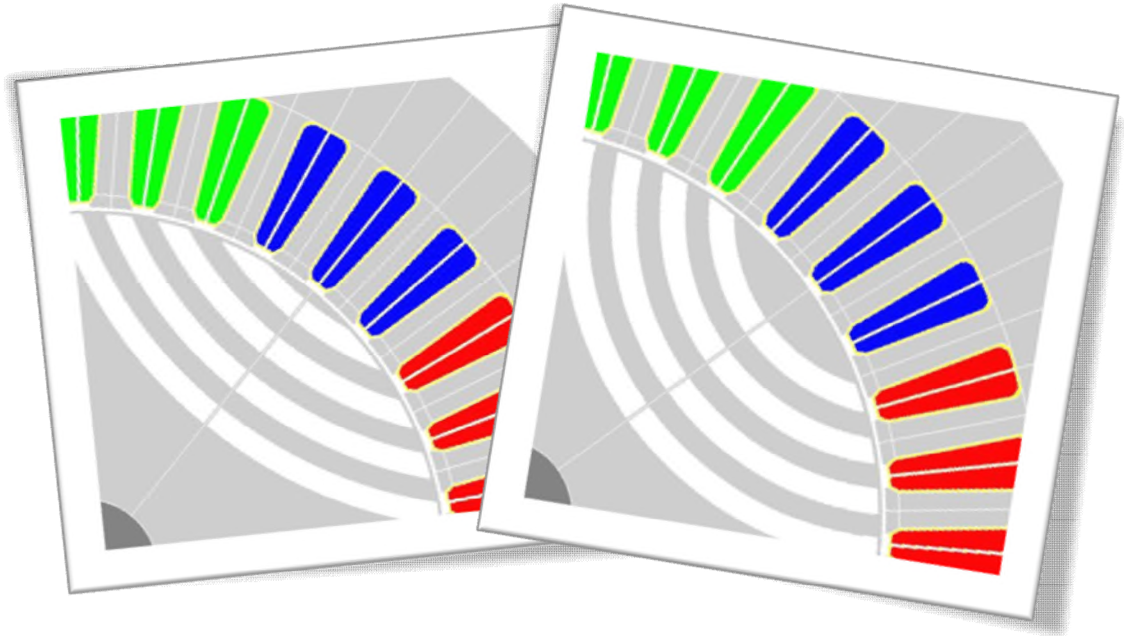
- Number of barriers?
- Ratio air/iron?



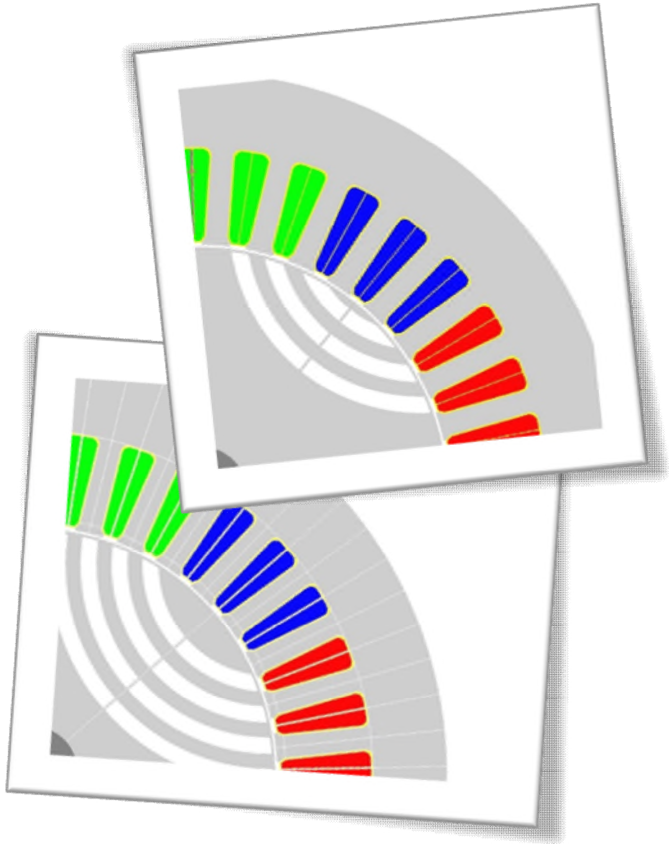
Parametrical approach - Evaluation of some crucial parameter

Which parameter influences rotor saliency?

- Radius of barriers?



- Distance to shaft?

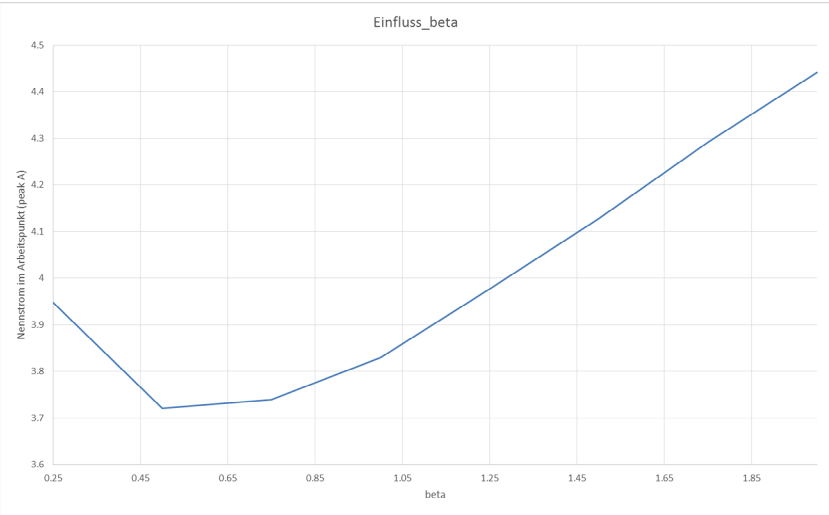


Parametrical approach – Definition of global optimisation grid

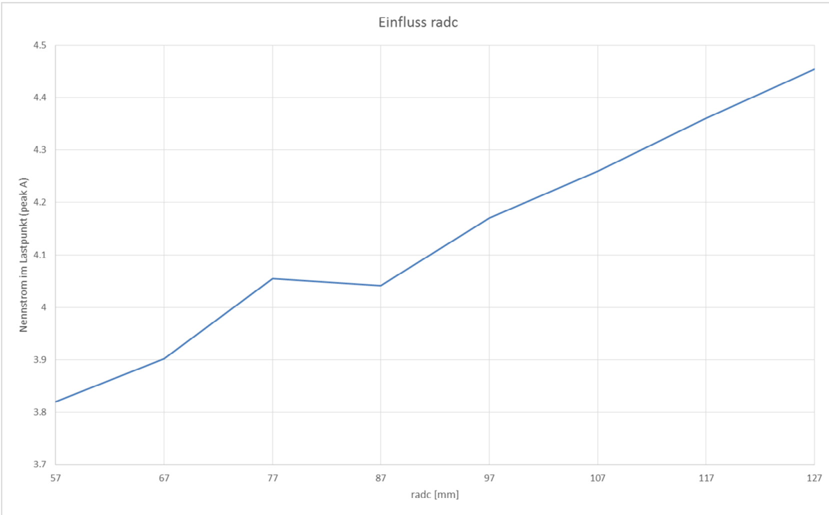
Subsequently…

… results helped to identify a reasonable grid of designs for a **global** parametrical optimization

e.g.

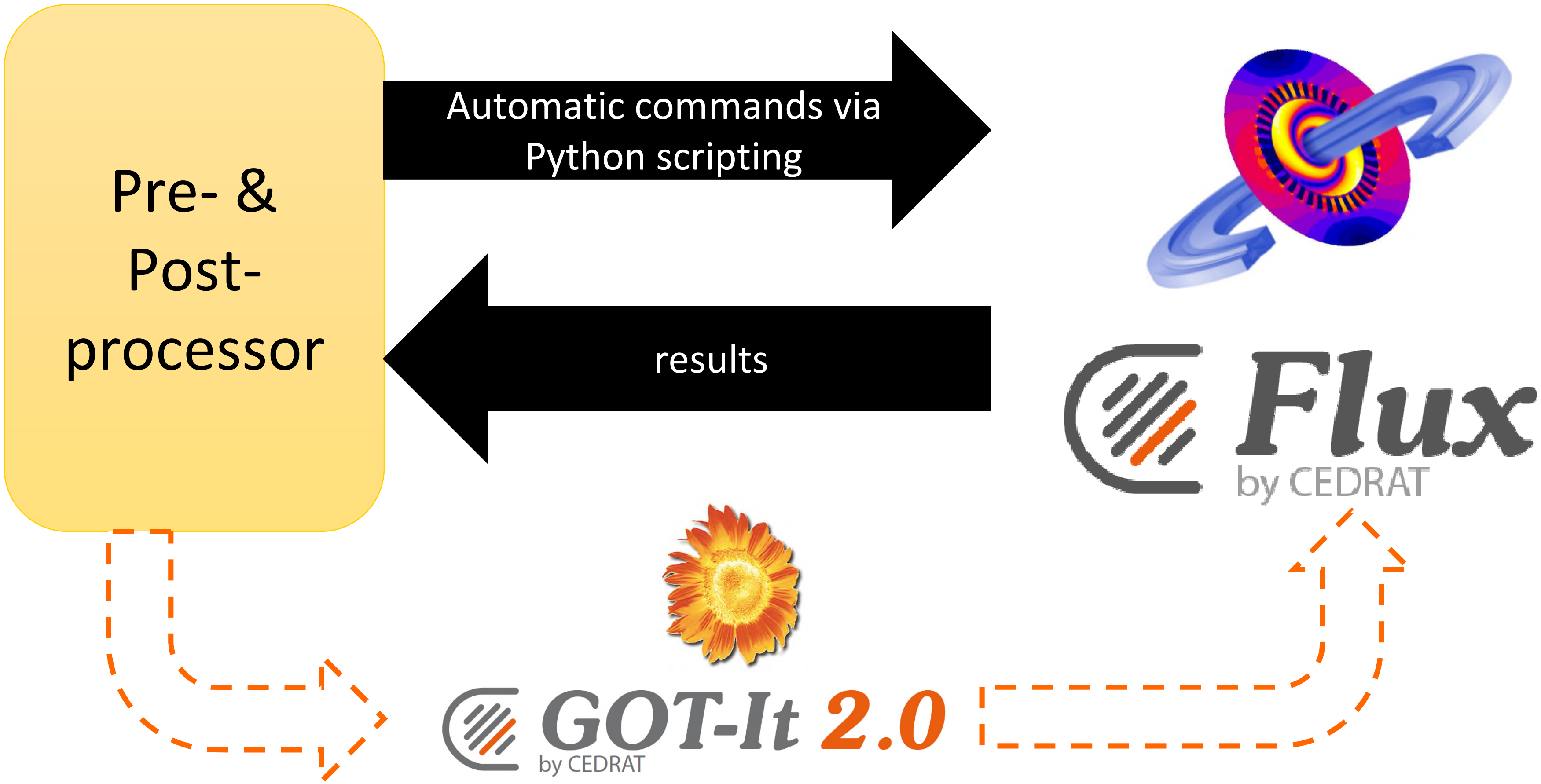


Optimal air/iron ratio between 0,5…1,25



Optimal radius as low as possible (due to geometrical restrictions)

Parametrical approach – global optimization



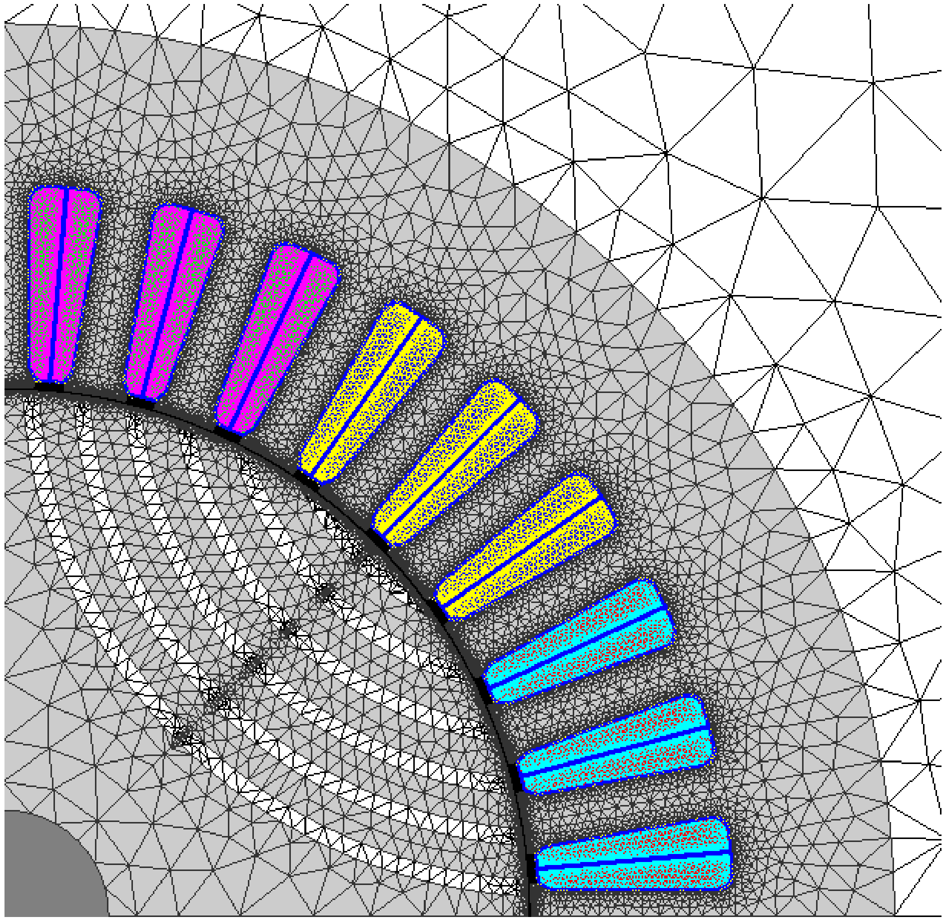
Aim for future work: implement optimisation methods provided by GOT-It

Parametrical approach – global optimization

Automatic computation of a grid of designs:

•Current controlled: i.e. current was adopted offline until load-point was reached +/-5%

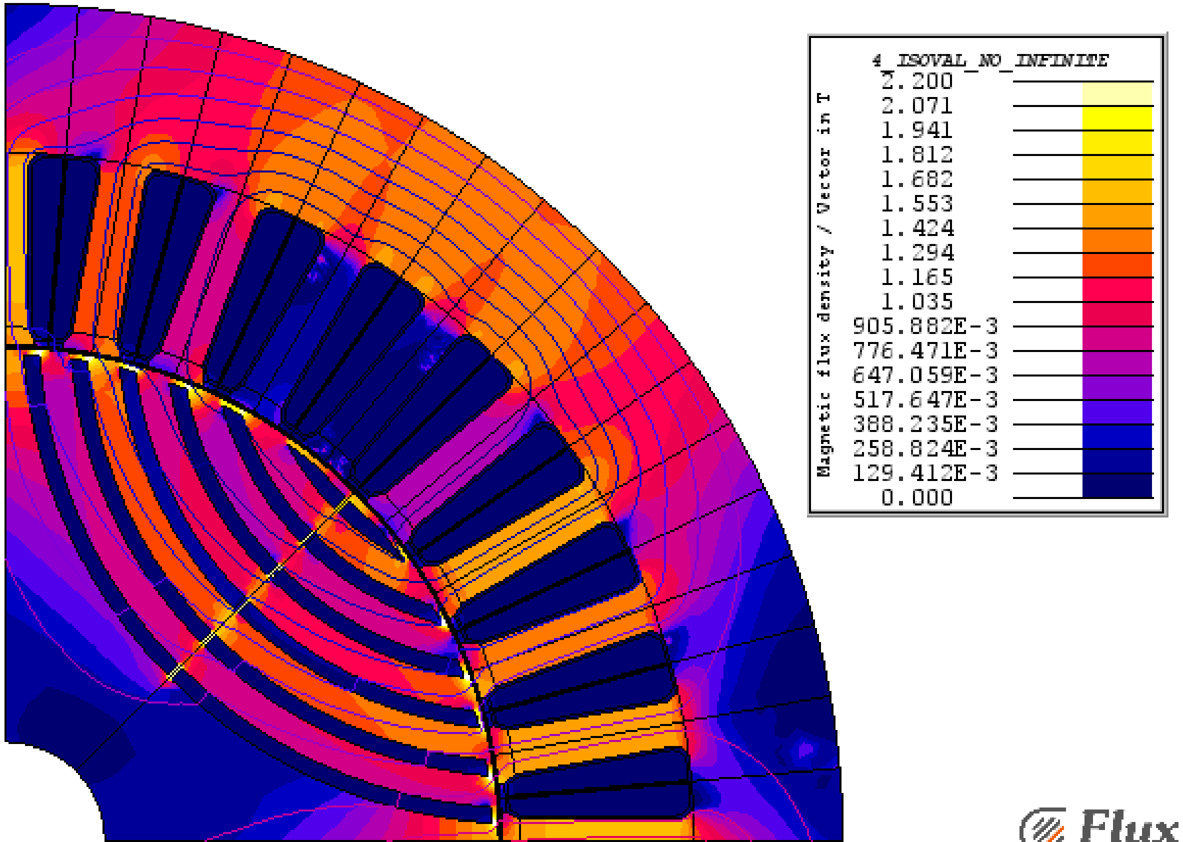
•Computation of around 2000 Designs



Parametrical approach – global optimization grid

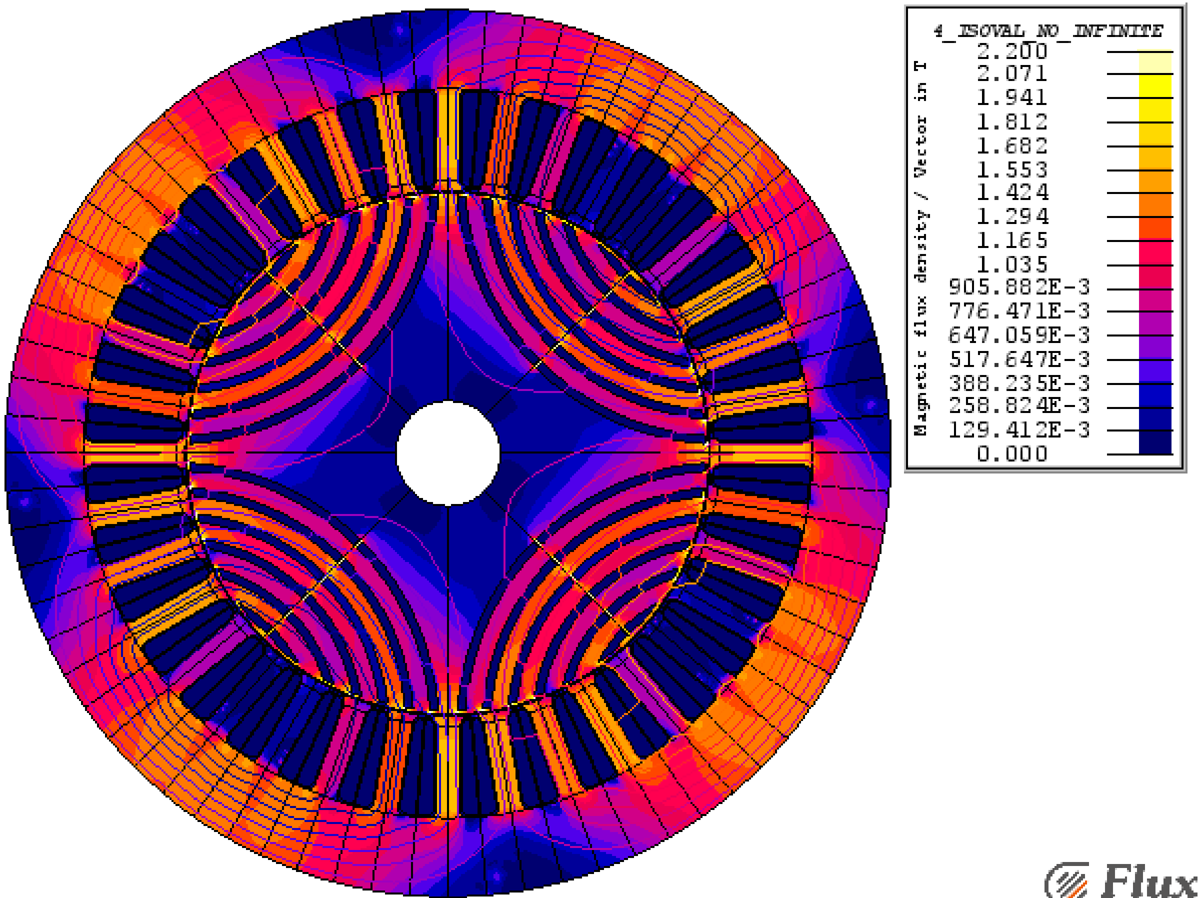
Design variable	Symbol	Lower boundary	Gradation	Upper boundary
No of layers	layer	2	1	6
Ratio air/iron	beta	0,5	0,25	1,25
Curve of flux barriers	radc	57 mm	0,5 mm	61 mm
Distance to shaft	radoffset	0 mm	0,5 mm	4 mm

Parametrical approach – field lines and magnetic loading distribution



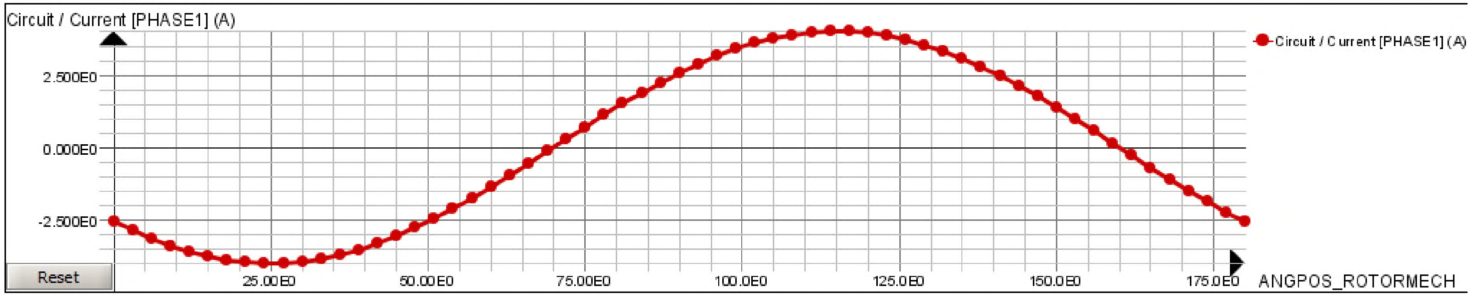
Field lines and magnetic loading distribution

Parametrical approach – field lines and magnetic loading distribution

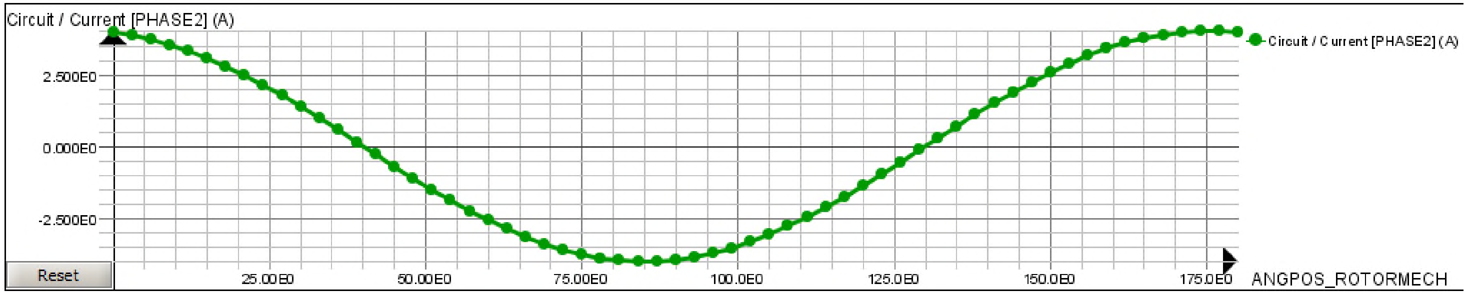


Parametrical approach – phase currents

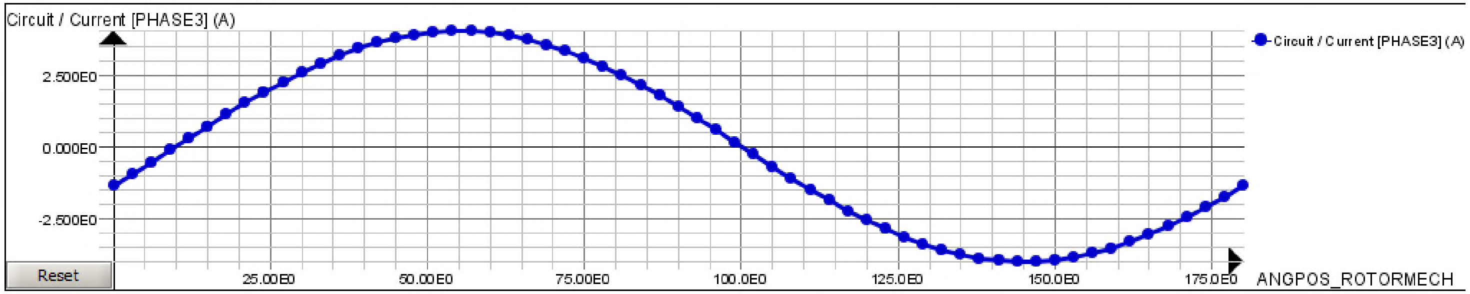
Circuit / Current [PHASE1]



Circuit / Current [PHASE2]

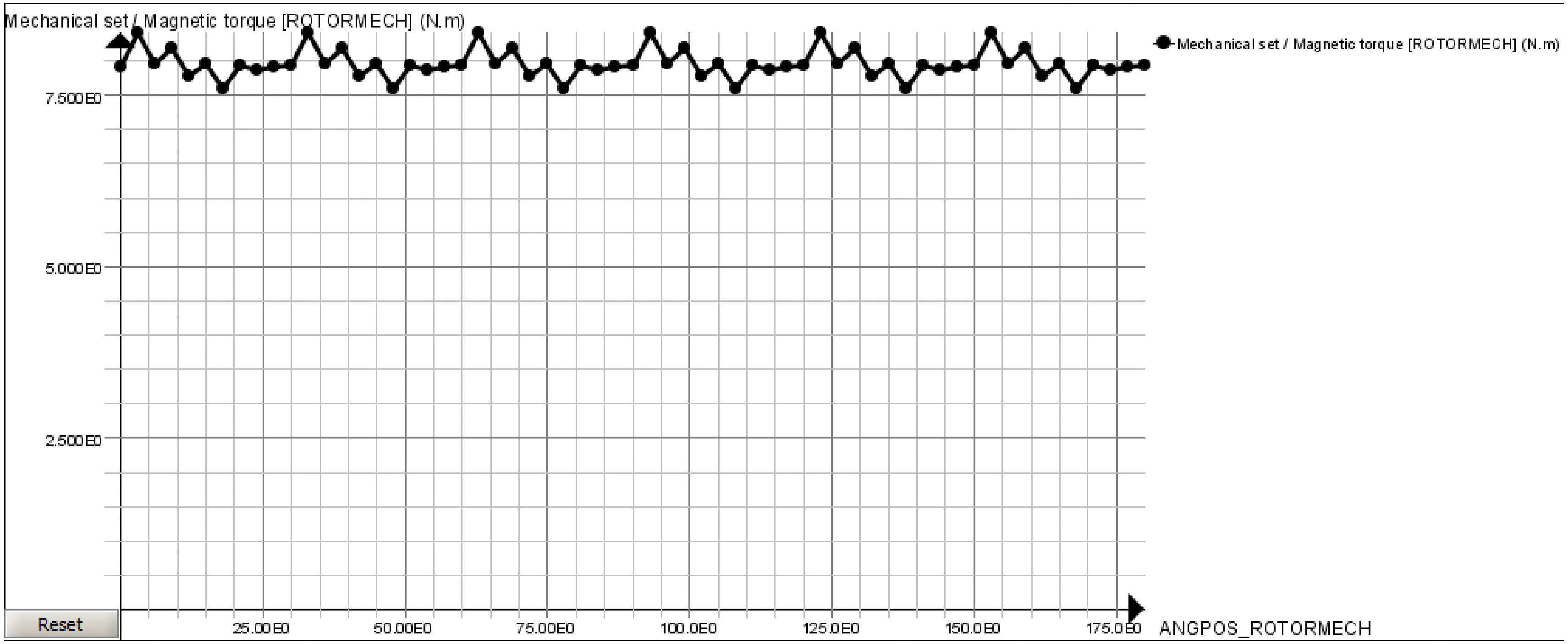


Circuit / Current [PHASE3]



Parametrical approach – torque variation over one electric period (180 °mech)

Mechanical set / Magnetic torque [ROTORMECH]

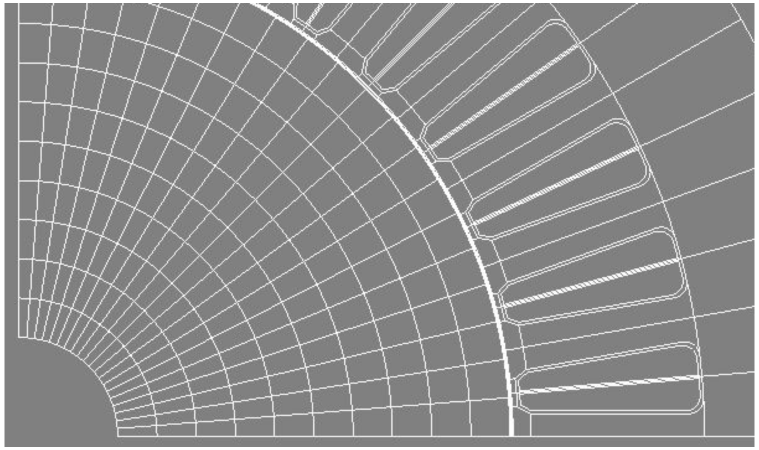


Objectives | Parametrical approach | **Topological approach** | Experimental validation

Topological approach

Approach

1. Topological optimization
2. Definition of boundary conditions
3. Functional principle of genetic algorithms
   - Randomly selected start-population
   - Cross-over/ mating
4. Results of the genetic algorithm

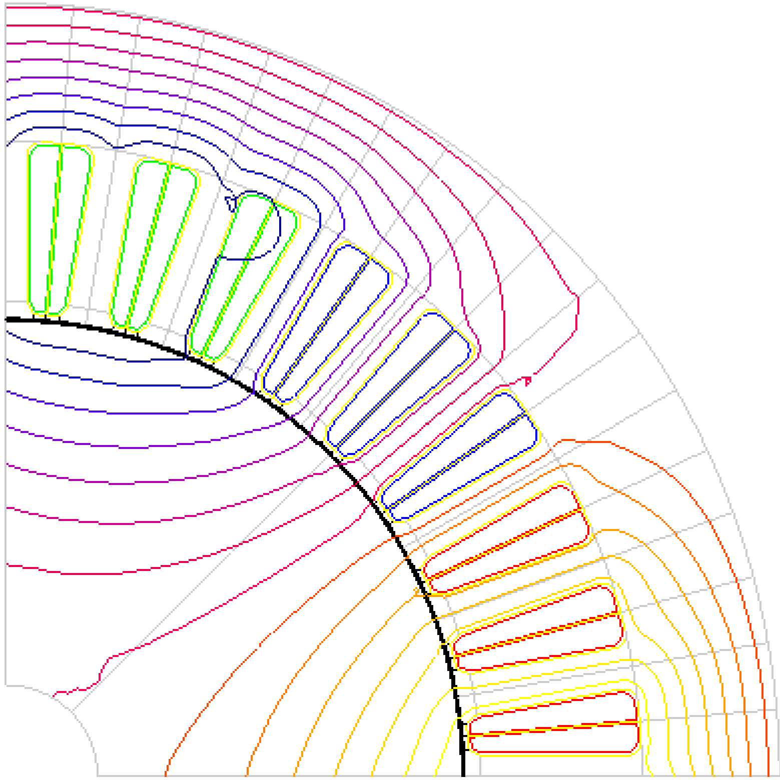


objectives

- Maximize rotor saliency
- Find optimal transversal geometry
- Decrease computation time by simulating biological selection-processes

Bildnachweis:

Topological approach



Originally approach

- Based on the experience of the designer
- Shape of the flux barriers within the rotor is orientated at the direction of flux in a full iron rotor

Aim:

- Impartial design solutions
- New ideas and inspiration

Topological approach

n – dimensional search methods

Calculus based	Enumerative	Random	Guided Random
- Gradient based - Newton-Raphson - Quadratic - Cubic - Euler	- Search complete domain (Grid Search)	- Monte Carlo	- Evolutionary - Simulated - Annealing - Ant colony

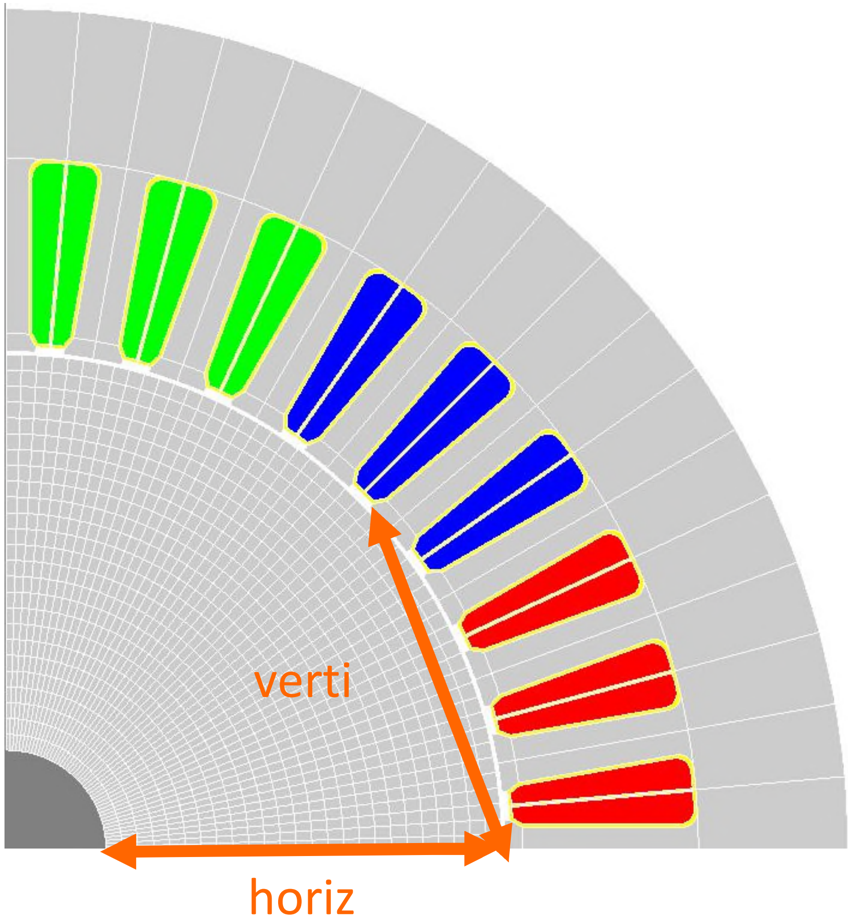
Parametrical approach

Topological approach

Guided Random search methods

Topological approach - boundary conditions

- Same stator as during parametric optimization (same shaft diameter; same airgap)
- Specification of winding scheme
- Segmentation into discrete number of elements (horiz*verti)
- Consideration of symmetry (half pole pitch)

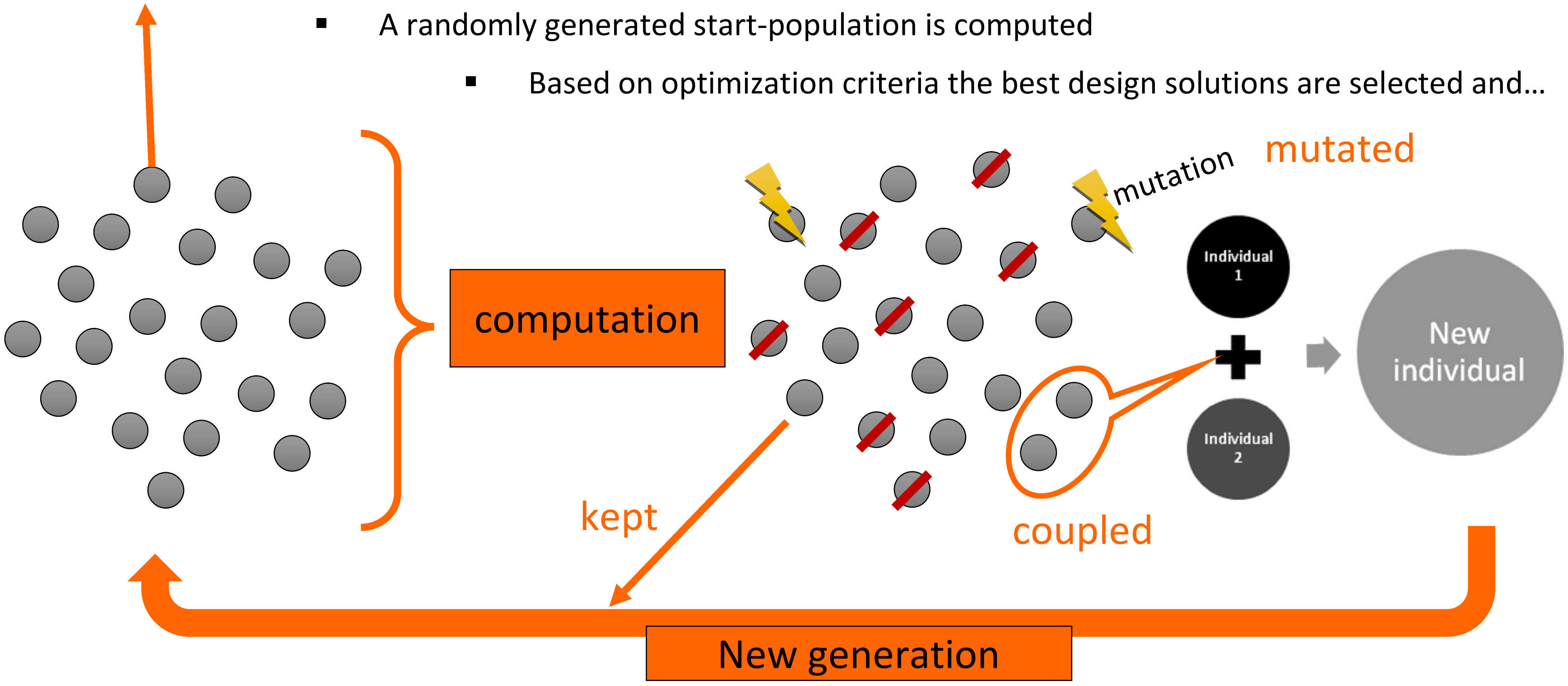


Topological approach – genetic algorithm by John Holland

- John Holland
  - Simulation of natural selection processes
  - Search space to complex
  - Survival of the fittest
  - criteria: objective function
  - Presentation of the results
    - ✓ Phenotype
    - ✓ Genotype

Topological approach – functional principle of genetic algorithms

- Every design is identified by a unique binary code "DNA"
  0001000100100000111101001110111111....
  - A randomly generated start-population is computed
    - Based on optimization criteria the best design solutions are selected and...



Topological approach – coupling process

Mutation before coupling

- “mother - DNA”: 0001000100100000111101001110111110001100010100010011101011100110

Mutation after coupling

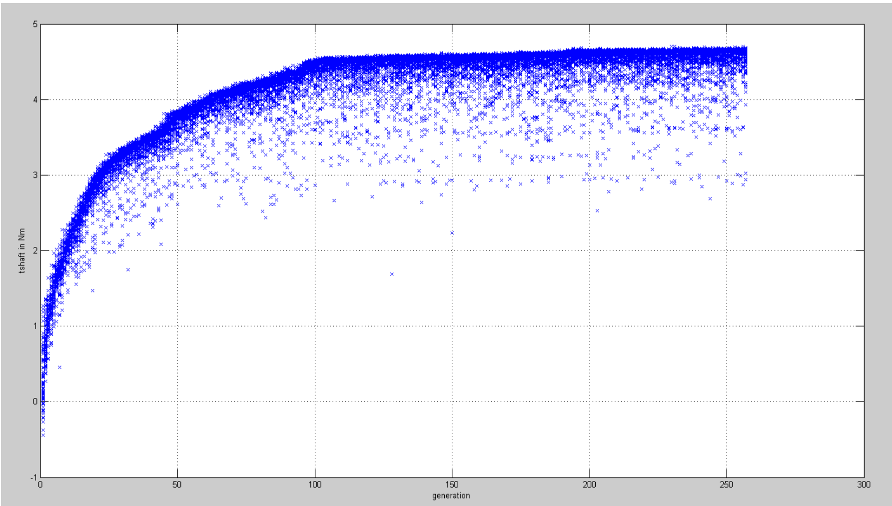
“child-DNA” | 0001000100100 | 0011010010000 | 0100111010100 | 000101000100 | 110101110011

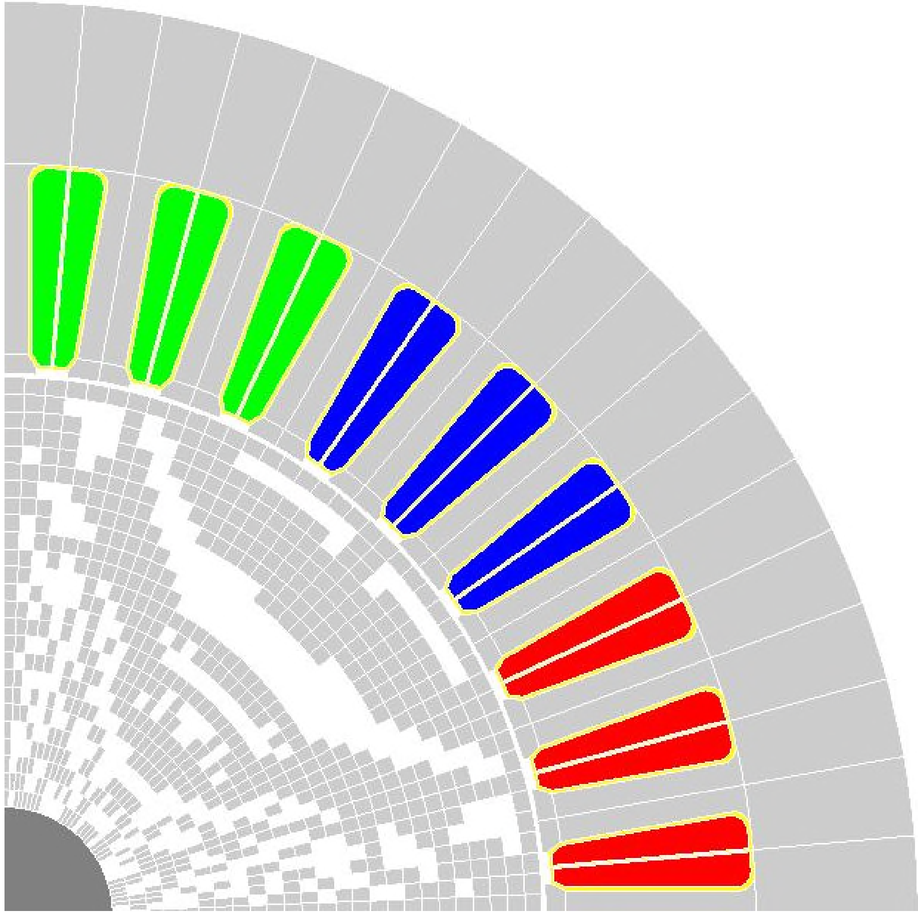
Mutation before coupling

- “father- DNA”: 0110111010111001101001000010001101010001000111001111001111111010

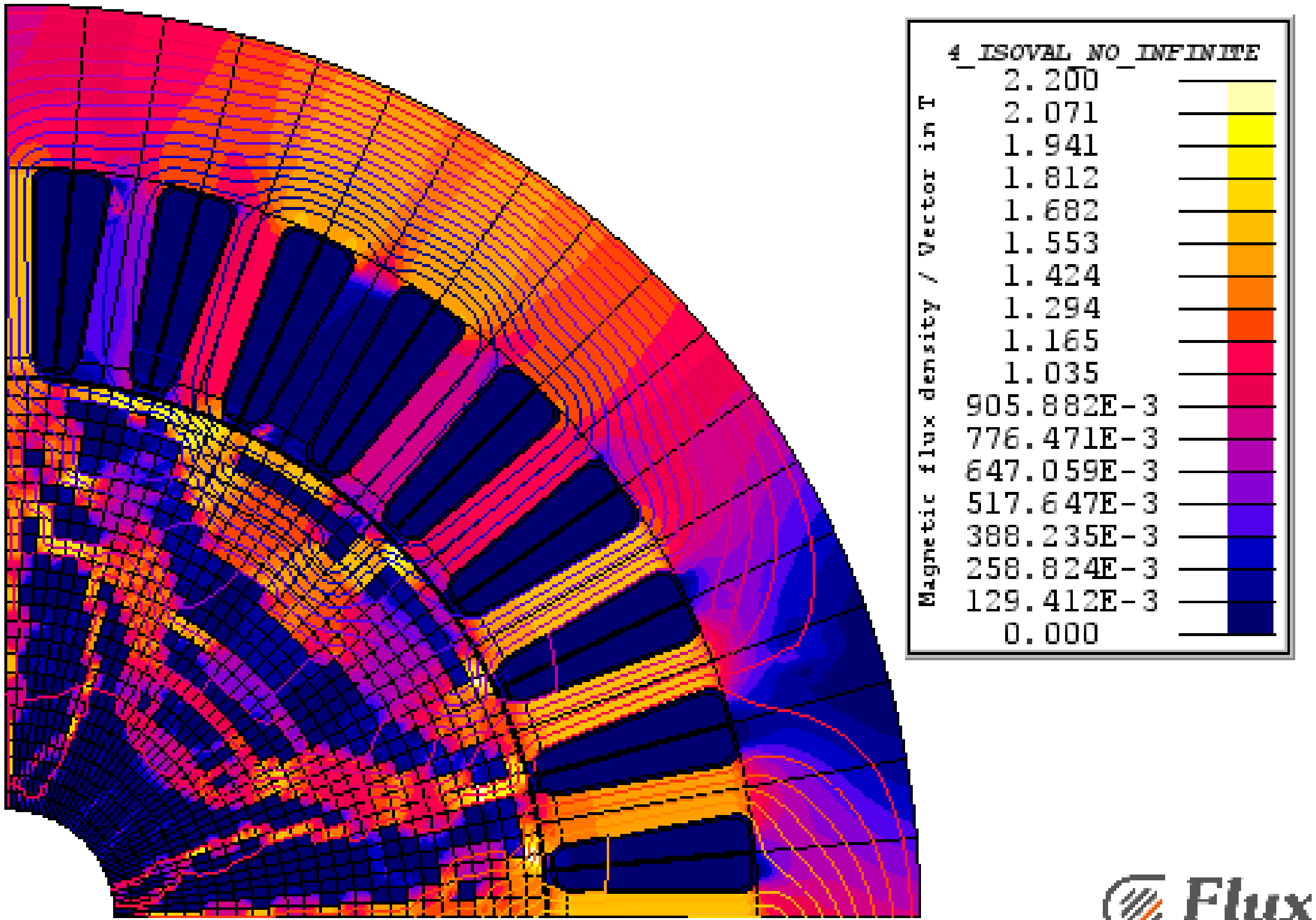
Topological approach – results

- 260 generation
- 100 individuals per generation
- 25*20 = 500 rotor-elements

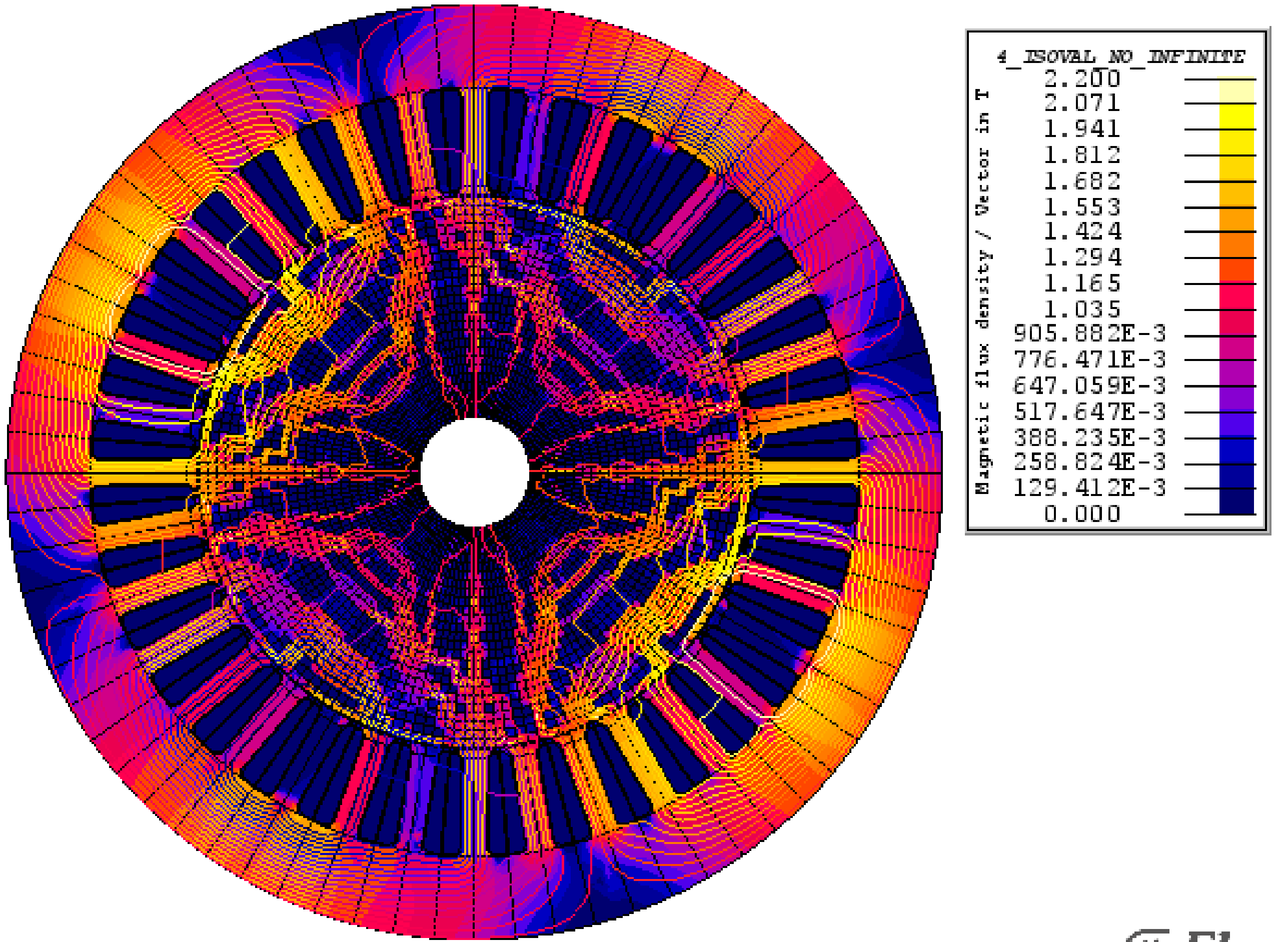




Topological approach – field lines and magnetic loading distribution

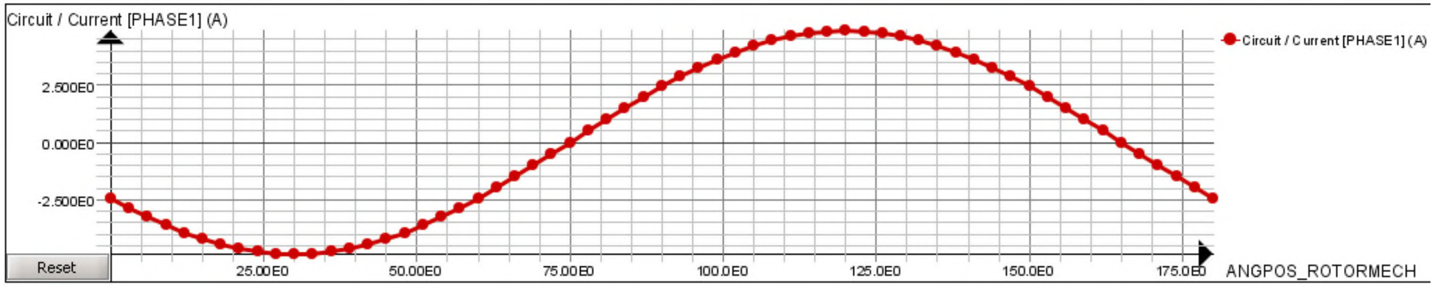


Topological approach – field lines and magnetic loading distribution (full motor)

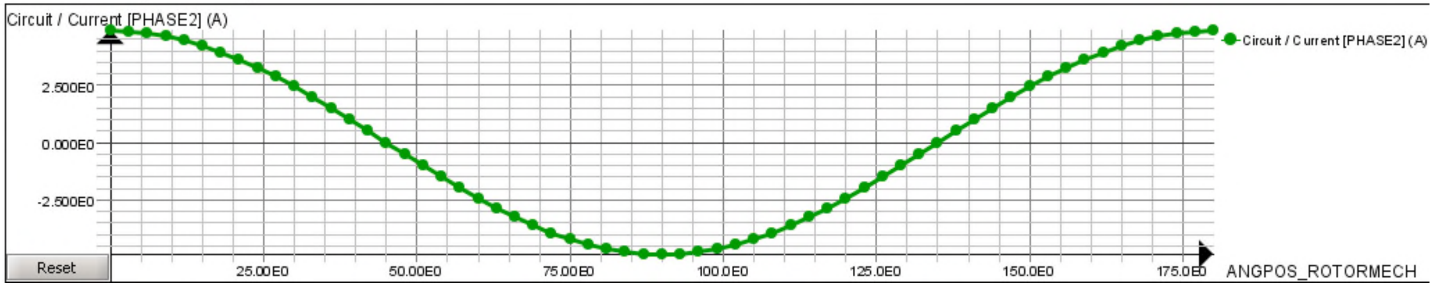


Topological approach – phase currents

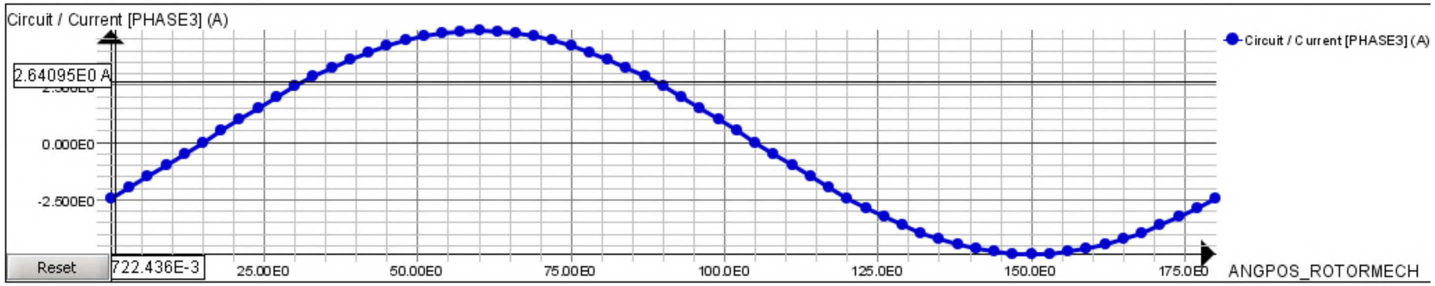
Circuit / Current [PHASE1]



Circuit / Current [PHASE2]

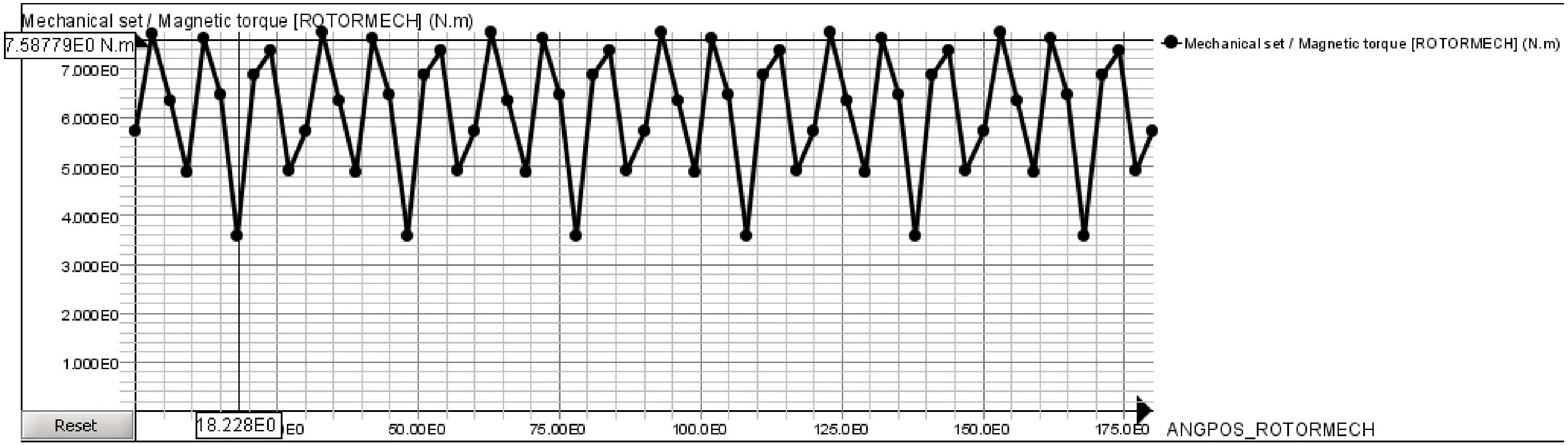


Circuit / Current [PHASE3]



Topological approach – Torque variation over one electric period (180 °mech).

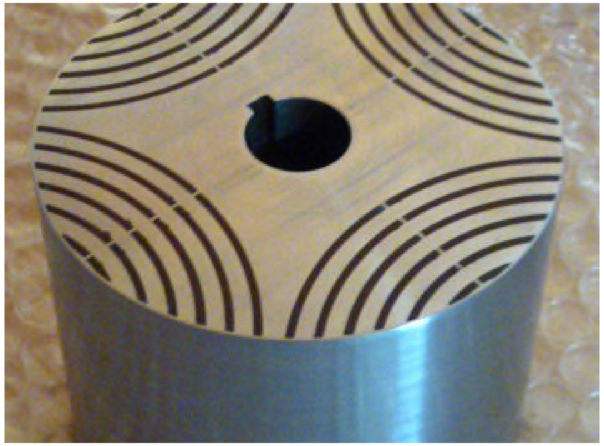
Mechanical set / Magnetic torque [ROTORMECH]



Experimental validation

Approach

1. Standstill test procedure
2. Prototype
3. Standstill test, results
4. Conclusion
5. Future work

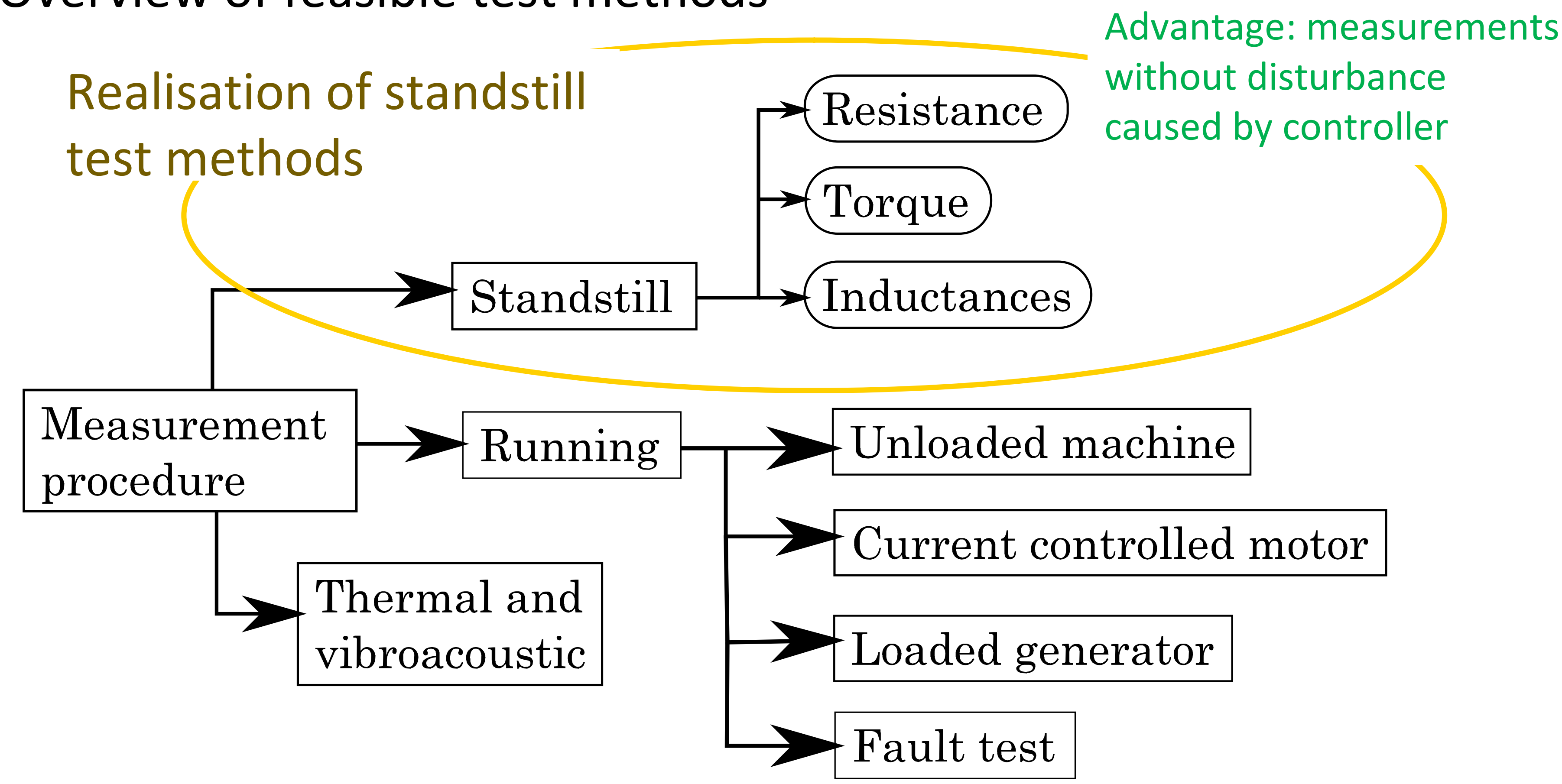


objectives

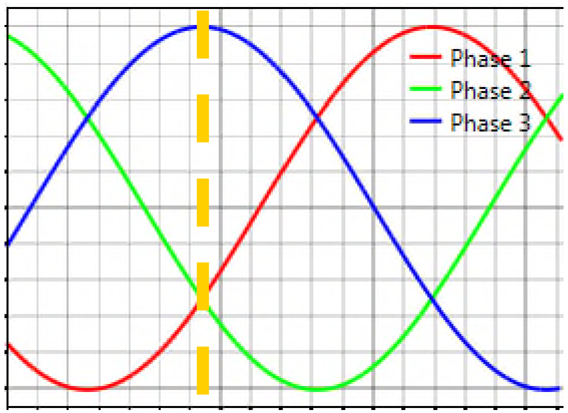
- Validation of the design
- Determination of machine parameter

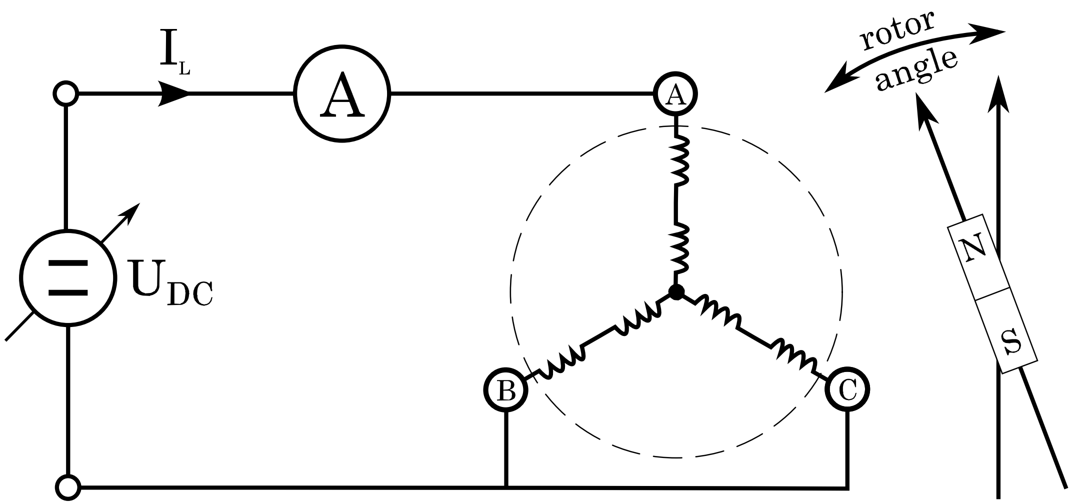
Bildnachweis:

Overview of feasible test methods



Applied test methods – standstill torque measurement

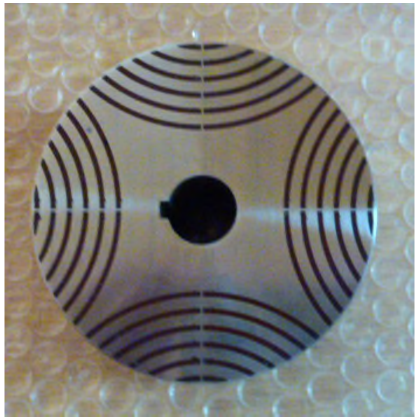


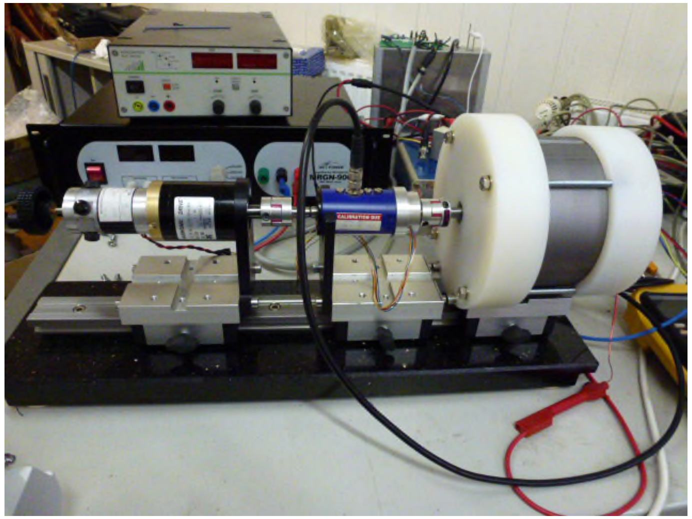


Measurement at a concrete point in time

- applying at zero speed a DC voltage at phase terminals
- a defined current is applied at all phase windings
- This current generates torque depending on rotor position

Prototype and test set-up

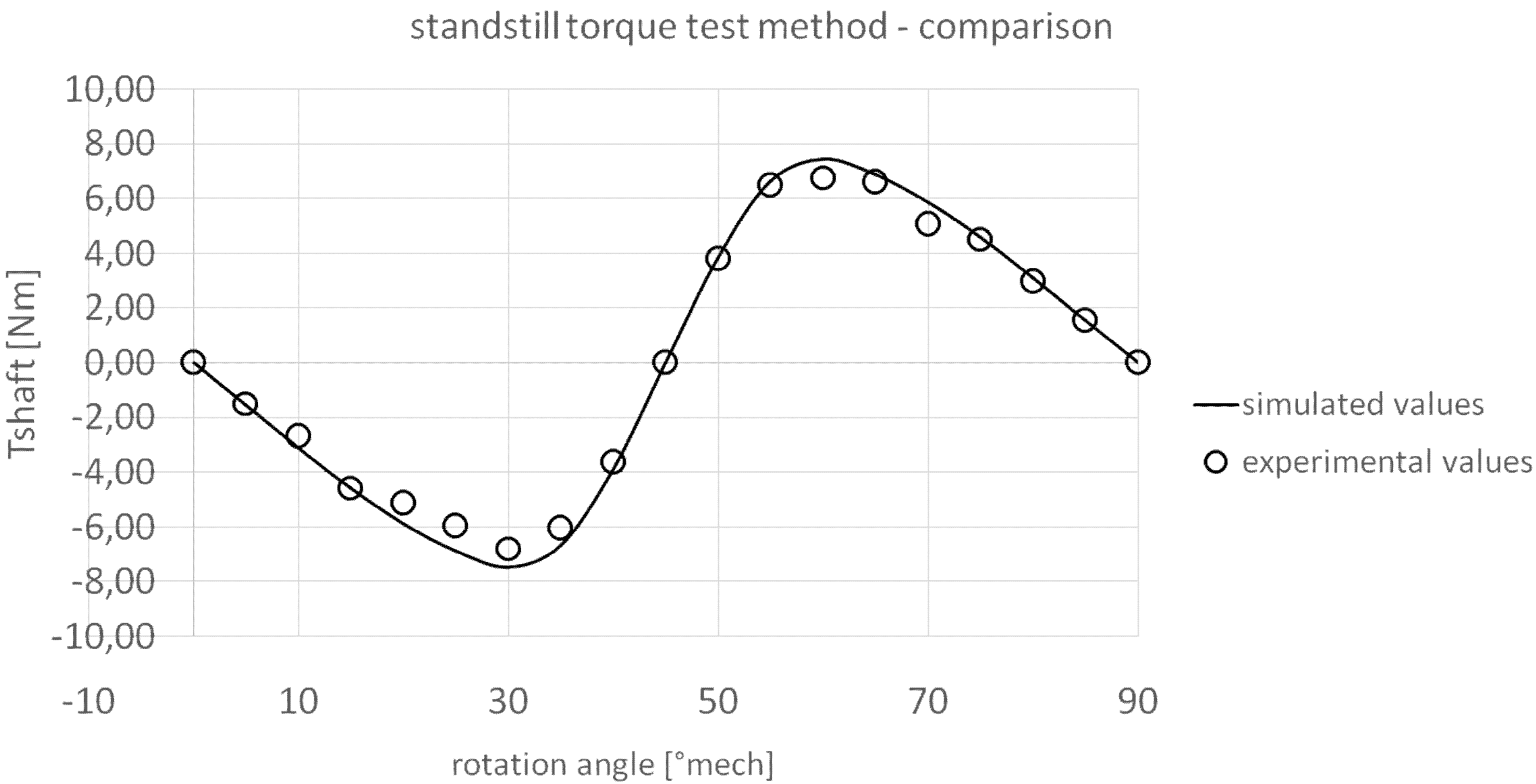




Prototype of the rotor

Test set-up

Experimental results



Conclusion and future work

RSM

- In our opinion RSM is able to keep up with the induction motor regarding efficiency
- In our opinion RSM is able to keep up with the PMSM regarding overall costs

Parametrical approach

- Has proven to be an effective method for maximising power and efficiency

Topological approach

- Is a scientific approach not yet feasible for practical application
- Enlarges the search space dramatically
- Requires more computational efforts (high potential in future due to increasing computation capacities)
- Transformation of results into a parametric model expedient

Reference 1/2

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