Hochschule Ulm
University of Applied Sciences

Workshop der ASIM/GI-Fachgruppen STS Und GMMS
Simulation Technischer Systeme
Und
Grundlagen Und Methoden In Modellbildung Und Simulation
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Development and Design Optimization of a High-temperature Superconducting Quasi-Diamagnetic Motor Demonstration Unit

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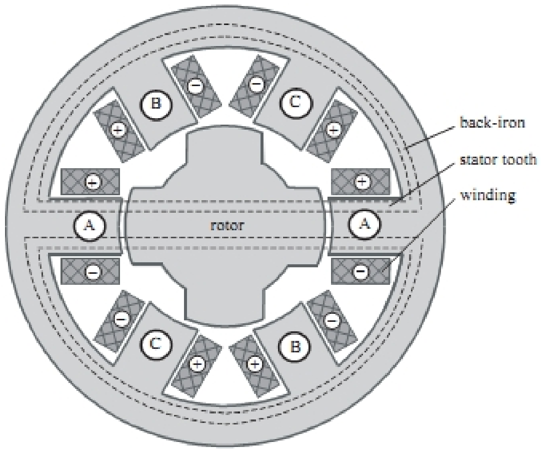
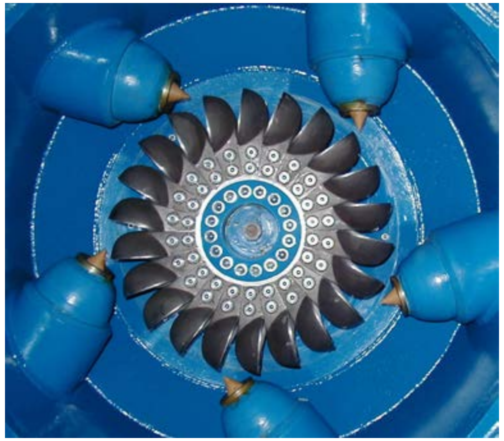
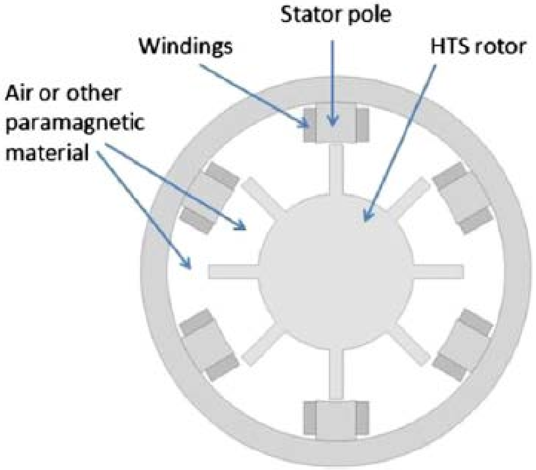
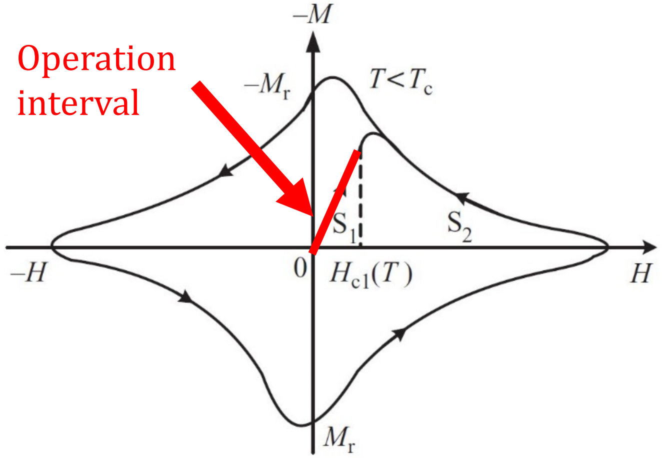
Óbuda University / Hochschule Ulm

PRELIMINARIES: ON OPERATING PRINCIPLE



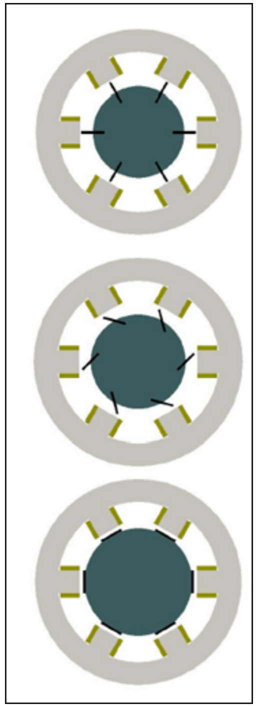


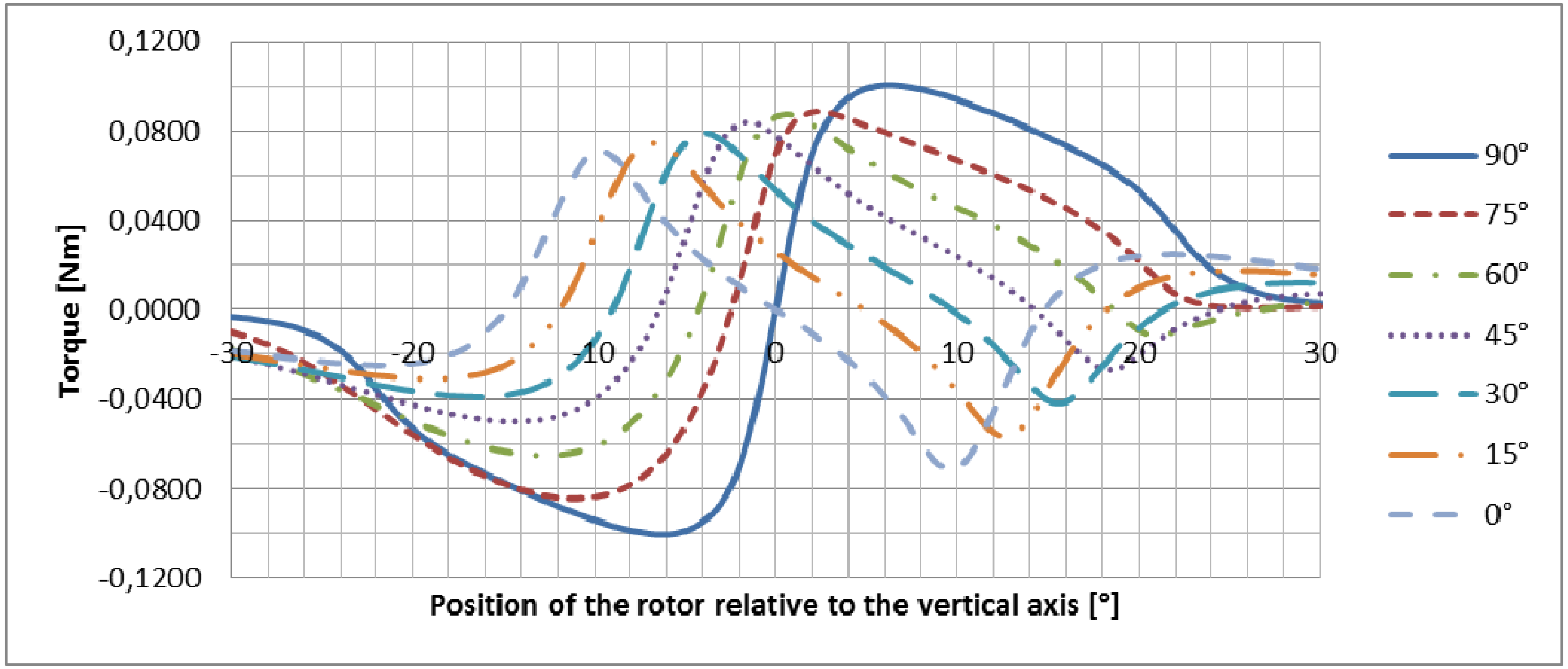




- Similarities with switched reluctance motors (SRM) and Pelton-turbine
- Operation interval on the first magnetization curve of type-II superconductive materials

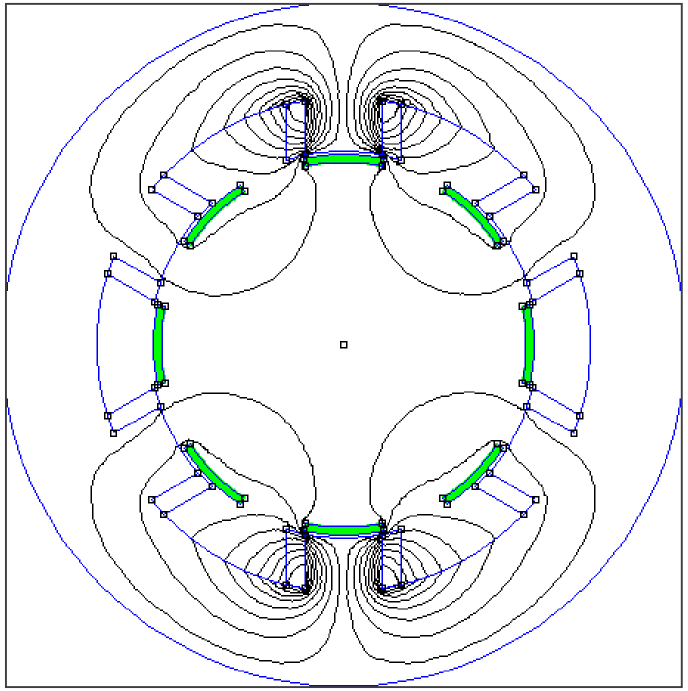
PRELIMINARIES: PARAMETER SWEEP I. – SLANTED ROTOR BLADES (SENSITIVITY ANALYSIS)

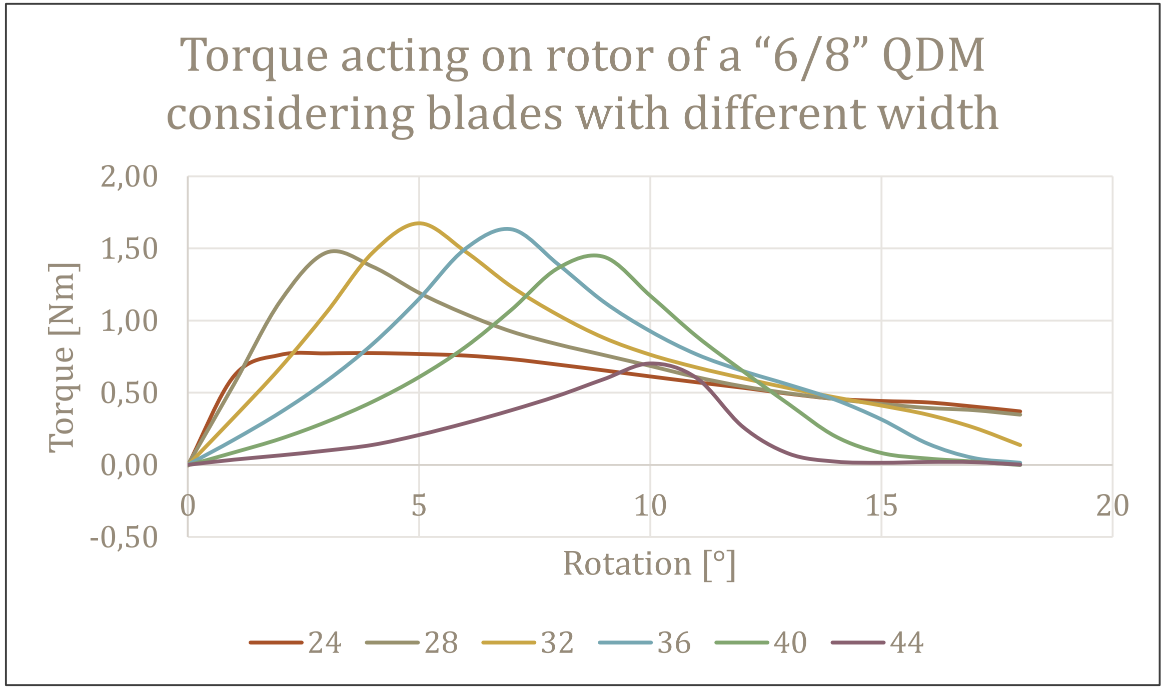




- The angle of the rotor blades influenced the torque exerted on the rotor. “Tangential” blades gave best results (40% greater torque compared to “radial” blades)
- The sign of torque is reversed. (Attractive force instead of repulsive.)

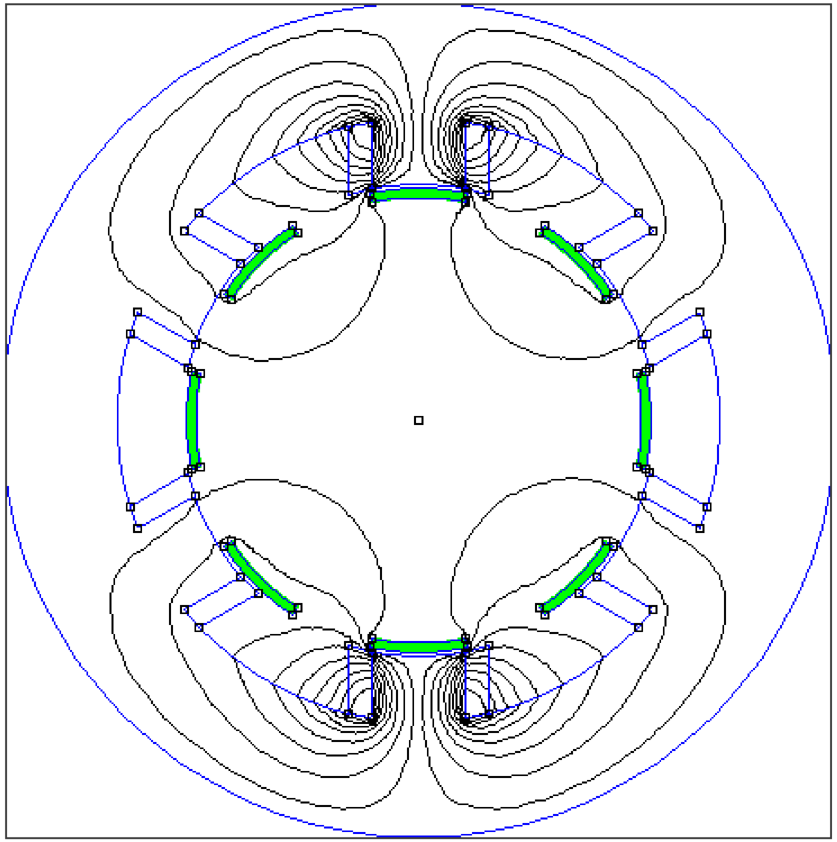
PRELIMINARIES: PARAMETER SWEEP II. – WIDTH OF ROTOR BLADES (SENSITIVITY ANALYSIS)

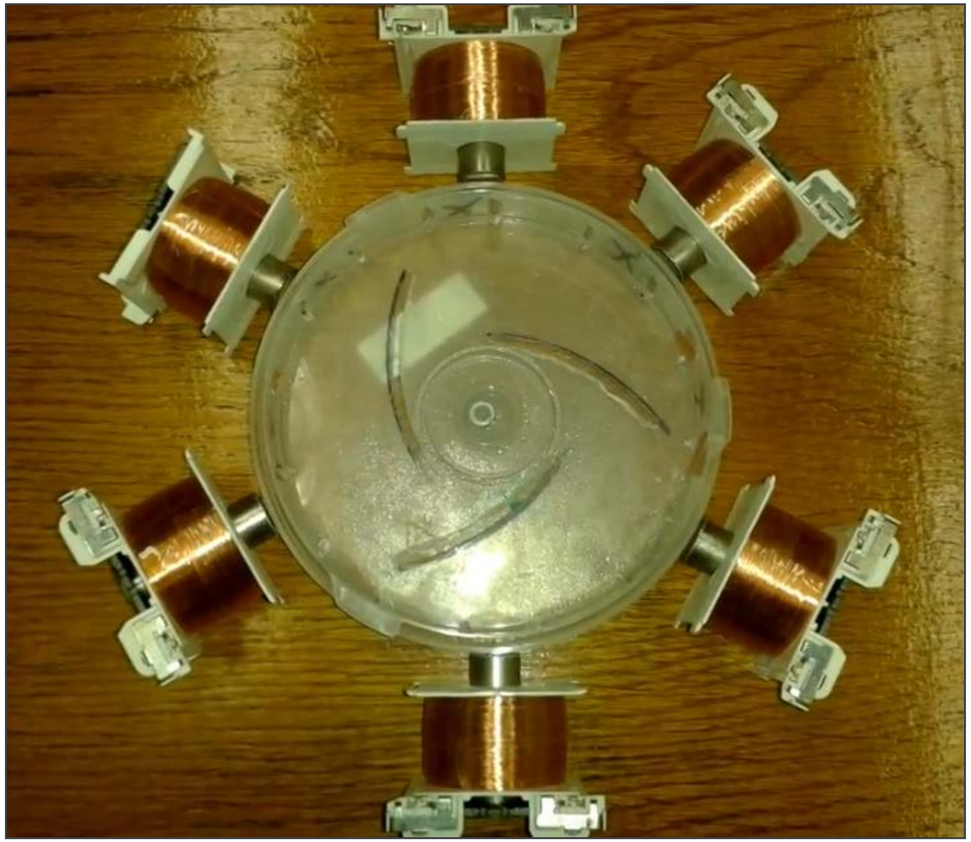




- Torque production is also very sensitive to width of the blade attached to the surface of the rotor.
- There is an ideal range for the ratio of the width of pole to the width of blade.

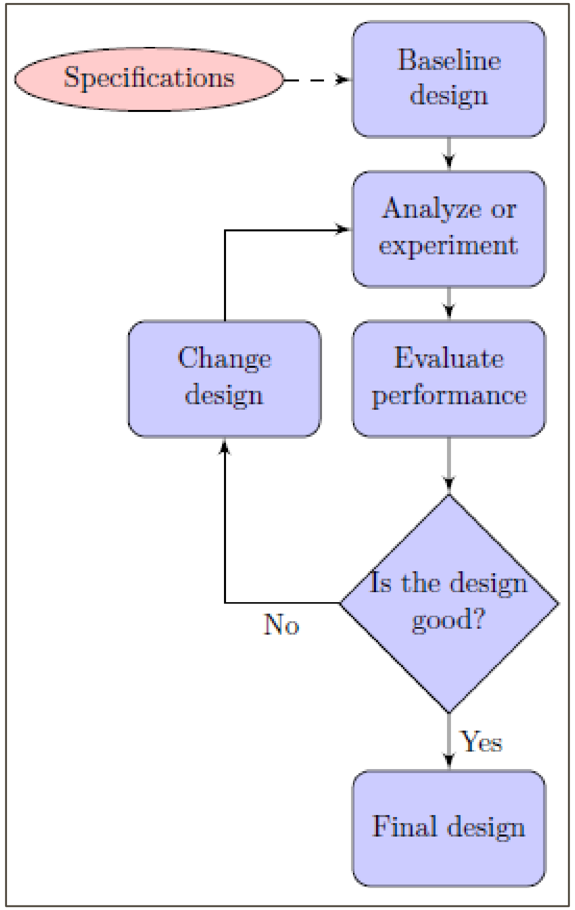
PRELIMINARIES: FIRST EXPERIMENTAL SETUP



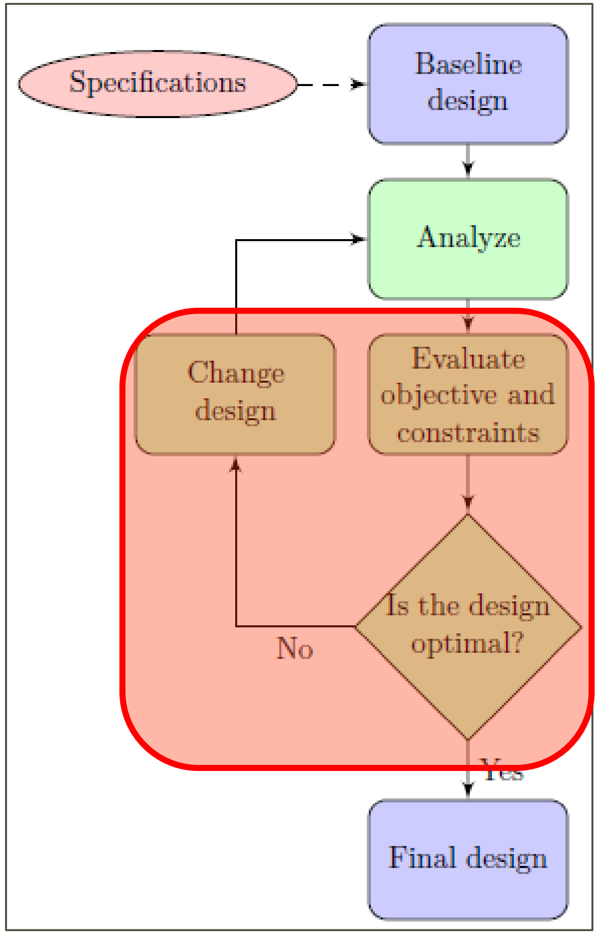


CONVENTIONAL DESIGN PROCESS VS. DESIGN OPTIMIZATION

Conventional Method

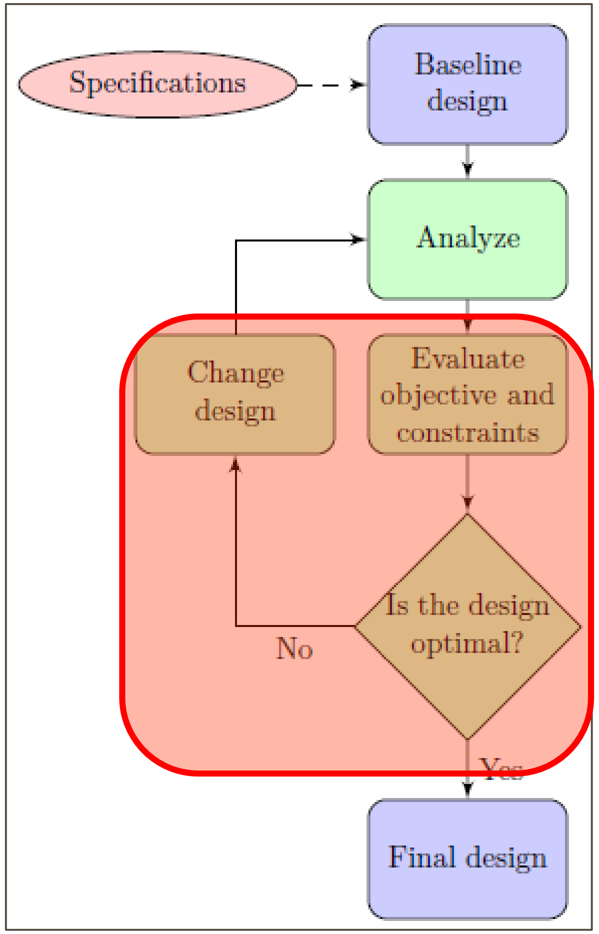


Design Optimization



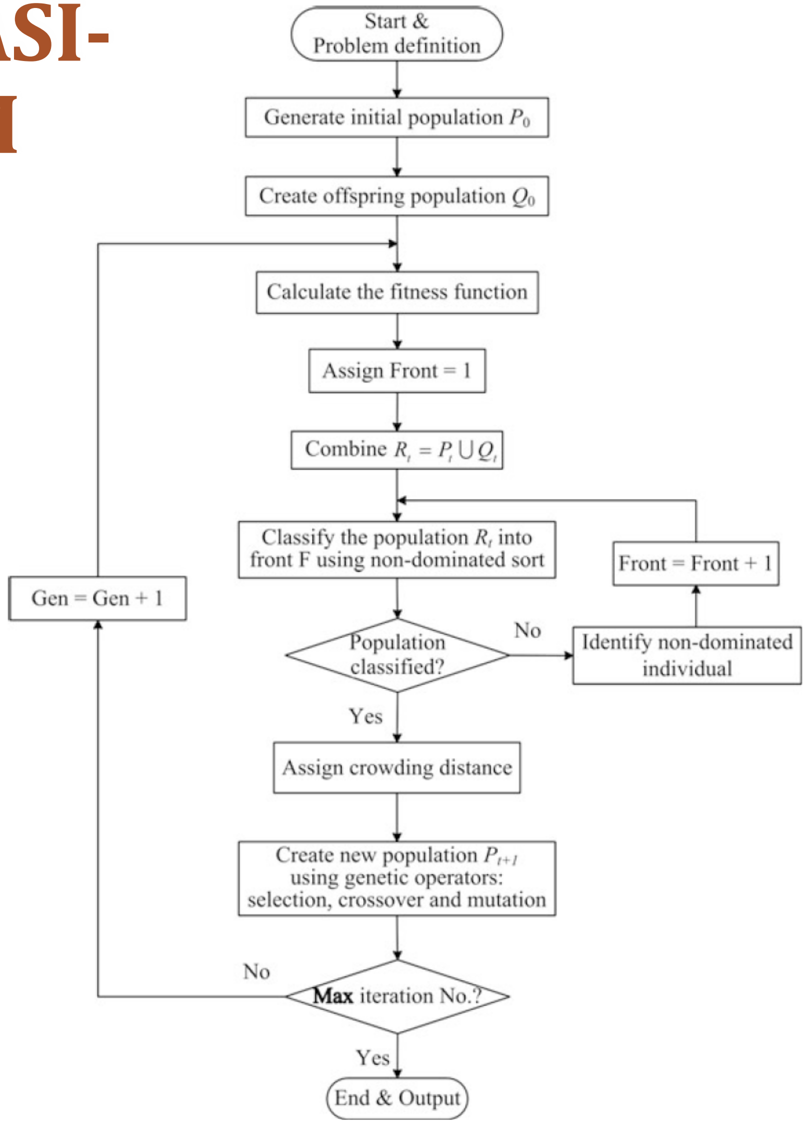
DESIGN OPTIMIZATION: METHODOLOGY

- Systematic approach of decision making is needed
- Need to decide on:
  - 1. Optimization algorithm
  - 2. Definition of variables
  - 3. Feasibility of model (geometrical constraints)
  - 4. Constraint functions
  - 5. Objective functions
  - 6. Stopping criterion



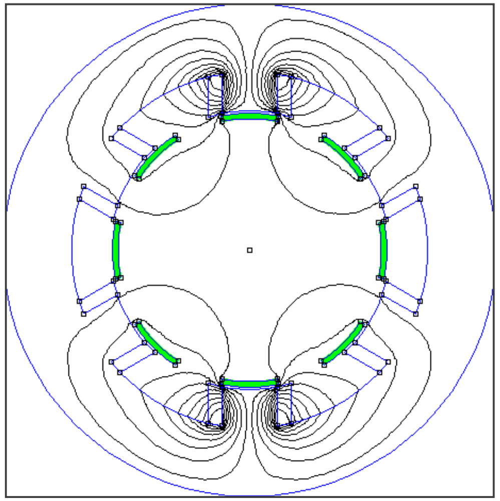
DESIGN OPTIMIZATION OF THE QUASI-DIAMAGNETIC MOTOR: ALGORITHM

- Wide variety of optimization techniques can be used for motor design
- Complex design → explicit optimization methods cannot be used
- Mostly metaheuristic techniques used, such as evolutionary algorithms
- For the optimization of QDM, I used the NSGA-II algorithm, that is readily available in MATLAB (gamultiobj function)



DESIGN OPTIMIZATION OF THE QUASI-DIAMAGNETIC MOTOR: DEFINITION OF VARIABLES

- Design variables are usually defined in two ways
  - directly (e.g. stator inner radius, number of stator poles, air gap etc.)
  - as ratios of model parameters (e.g. ratio of slot width to the slot depth)



Parameter and unit	Symbol
Thickness of superconductor blade [mm]	a
Width of superconductor blade [mm]	b
Position of the rotor blade measured from the vertical axis [°]	α
Stator outer radius [mm]	R_{so}
Stator inner radius [mm]	R_{si}
Stator pole inner radius [mm]	R_{pi}
Width of stator pole [mm]	w_p
Width of stator pole with winding [mm]	w_w
Axial length of the machine [mm]	l
Peak current in stator winding [A]	I_{pk}
Number of stator poles	N_{sp}
Number of rotor blades	N_{rb}
Turns of stator winding	N_{sw}
Air gap [mm]	δ

Model parameters of the QDM

DESIGN OPTIMIZATION OF THE QUASI-DIAMAGNETIC MOTOR: OBJECTIVE FUNCTIONS, CONSTRAINTS

Minimize	$-\ \mathbf{M}\,(\mathbf{a}, \mathbf{b}, \boldsymbol{\alpha}, \mathbf{wp})$
	$V_{sc}(\mathbf{a}, \mathbf{b})$
Subject to	$a_{min} \leq \mathbf{a} < R_{pi} - \delta$
	$b_{min} < \mathbf{b} < \dfrac{2 \cdot (R_{pi} - \delta) \cdot \pi}{N_{rb}}$
	$\alpha_{min} < \alpha < \dfrac{360°}{2 \cdot N_{rb}}$
	$w_{wmin} < w_w < 2 \cdot R_{pi} \cdot sin\left(\dfrac{360°}{2 \cdot N_{sp}}\right)$

Parameter and unit	Symbol
Thickness of superconductor blade [mm]	a
Width of superconductor blade [mm]	b
Position of the rotor blade measured from the vertical axis [°]	α
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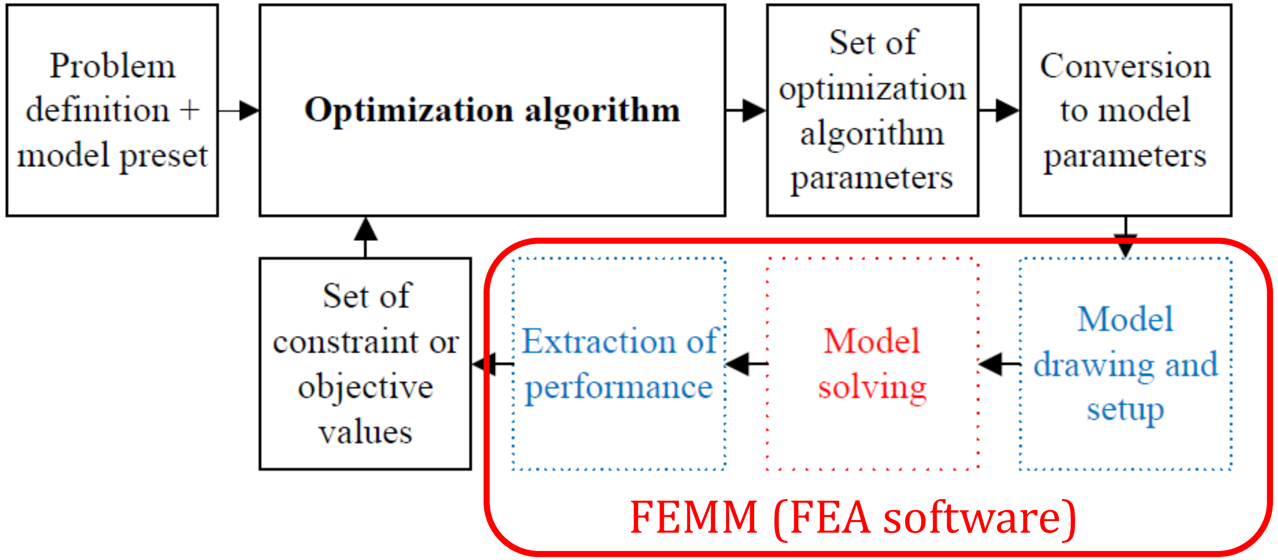
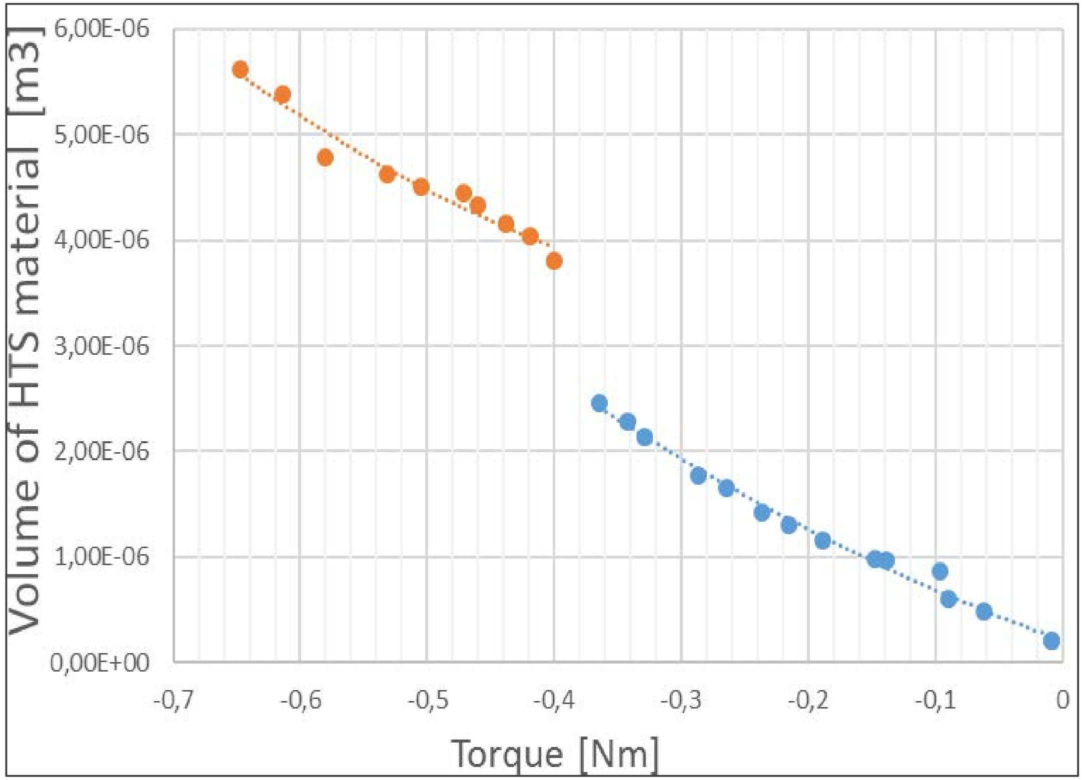
Air gap [mm]	δ

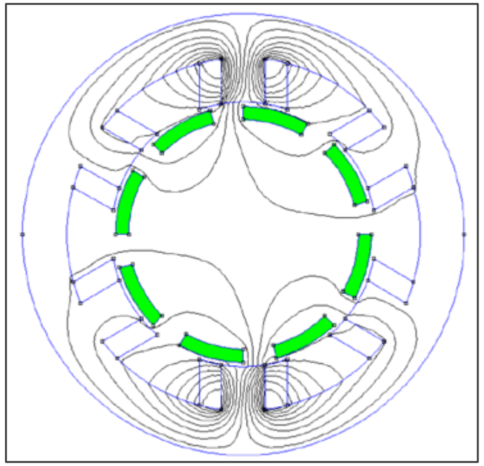
DESIGN OPTIMIZATION OF THE QUASI-DIAMAGNETIC MOTOR: WORKFLOW OF OPTIMIZATION

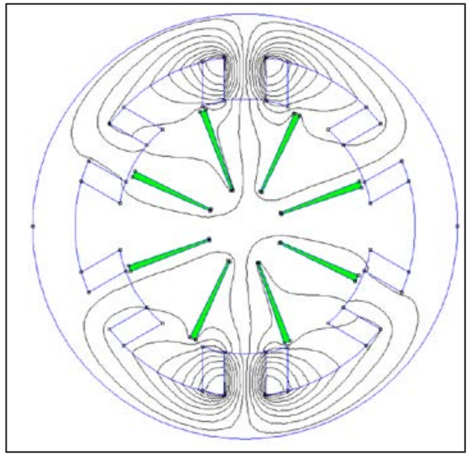
- 1. Problem definition: setup of boundaries, objectives, constant model parameters (number of poles, winding etc.)
- 2. The NSGA-II algorithm in MATLAB generates variables/parameters
- 3. The model is drawn/setup in FEMM (by means of scripts in MATLAB)
- 4. Model is solved (in FEMM)
- 5. The performance of the model is extracted (post-processing in FEMM)
- 6. Values of objective functions are passed back to MATLAB.
- 7. Steps 2-6 performed iteratively, optimal solution is obtained after termination.



DESIGN OPTIMIZATION OF THE QUASI-DIAMAGNETIC MOTOR: RESULTS





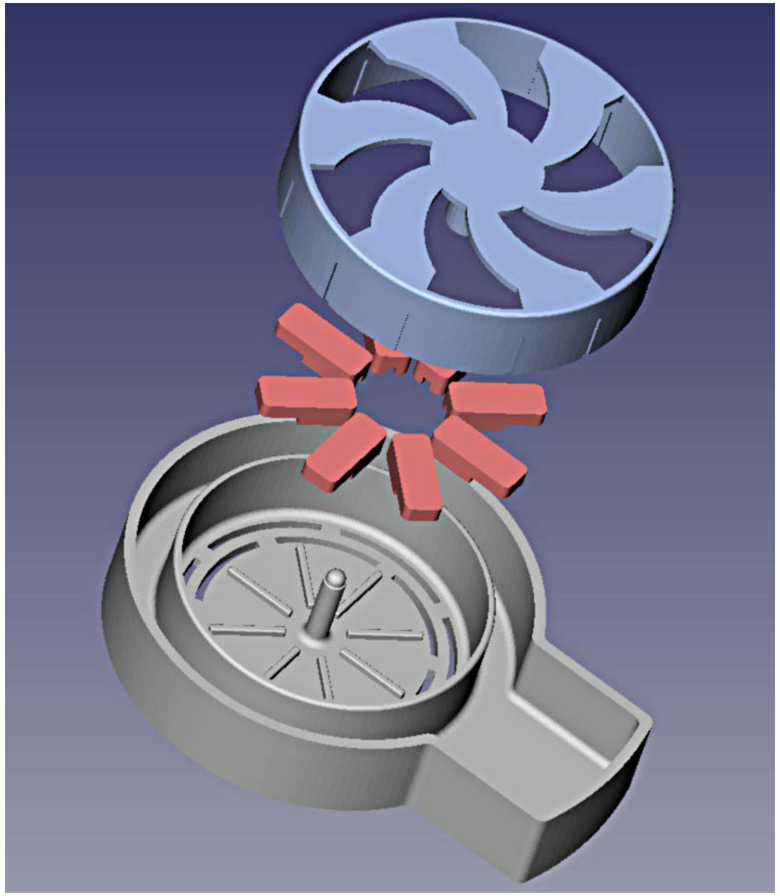


←Set of non-dominated ("Pareto") solutions.

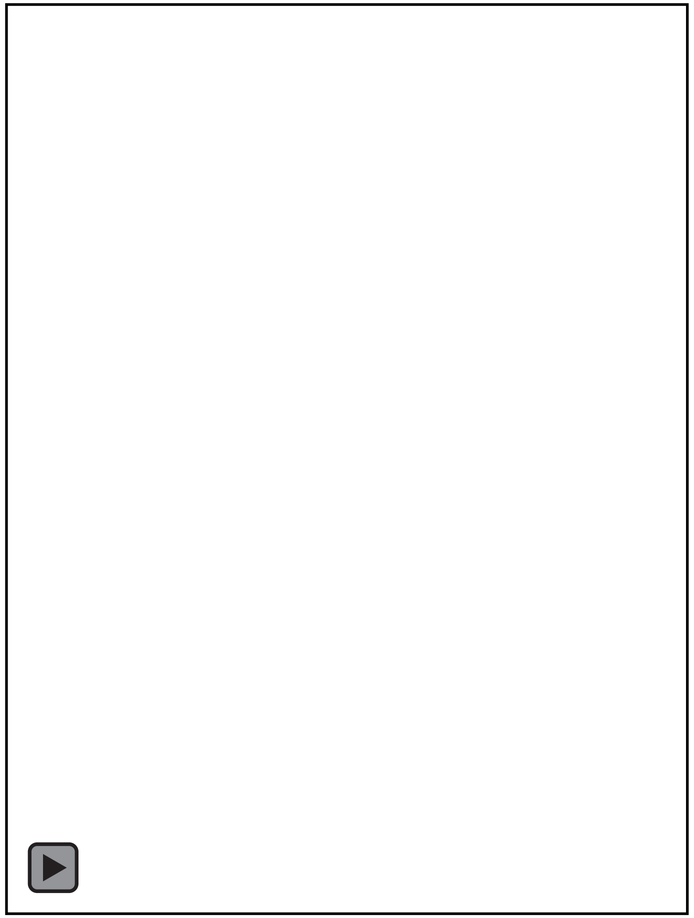
Two kinds of optimal designs:
a) Wide blades along the circumference → better torque production
b) Radial blades of the early design → less superconductive material

DESIGN OPTIMIZATION OF THE QUASI-DIAMAGNETIC MOTOR: NEXT STEPS

- New inner stator – outer rotor design concept, cooling of superconducting wire made easier (the baseline design is ready)
- Design optimization process to be applied on new basic design
- New experimental setup to be built based on results
- Measurements to be carried out to determine operating characteristics



VIDEO: FIRST EXPERIMENTAL SETUP



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THANK YOU FOR YOUR ATTENTION!

Any questions?