Presented at the COMSOL Conference 2008 Hannover

Optimization of an electromagnetic actuator with COMSOL Multiphysics

Institut für Grundlagen der Elektrotechnik und Messtechnik

Dipl.-Ing. Tankred Müller

Overview

- Motivation
- Implementation
- The Model
  - The geometry to be optimized
  - Calculating the electric parameters
  - Angle control
- Optimization
  - Quality functions
  - Results
- Conclusions

Motivation

Leibniz Universität Hannover

Optimization of electromagnetic actuators is often confusing:

- Structures are often complex
  - An optimization of a single aspect may lead to a degradation of other aspects
- A lot of specifications have to be kept in mind

Conclusions:

- To speed up and simplify the design procedure, the problem should be analyzed completely
- The demands of the application should be incorporated

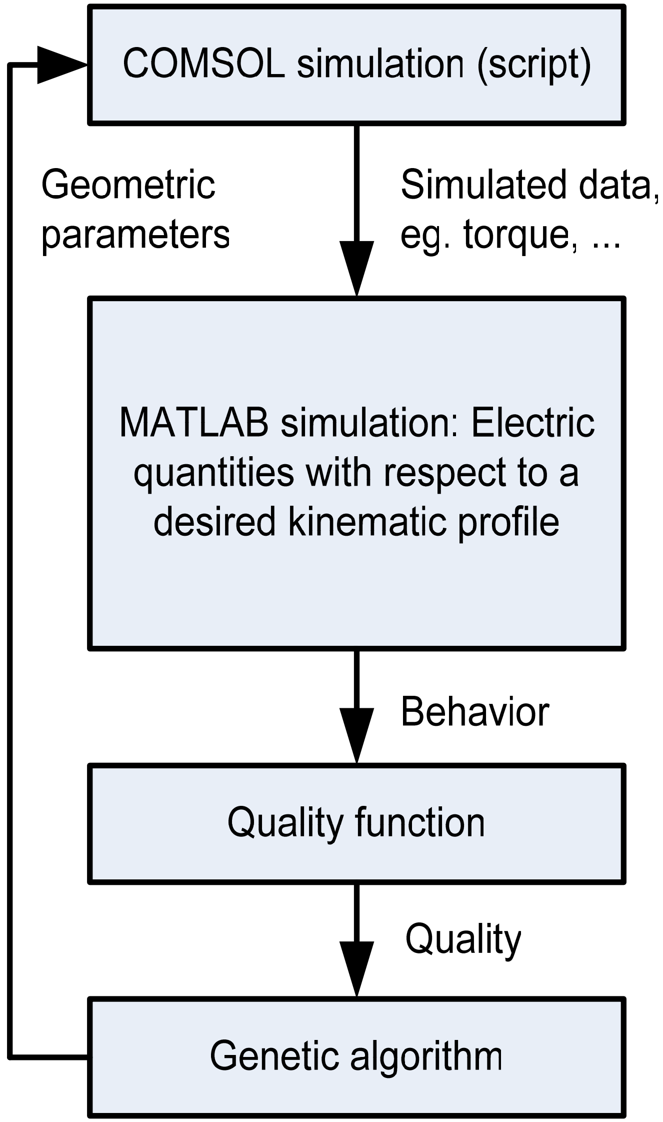
Solution:

- COMSOL simulation for the electromagnetic field problem, embedded in a flexible MATLAB simulation
- Optimization algorithm in MATLAB

Implementation

- The COMSOL script computes operating maps, describing an actuator defined by a specific set of parameters (27 positions at 7 currents are used here)
- Operating maps are analyzed in a MATLAB script
  - Electric quantities are calculated with respect to the desired movement of the actuator
  - The actuator's quality is computed from its behavior
- Optimization process is controlled by a genetic algorithm (available as free MATLAB toolbox)

Optimization process

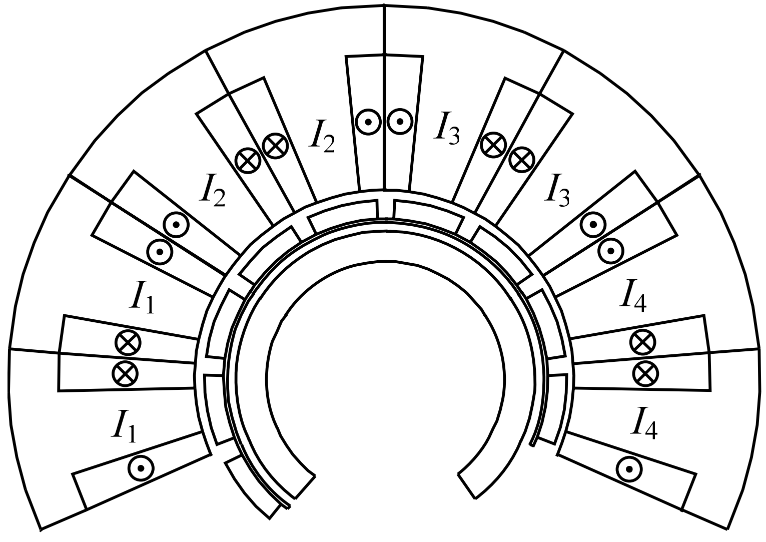


The geometry to be optimized

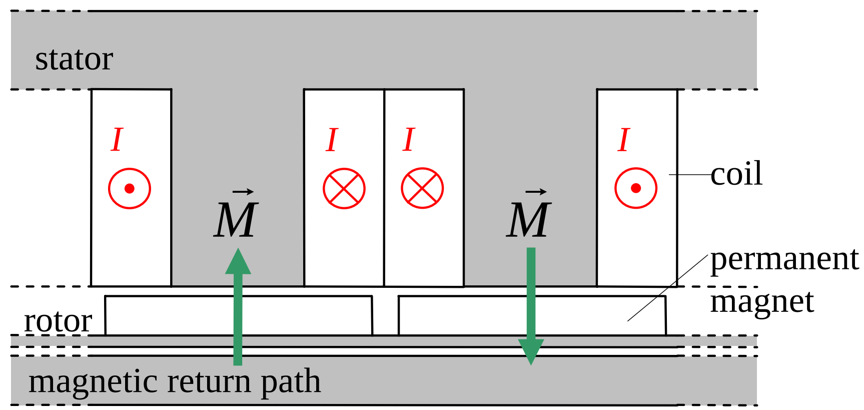
Charge changing valve actuator for an internal combustion engine

- 1 kN, lift of 10mm in ~4 ms for an outtake valve
- Moving magnets
- COMSOL GUI was used to build a MATLAB compatible script (save and replace method)
- Model is defined by 6 geometric variables (radiuses and angles)

The whole geometry:



Only one segment is simulated in COMSOL Multiphysics…



Calculating the electric parameters

We know…

- The torque and the flux linked to the coils, both depending on angle and current, as computed in the COMSOL simulation
- The desired kinematic behavior, taken from a mechanical valve
- Gas forces and mass acceleration effects, which define the torque that is needed

Electric parameters of an optimal actuator

$\alpha(t), M(t)$ — The application defines the rotor position and the actuator's torque as function of time

$i(M,\alpha), \psi_{ges}(M,\alpha)$ — Current and flux linkage are computed from operating maps and kinematics

$$u = R \cdot i + \frac{d}{dt}\Psi_{ges}$$

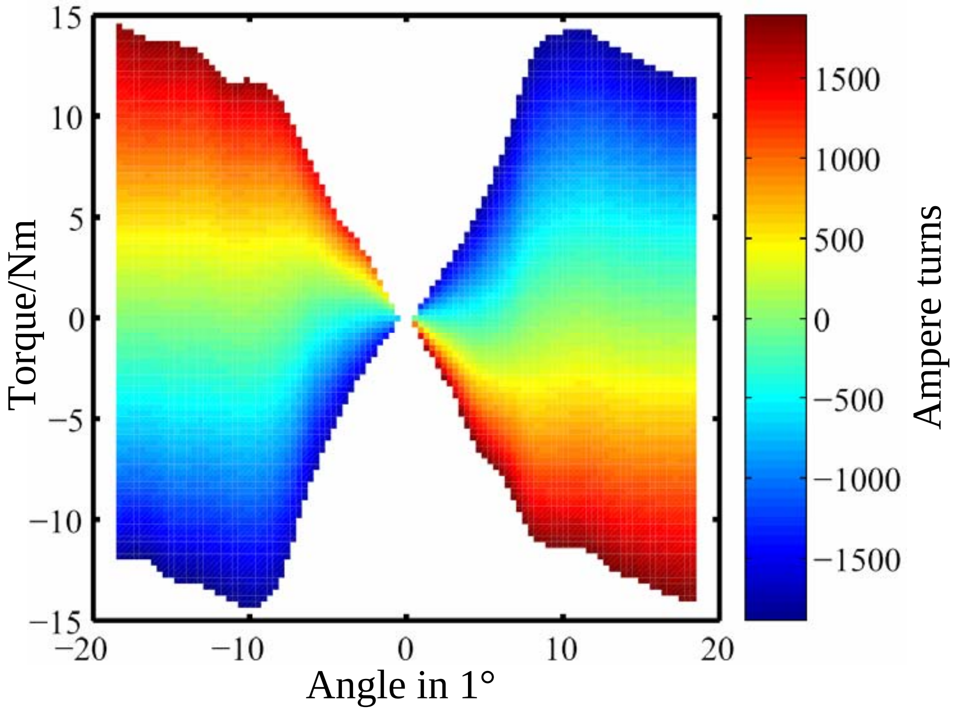
Voltage equation

P_{el}, E — Power consumption, etc.

Angle control

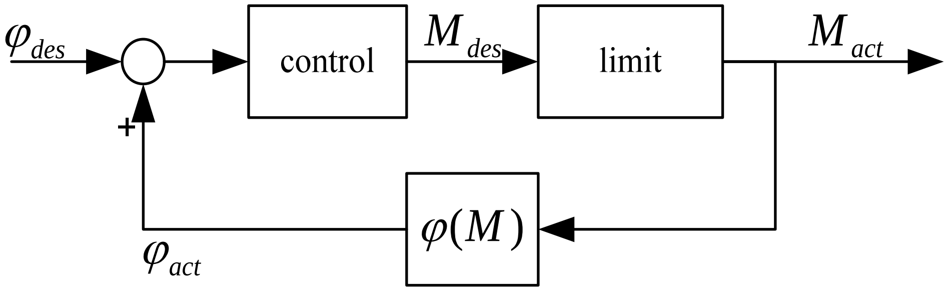
Leibniz Universität Hannover

Torque in reality



- Torque is limited due to current limitations (70A, 0.8mm wire)
- Valve kinematics are desired values
- Control structure needed to adapt the movement to the abilities of the actuator

Block diagram of the control structure (gas forces are disregarded)

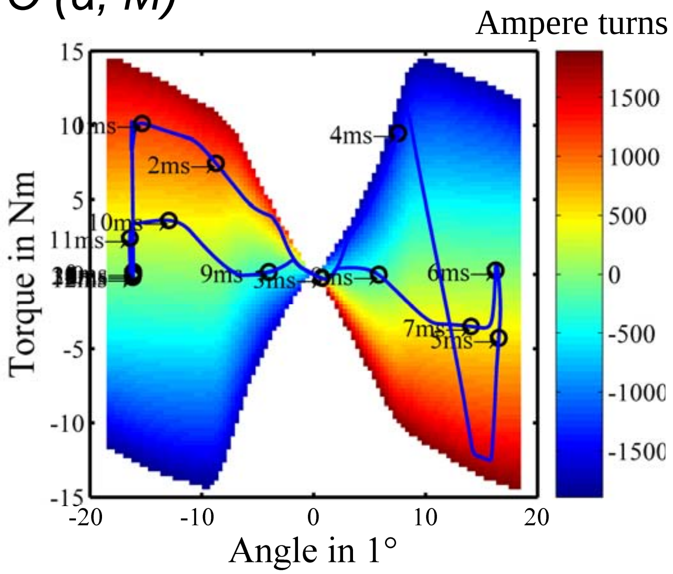


- Input variable: Desired angle
- Output variable: Actual torque M_{act} and angle φ_{act}

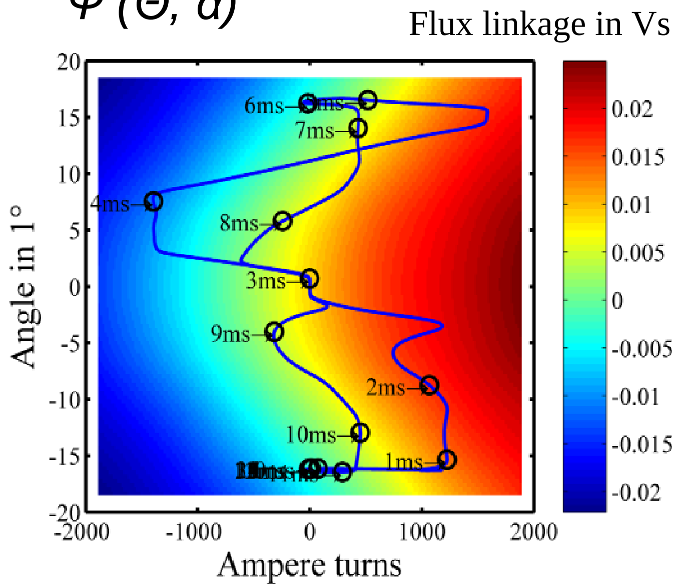
Electric parameters

Leibniz Universität Hannover

Θ (α, M)

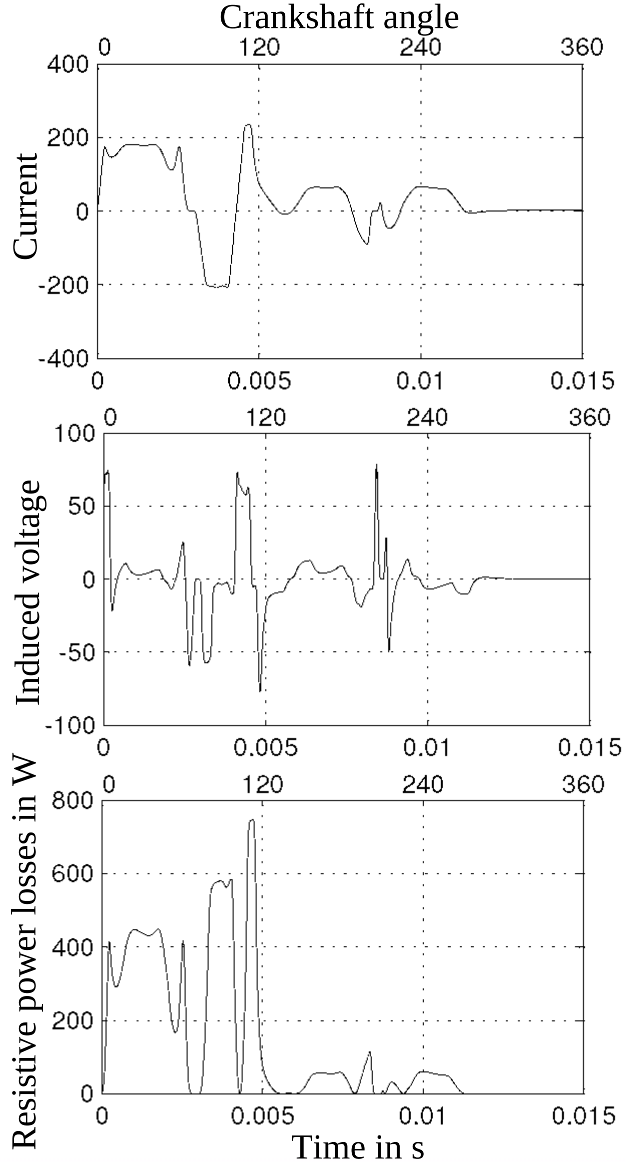


Ψ (Θ, α)



Blue line: Trajectory of the actuator

Derived data



- The valve kinematics computed before provide the ampere turns in the cores and the flux linked to the coils
- The induced voltage is the flux linked to the coils differentiated with respect to time
- The resistive power losses result from ampere turns and coil geometry
- The derived data is used to rate the quality of the actuator!

Quality function

- The result of the optimization strongly depends on the quality function being used
- Certain characteristics of the actuator are combined to a single value
  - The mean value of the resistive power losses
  - The maximal current
  - The sum of the squared control deviations

Quality function for an outtake valve actuator

$$Q = 2 - \left(0.5 \frac{\overline{P}}{63.2\mathrm{W}} + 0.2 \frac{|I|_{\max}}{234.4\mathrm{A}} + 0.3 \frac{\sum (\Delta\varphi)^2}{0.464} \right) \longrightarrow \max$$

4000 min^{-1}, valve opens against gas pressure

- Better actuators have higher qualities
- The reference values are taken from the startup configuration (Q_{start}=1)

Results

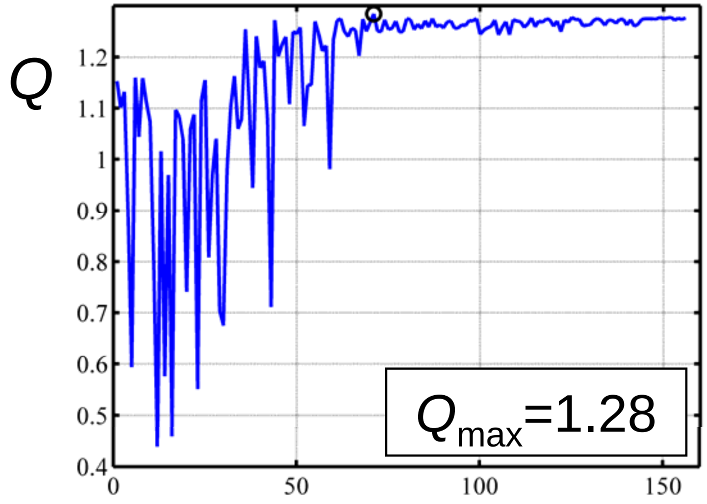
Leibniz Universität Hannover

Characteristics of the optimized actuator

	$\overline{P}_{SP}$	I_{max}	$\Sigma(\Delta\alpha)^2$
original	63.62W	234.4A	0.464
favourite	50.29W	219.8A	0.206

Power consumption and maximum current were reduced, while the actuator follows the desired movement more precisely.

Actuator quality progress



Geometry of the optimized structure:

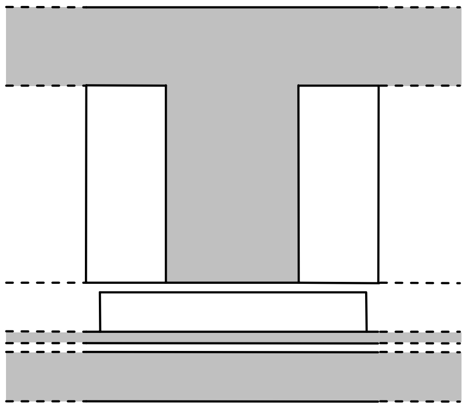
- Magnets are thicker, slightly narrower and moved towards the outer diameter

⇒ Higher moment of inertia

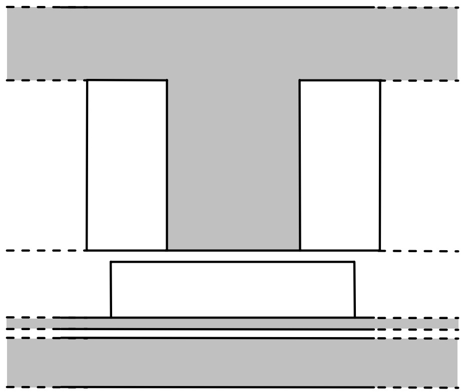
⇒ More magnetic material in the air gap

⇒ Better matching between operating map and movement

⇒ Reduced effort for the desired movement



Before…



… and after the optimization

Institut für Grundlagen der Elektrotechnik und Messtechnik

Dipl.-Ing. Tankred Müller

Summary

- Any optimization algorithm can be used with COMSOL, if it is embedded in a MATLAB simulation
- It is possible to compute electric data from a kinematic behavior, but the abilities of the structure under investigation has to be kept in mind
- The quality function should incorporate the whole application