

Determining the electric characteristics of an electromagnetic actuator by static simulations

Abstract

This publication describes the determination of the electric characteristics of an electromagnetic actuator with respect to a required time dependent displacement.

The model used here analyzes an actuator with a permanent magnet rotor; a nonlinear iron magnetization curve is considered. Several operating points are calculated using the script language of COMSOL Multiphysics. The result is the force of the actuator depending on ampere-turns and displacement. Additionally, the flux linkage to the coils is computed from the vector potential.

The obtained data, which characterises the actuator's electrical and mechanical behaviour completely, is solved for the current. The voltage equation of the actuator delivers terminal current and voltage, and therefore the necessary electrical power to achieve the demanded displacement.

Introduction

During the development of electromagnetic actuators the electrical operating parameters are the most important information. The designed actuator has to meet the specified electric and kinematic demands. In complex geometries a comparison of simulation and measurements in existing configurations is essential to justify the model. Often the simulation of static operating points is easier to realize than a dynamic simulation. The implementation in software is more directly and less susceptible to errors. Finally an automated adaption of the actuators geometry to the needs of the application is described.

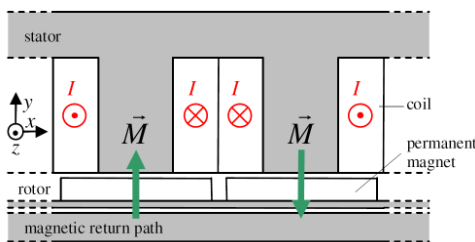


Figure 1: Schematic diagram of the construction in an unwinded view

The actuator is composed of several segments. An unwinded segment is shown in figure 1. The construction is circular, but not axially symmetric. The working angle of the rotor is about the angle between two permanent magnets. The magnetic nonlinear iron parts are implemented as interpolating function. The magnets magnetization curve is nearly linear, so it is modeled by their remanent flux density B_r and relative permeability μ_r . A two dimensional simulation is adequate.

Calculating the operating maps

The appropriate mechanic variables for the operating map are torque and angle.

With COMSOL Multiphysics the easiest operating map to compute is the torque M that is produced at a certain displacement angle α with a certain current I flowing in the coils.

The operating map consists of a multitude of discrete points, each computed automatically by nested loops. The implemented model is a completely parametrically MATLAB script. The geometry is built just once, the rotation of the rotor and the setting of the current is done separately.

A change of the geometric model parameters can result in reordered subdomains. The numbering of the subdomains changes. The necessary geometry analysis with the function `geomanalyze` will then result in a wrong assignment of material parameters, since this function numbers the subdomains. An algorithm to avoid this problem is implemented, so a completely parametric geometry is achieved.

Computing the electric quantities

The torque is determined by evaluating the Maxwell stresses in the rotor subdomains. This is done automatically by COMSOL Multiphysics. The results of a comparison between a measured and a simulated operating map are shown in figure 2.

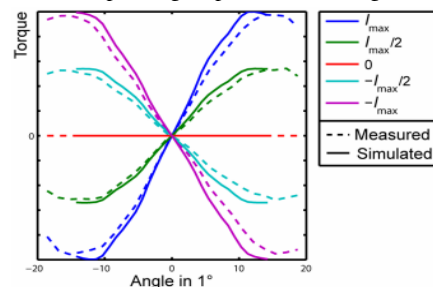


Figure 2: Achieved torque at different angles and five constant coil currents (measured and simulated, torque at $I=0$ was subtracted from all lines due to measurement reasons)

The flux linkage to the coils is computed from the magnetic vector potential:

$$\Psi_{ges} = \frac{nl}{F_1} \int_{F_1} A_{z1} dF_1 - \frac{nl}{F_3} \int_{F_3} A_{z3} dF_3$$

This equation is easily to implement in COMSOL Multiphysics by subdomain integrations over the coil areas F_1 and F_3 .

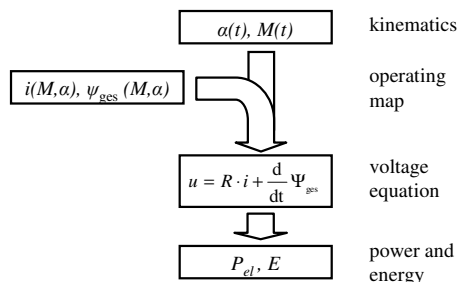


Figure 3: Calculating the electric data

Calculating the electric parameters

The time dependent electric parameters can be calculated from the operating maps and the desired kinematic profile. The procedure shown in figure 3 will be used here.

The simulated static operating map $M(\alpha, I)$ is inverted to $I(\alpha, M)$ by interpolation (see figure 4). The flux linked to the coils $\Psi(\alpha, I)$ is already known (see figure 5).

From time dependent functions of displacement angle α and torque M now follow the current $I(t)$ as a function of time, in the next step follows the flux linkage $\Psi(t)$.

The voltage induced in the coils follows from the derivative of $\Psi(t)$ with respect to the time t . The resistive part of the voltage equation is calculated from the homogeneous power density in the coils.

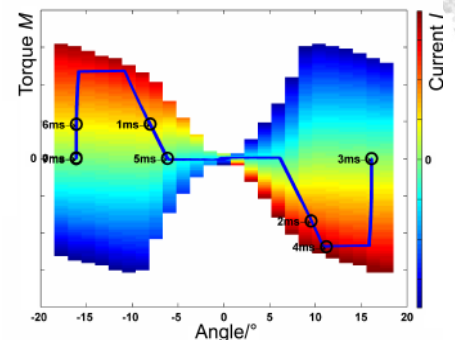


Figure 4: Current depending on torque and angle. The movement of the actuator is also shown.

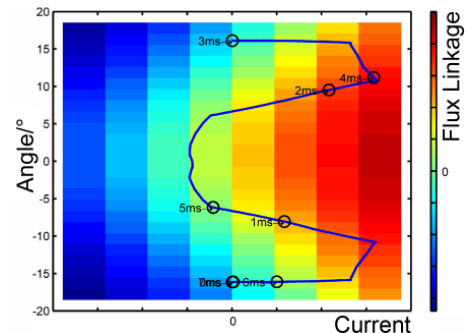


Figure 5: Flux linkage depending on current and angle.

With respect to the coil wiring, the electrical quantities needed to achieve the demanded kinematic behaviour are known.

Power and energy as functions of time are easily calculated.

Summary

With the proposed simulation a practical numeric simulation of an electromagnetic actuator is available. Calculated operating maps, verified by measurements, provide the electrical quantities needed to perform a desired kinematic profile.

In the near future the programmed script language simulation will be used in an automated optimization.