A comparison of different simulation models considering a linear actuator as an example

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ABSTRACT

Based on the example of an electro magnetic linear actuator different *Matlab/Simulink*[1] models of varying complexity are presented and the results compared with the results of a direct CoSimulation of *Matlab/Simulink* and *FLUX2D*[2].

NOMENCLATURE

B	flux density	Vs/m^2
c	spring constant	N/m
F	force	N
F_{Mag}	magnetic force	N
F_{Spr}	resetting force of the spring	N
I	current	A
L	inductance	H
R	resistance	Ω
t	time	s
TC	turns per coil	
v	velocity	m/s
x	position, moving range	mm
ρ	resistivity	Ωm

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[1] *Matlab/Simulink*, The MathWorks, Inc.

[2] *FLUX*, CEDRAT

1 INTRODUCTION

In this paper the question will be discussed where and when the expense of a CoSimulation with two established simulation tools such as

i. *Matlab/Simulink* and

ii. *FLUX*

is worth while. A linear actuator is used as an example, which is simplified and abstracted from a real part due to confidentiality reasons.

Figure 1 shows half of the cross section of the linear actuator with its coil, core and armature (the symmetry line is along the armature bar). The outer diameter of the core is 26 mm and its length is 27 mm. The turns per coil are $TC = 500$. The coil resistance is $R = 5.5\ \Omega$. The actuator is supplied with 10 V, DC (at $t = 0$ s, a switch closes and connects the coil with the supply voltage).

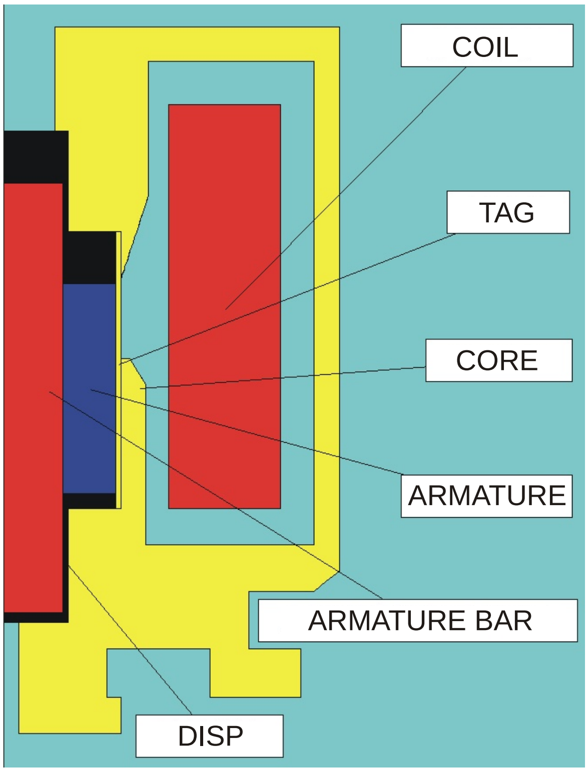


Figure 1: Cross section of the linear actuator with the coil, core, armature, armature bar, translating air gap (tag), region of displacement (disp) and surrounding air.

The moving range of the armature with its armature bar (the moving parts) is from x = 0.0 to 1.8 mm. The actuator acts against a resetting spring with a spring constant of c = 1900 N/m. The solid materials characteristic have been set to standard construction steel due to unknown specification.

2 THE EXAMINED MODELS

The examined simulation models are:

I: Simulation with *Matlab/Simulink* using only a force characteristic map (F = f(I, x), *model no. 1*, see **Figure 2**) with internal bemf calculation, constant inductance (L = 20.0, 27.5 and 35.0 mH) and resistance (R = 5.5 Ω).

II: Simulation with *Matlab/Simulink* using a force and an inductance characteristic map (F = f(I, x), L = f(I, x), *model no. 2*, see **Figure 3**) with internal bemf calculation and constant resistance.

III: Simulation with *Matlab/Simulink* using the *„Flux to Simulink Technology“* (*model no. 3*, see **Figure 4** and **Figure 5**), neglecting the eddy currents in the solid parts (high resistivity of the core material, e.g. soft magnetic composites).

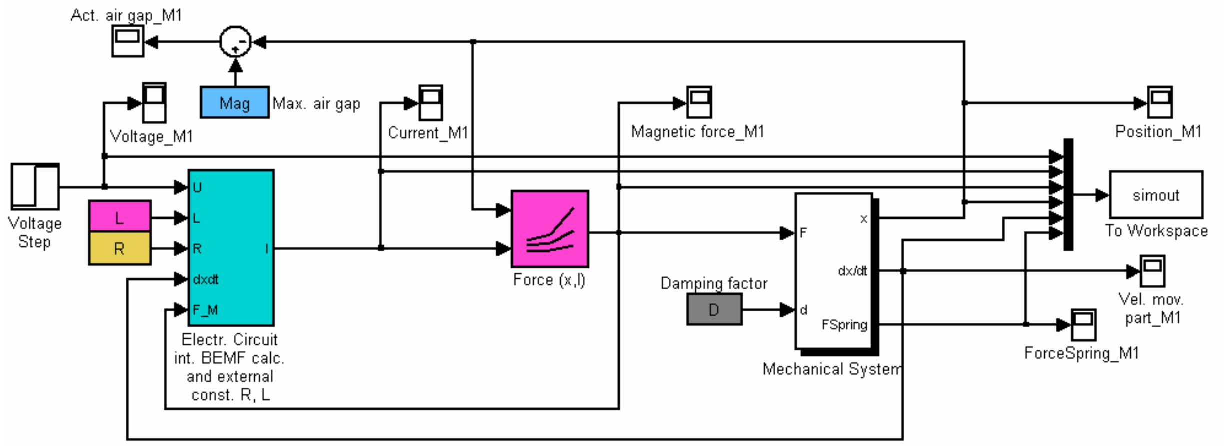


Figure 2: Basic Simulink simulation model no. 1 with a force characteristic map, internal bemf calculation, constant incuctance and resistance.

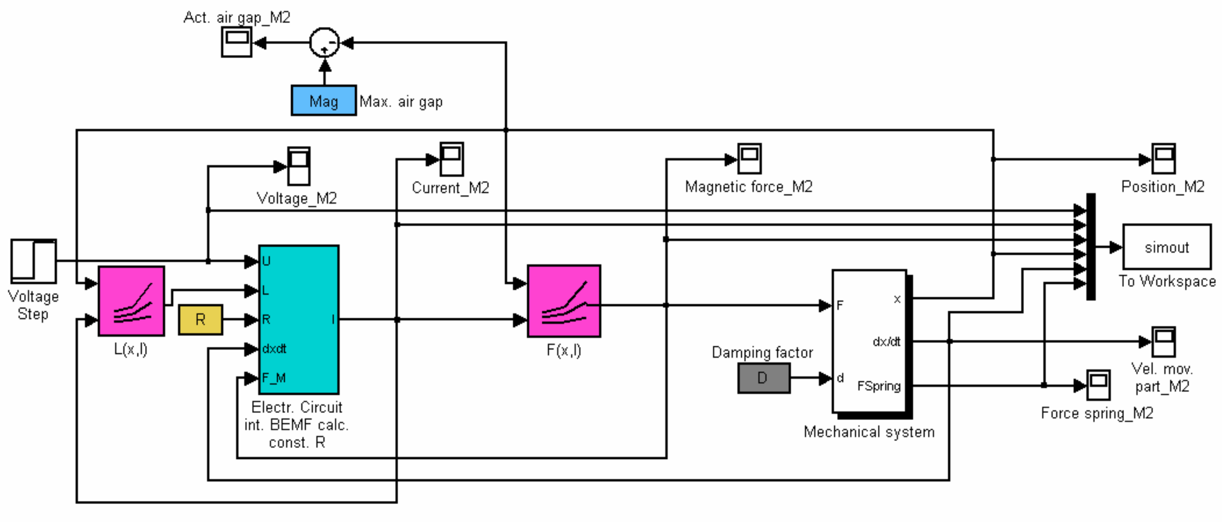


Figure 3: Simulink simulation model no. 2 with a force and an inductance characteristic map, internal bemf calculation and constant resistance.

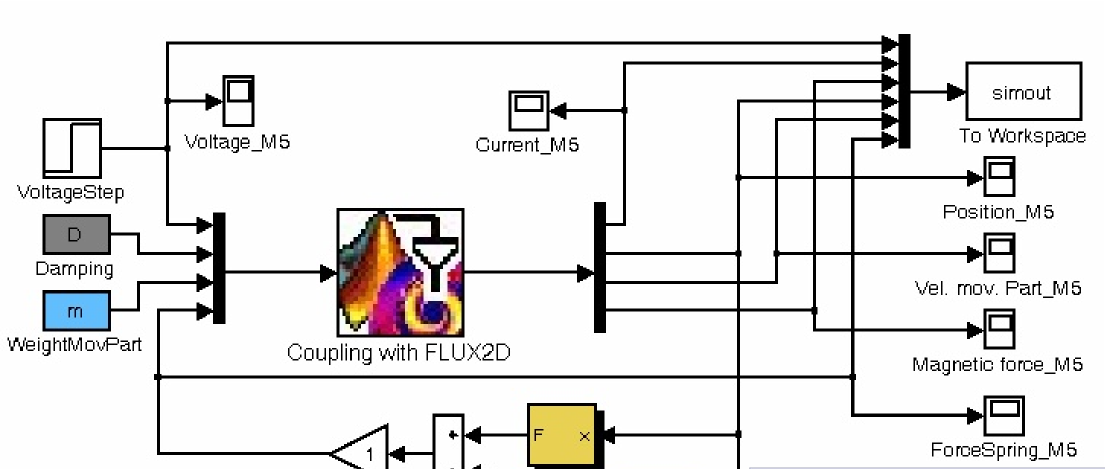
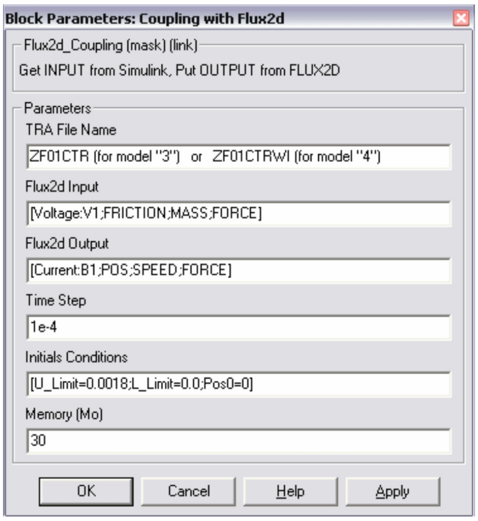


Figure 4: Simulink model no. 3 and 4 using the „Flux to Simulink Technology“.



Flux2d_Coupling (mask) (link)

Get INPUT from Simulink, Put OUTPUT from FLUX2D

Parameters

TRA File Name: ZF01CTR (for model "3") or ZF01CTRWI (for model "4")

Flux2d Input: [Voltage:V1;FRICTION;MASS;FORCE]

Flux2d Output: [Current:B1;POS;SPEED;FORCE]

Time Step: 1e-4

Initials Conditions: [U_Limit=0.0018;L_Limit=0.0;Pos0=0]

Memory (Mo): 30

Figure 5: Definition of the block parameters for the Coupling with FLUX2D in Simulink

IV: Simulation with *Matlab/Simulink* using the *„Flux to Simulink Technology“* (*model no. 4*, see also Figure 4 and 5) but including eddy currents in the solid parts of the FE-model (low resistivity of the core material: $\rho = 1 \cdot 10^{-7}$, $2 \cdot 10^{-7}$ and $1 \cdot 10^{-6}$ Ωm).

The parameters included in the *models 1* and *2* (force *F* in dependence of the position *x* and the current *I*) can be derived by measurements or by means of a FEM calculation. In this paper the parameters of the *Matlab/Simulink* models are all determined by means of a magneto static field calculation using the FEM-program *FLUX2D.* In *FLUX2D* the whole geometry and its mesh (see **Figure 6**) are fully parametrized, so that changes in the geometry can easily be adapted.

3 MAGNETO STATIC FE CALCULATIONS

From the magneto static FE calculations the force $F = f(I, x)$ and inductance $L = f(I, x)$ characteristic map is derived for the pure *Simulink* simulation *models 1* and *2*. The force *F* and the inductance *L* of the linear actuator are dependant mainly on the position *x* of the armature and the current *I* in the coil. The armature starts on the “bottom” with a position of $x = 0.0$ mm. At a position of $x = 1.8$ mm the armature is 0.2 mm ahead of the core. This is the “top“ position.

FLUX lets you easily define the range of the ampere turns (50 to 500 ampere turns), the position (0.0 to 1.8 mm) and the step size (50 ampere turns and 0.1 mm, resp.) just before solving the case. Both parameters will be varied accordingly during the solving process, which leads to 100 magneto static cases (solved within 5 min. on a Pentium IV, 1.8 GHz, 512 MB RAM).

The results of the magneto static calculations for the force and the inductance are visible from **Figure 7** and **Figure 8**, resp. The force *F* has its maximum at the top position of the moving part with max. current. The highest inductance *L* is at the lowest current but greatest position value.

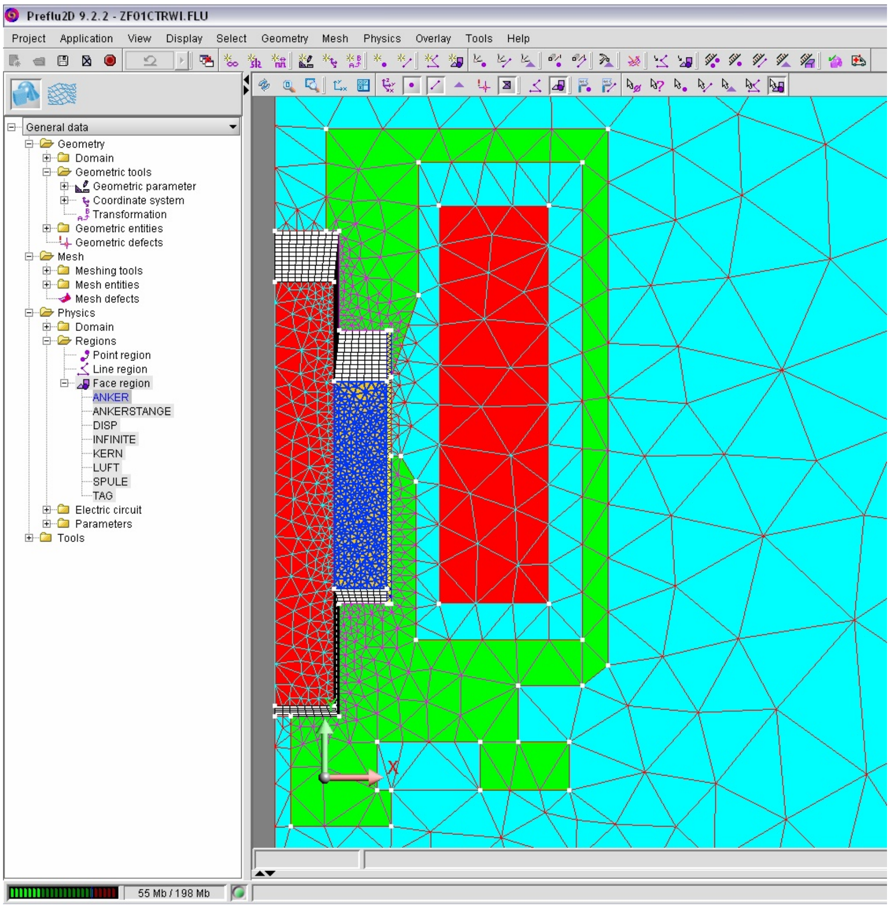


Figure 6: The cross section of the actuator with the mesh in the PreProcessor of FLUX2D for the magneto static calculations (appr. 11.000 nodes)

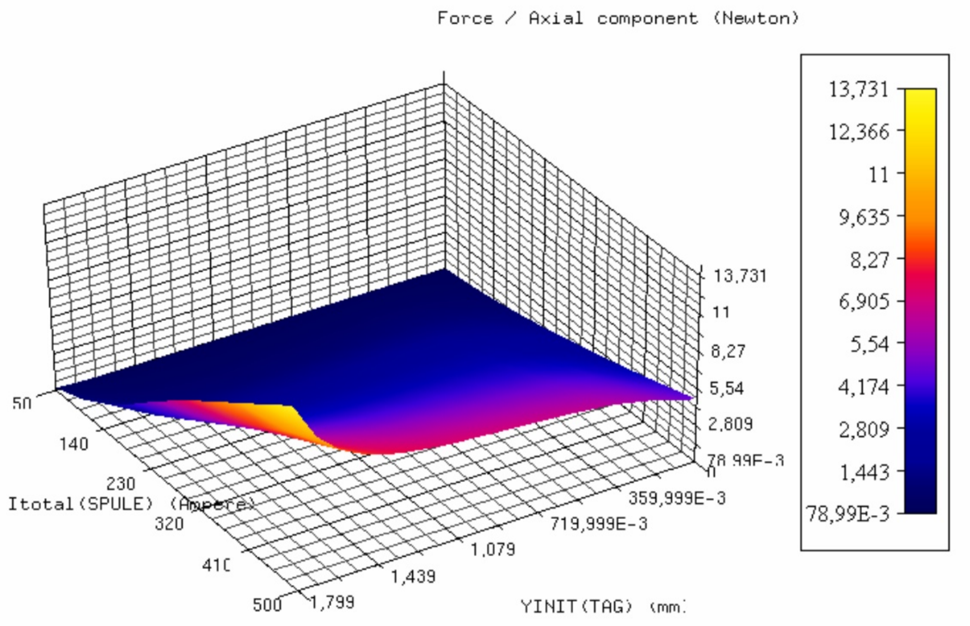


Figure 7: Force vs. position (Yinit) and ampere turns (Itotal), PostProcessor FLUX2D

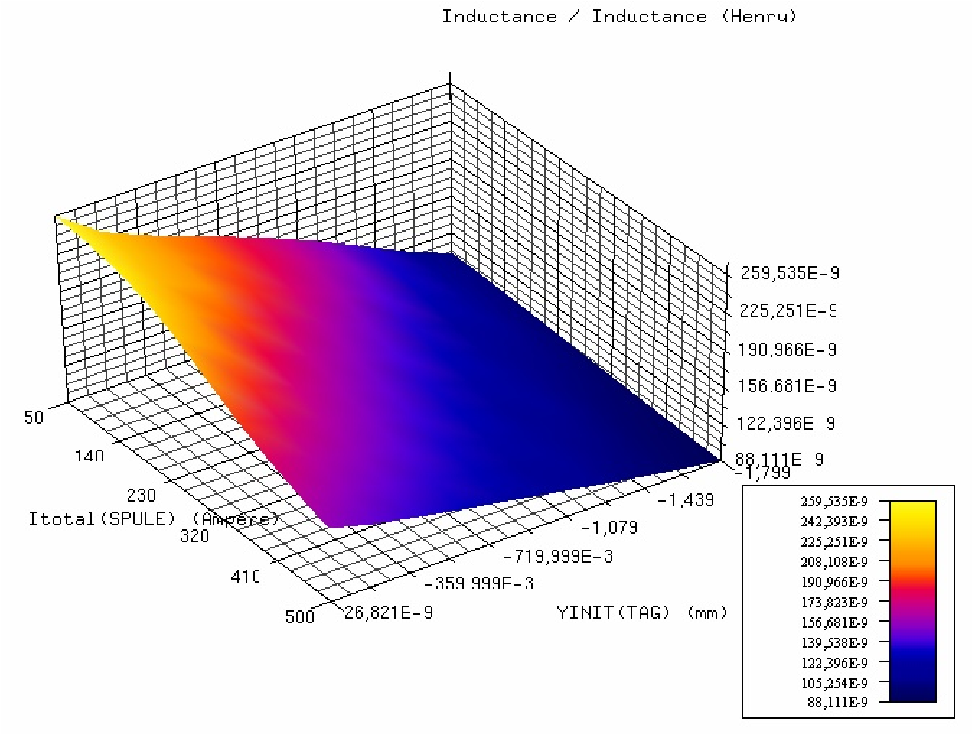


Figure 8: Inductance for one turn per coil vs. position (Yinit) and ampere turns (Itotal), PostProcessor FLUX2D

From **Figure 8** it can be seen, that the inductance is varying over a wide range (from 20 mH to 62.5 mH). Therefore the inductance for the first model was varied between the three constant values of L = 20.0, 27.5 and 35.0 mH to see its influence on the current and force.

4 COMPARISON OF THE SIMULATION RESULTS

In the next figures

- the position x, **Figure 9**,
- the velocity v of the moving part (armature and armature bar), **Figure 10**,
- the current I in the coil, **Figure 11** and
- the magnetic force F_{Mag}, **Figure 12**

are presented for the four described models including the variation of the inductance in *model 1* and the variation of the resistivity of the solid material for the core and the armature in *model 4*. The curves from the *Simulink to Flux Technology* with a resisitivity of ρ = 2·10^{-7} Ωm are chosen as the reference curves. In Figure 12 the force of the resetting spring F_{Spr} at the position $x = 0$ is included, so that it is more obvious why the position and the velocity starts to rise with a time delay of several ms. This is the time needed from the magnetic force generation to overcome the force of the spring with a value of 5.5 N at the bottom position ($x = 0$).

From the Figures 9 to 12 it can be seen, that in general the curves don't differ very much, except the curve derived by *model 1* with a high inductance (L = 35 mH). It's interesting to notice that *model 2* with the inductance characteristic map is close to the results of the CoSimulation including the eddy currents for ρ = 1·10^{-7} and 2·10^{-7} Ωm) although the inductance characteristic map was derived only by the magneto static FE calculations.

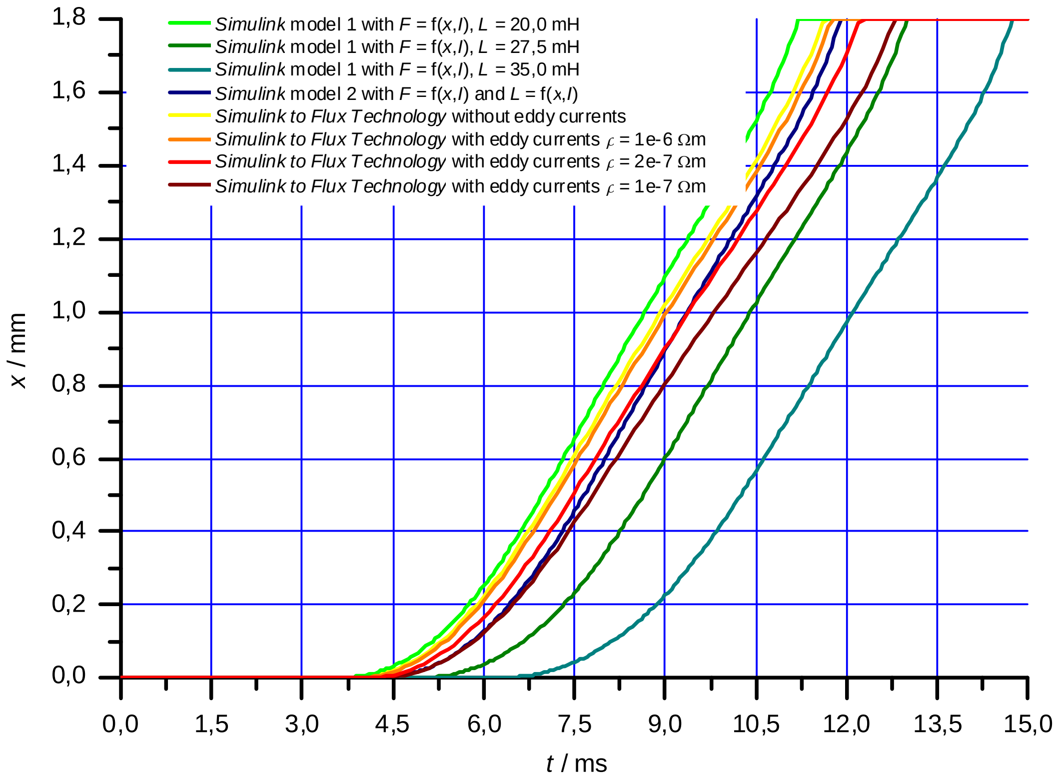


Figure.9: Position x vs. time t

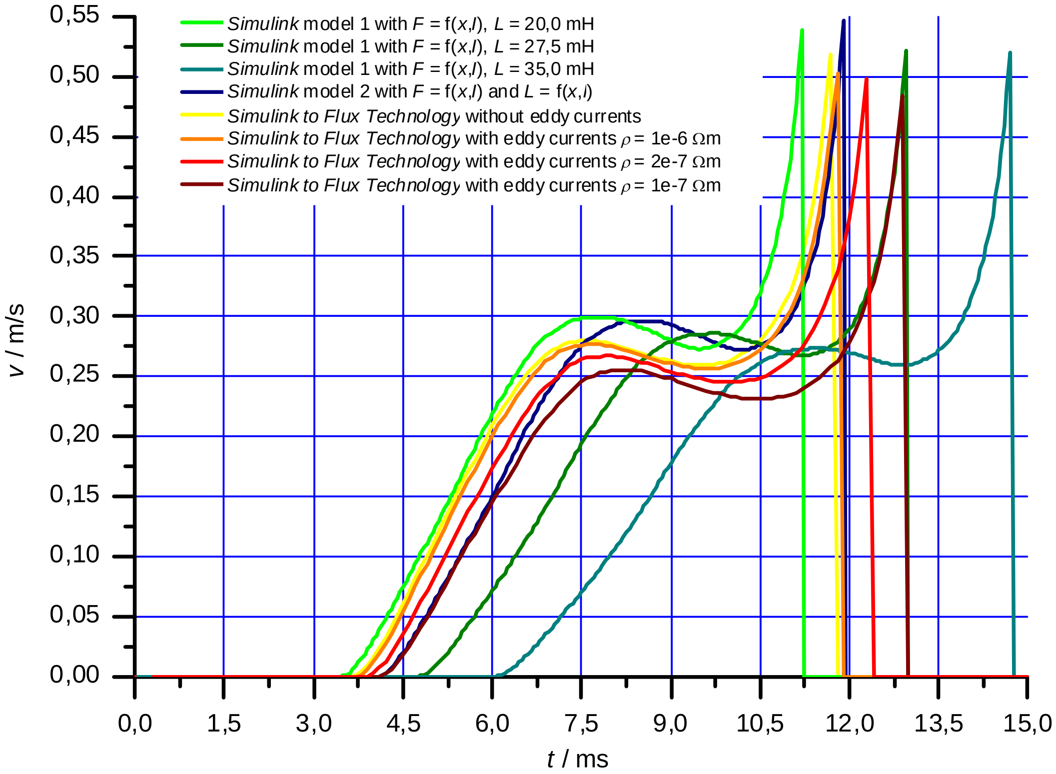


Figure 10: Velocity v vs. time t

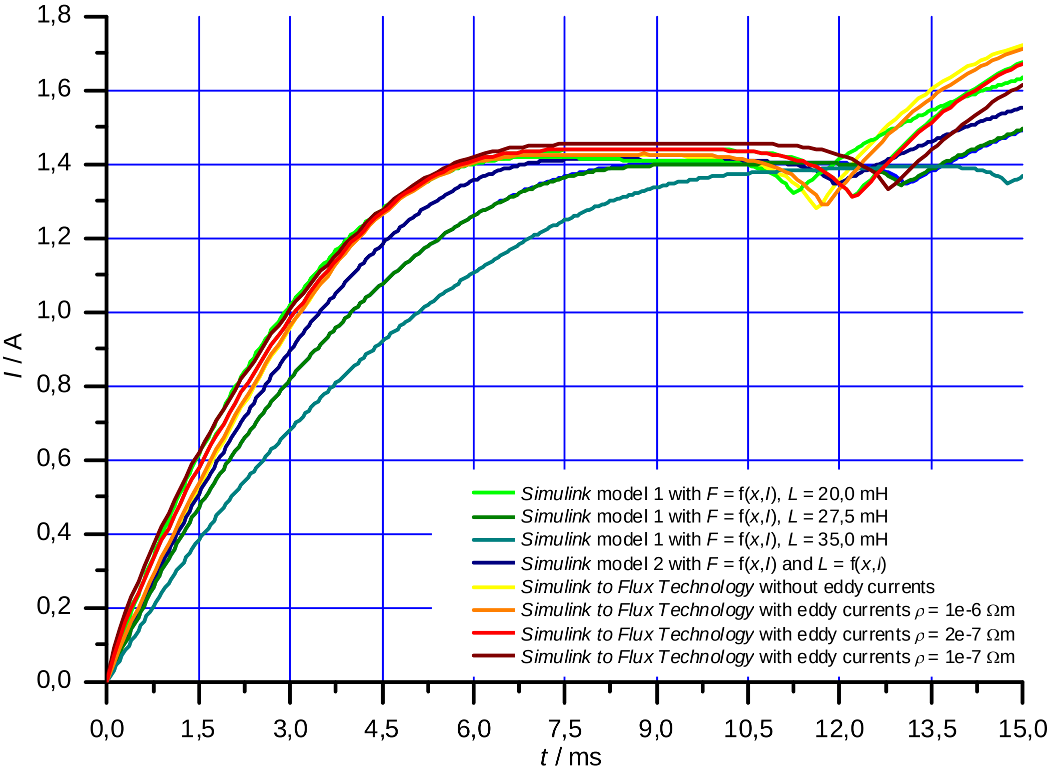


Figure 11: Current I vs. time t

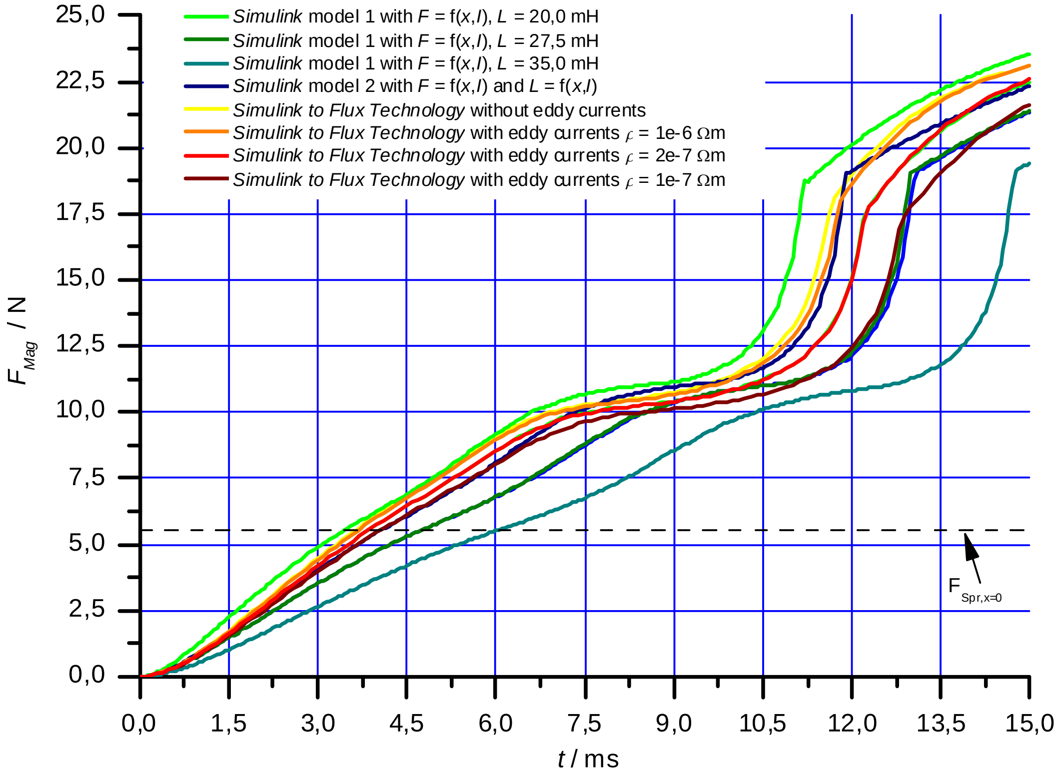
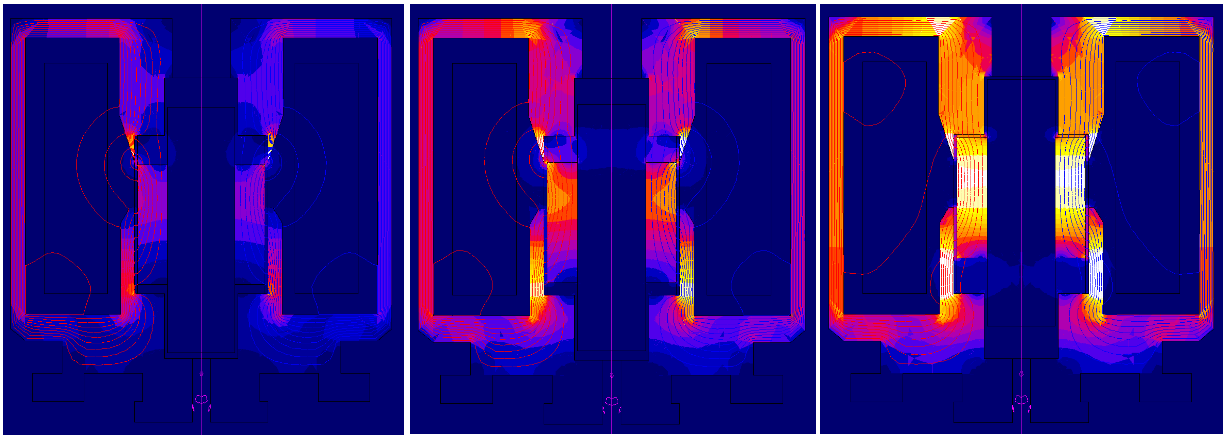


Figure 12: Magnetic force F_{Mag} vs. time t

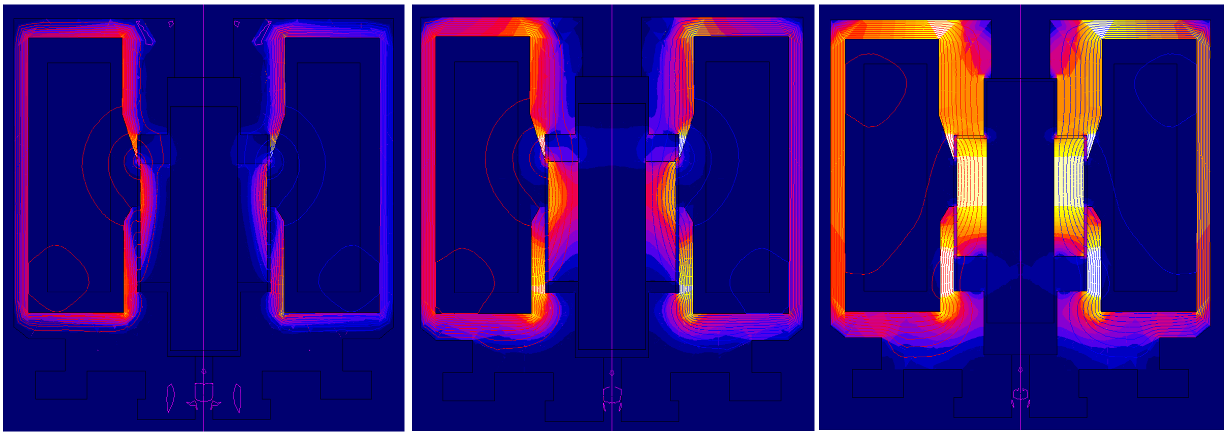
The *model 1* shows quite good results, if the inductance has in this particular case a value of *L* = 27.5 mH. With *L* = 20.0 mH the current rise is closer to the reference, but then the force generation is too fast as the damping effects of the eddy currents are missing (it takes some time that the field can penetrate the solid parts, s. **Figure 13** and **14**). This results in a higher acceleration and velocity.

The influence of the eddy currents in the solid parts leads to an increasing time delay of 1 ms to reach the top position (x = 1.8 mm) with decreasing resistivity. The eddy currents have an influence on the penetration of the field and therefore on the force generation, which leads to a delay of 0.5 ms in the movement of the armature (Figure 9). The figures 13 and 14 show the field distribution with and without eddy currents for three different time steps. The field fully penetrates the solid parts in the presence of eddy currents after 15 ms (Figure 14 c)).



a) *t* = 2 ms b) *t* = 6 ms c) *t* = 15 ms

Figure 13: Field lines and flux density distribution without eddy currents for different time steps



a) *t* = 2 ms b) *t* = 6 ms c) *t* = 15 ms

Figure 14: Field lines and flux density distribution including eddy currents in the solid parts for different time steps

The time step in *Matlab/Simulink* (*model 1* and *2*) is set to 50 µs and for the CoSimulation with *FLUX2D* to 100 µs. The calculation time for the *model 1* and *2* is about 5 s, whereas the CoSimulation runs for appr. 2 hours (Pentium IV, 1.8 GHz, 512 MB RAM).

CONCLUSION

The introductionary question was, where and when it is worth while to set up a CoSimulation. Well, for a rapid basic design with a failure of approximately 6% in reaching the top position, the simplest model can be used or even should be used. The main problem or difficulty for this model is to find a good value for the constant inductance to reach such a small error value.

For the final design, where high accuracy is demanded or the geometry has to be optimized or a special force curve has to be derived or in those cases where the time delay due to the induced eddy currents is critical, CoSimulation is indeed needed. With the latest generation of computers these calculations are executed fast enough.

ACKNOWLEDGEMENT

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