ANNUAL MEETING 2015

A New Model of Electromechanical Relays for Predicting the Motion and Electromagnetic Dynamics

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Outline

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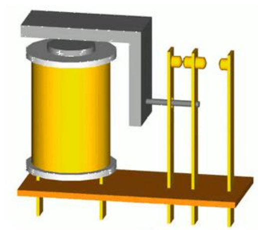
1. Introduction

What is an electromechanical relay?

Electromechanical Relays are…



- *Electromechanical devices,*
- *Activated by low voltages or weak electrical currents,*
- *That are able to open and close a secondary electrical circuit*
- *Which can block high voltages or conduct high electrical currents.*

Currently used in…

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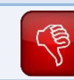
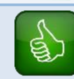
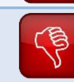
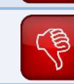
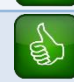
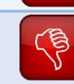
1. Introduction

Comparison with semiconductor devices (for power applications)

Voltage-controlled switches

	Electromechanical relays	Semiconductor devices
Energy losses		
Current conduction capability		
Voltage blocking capability		
Activation mode		
Cost		
Galvanic isolation		

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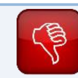
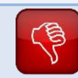
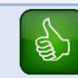
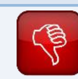
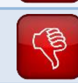
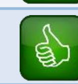
1. Introduction

Comparison with semiconductor devices (for power applications)

	Electromechanical relays	Semiconductor devices
Service life		
Acoustic noise		
Operating time		
Max. operating frequency		

Proposal: Eliminate or reduce these problems by means of systems theory

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1. Introduction

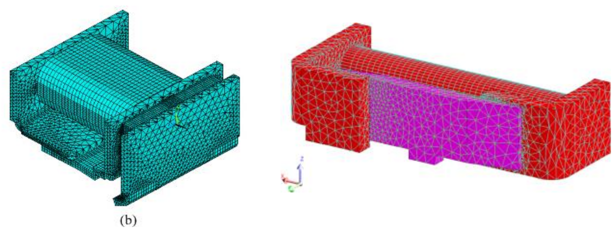
In this work: Dynamic model for electromechanical relays

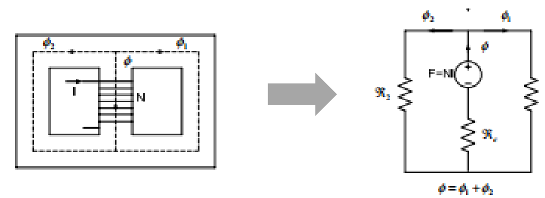
State of the art

Finite Element Method

Magnetic Equivalent Circuit

Electromagnetic modeling

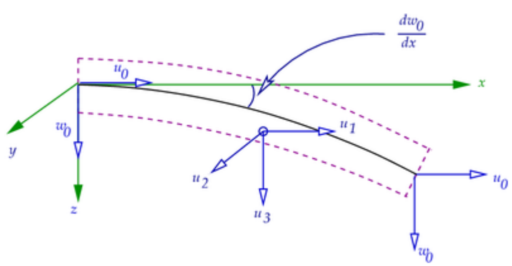


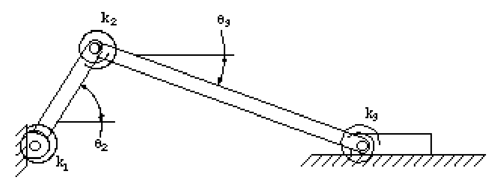


Euler-Bernoulli

Rigid body dynamics (1 DoF)

Mechanical modeling





In addition… Contact forces between bodies (bounces)

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Outline

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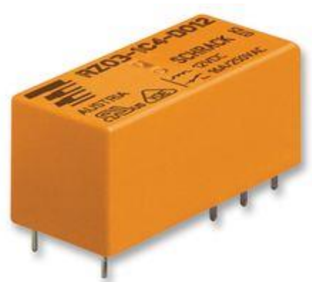
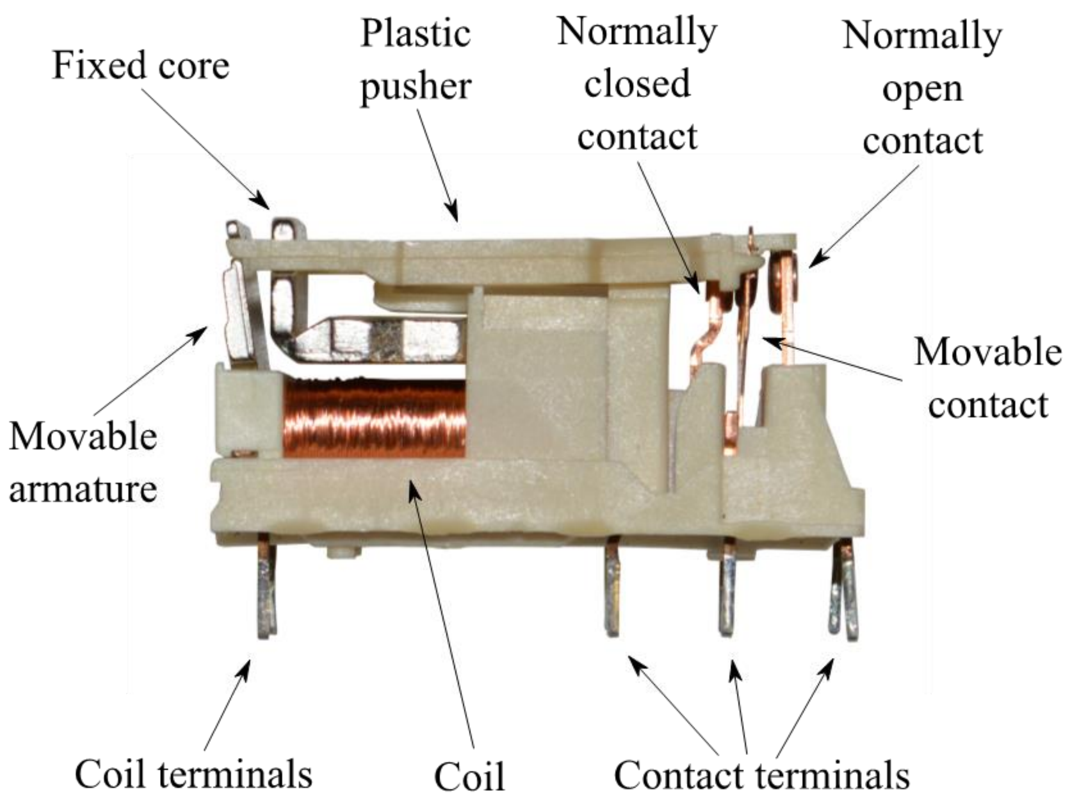
2. System description

Tyco Electronics RZ Relay



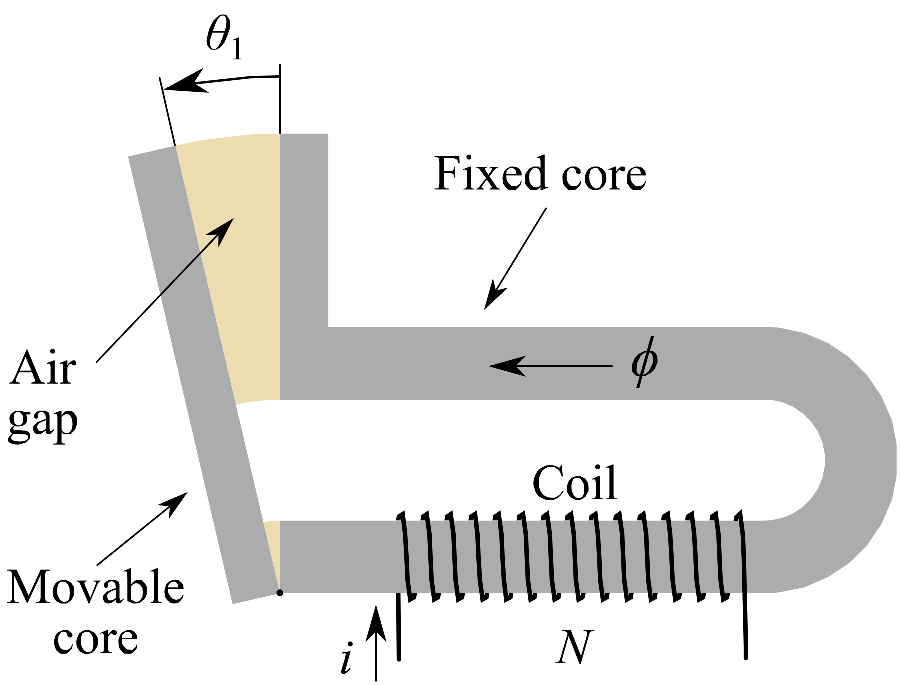


- Power relay
- PCB mounting
- High galvanic isolation
- Single-pole Double-throw

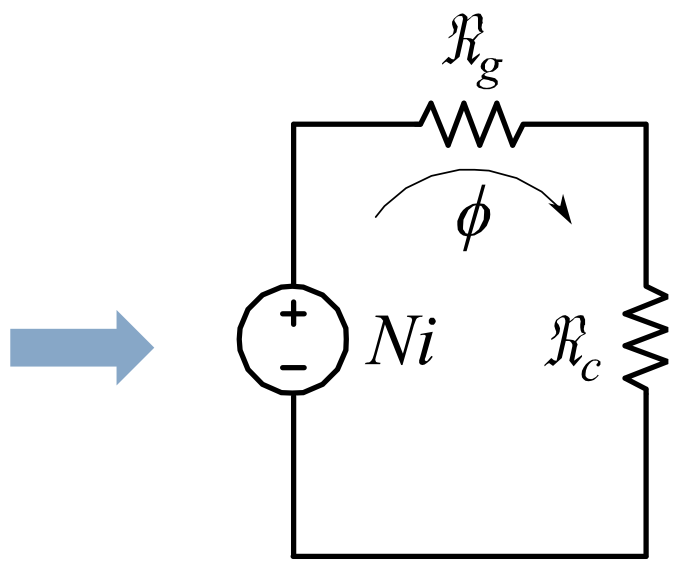
Outline

3. Electromagnetic model

Electromagnetic components



Magnetic equivalent circuit



3. Electromagnetic model

Electrical circuit equation

$$v = Ri + N\frac{d\phi}{dt}$$

Magnetic equivalent circuit equation

$$Ni = \phi\Re$$

2 Equations

1 Input

$$v$$

2 Independent variables

$$i \quad \phi$$

1 Unknown parameter

$$\Re$$

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3. Electromagnetic model

Reluctance calculation

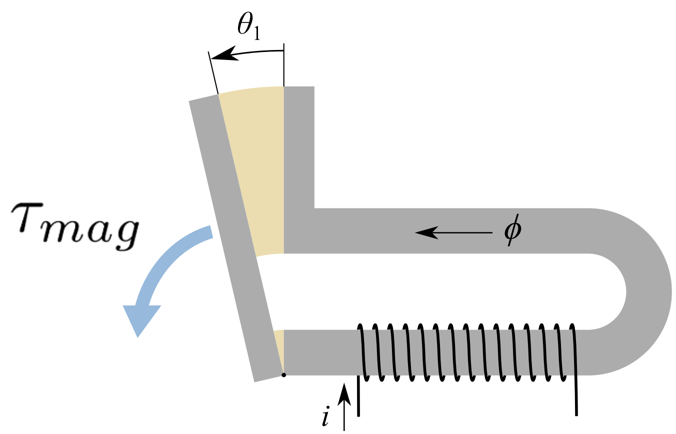
$$\Re = \Re_g + \Re_c = \frac{r_g \theta_1}{\mu_0 A_g} + \frac{l_c}{c_1 A_c - c_2 \left|\phi\right|}$$

Magnetic saturation (Froëlich eq.):

$$B_c = \frac{c_1 H_c}{1 + c_2 \left|H_c\right|}$$

3. Electromagnetic model

Magnetic torque calculation



Energy balance

$$W_e = W_{em} + W_m + W_l$$

Electrical work — Electromagnetic energy — Mechanical work — Losses

$$\tau_{mag} = -\frac{1}{2}\phi^2 \frac{r_g}{\mu_0 A_g}$$

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2. System description
3. Electromagnetic model
4. **Mechanical model**
5. Model validation
6. Conclusions

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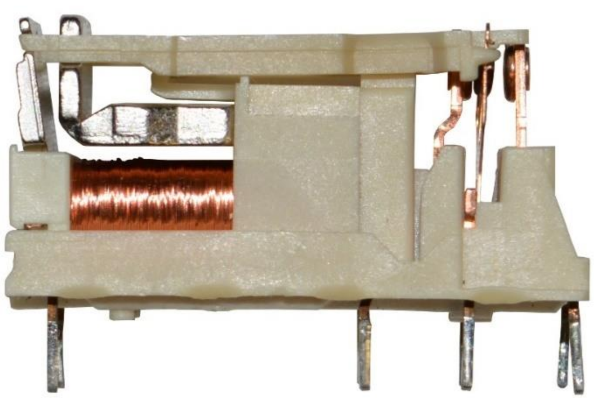
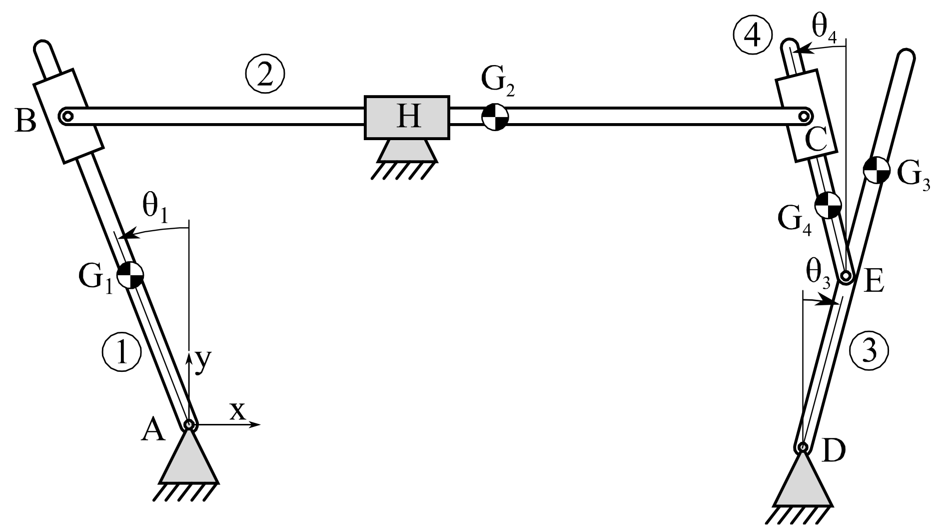
4. Mechanical model

Rigid body dynamics

- Planar mechanism
- Two degrees of freedom
- Four bodies





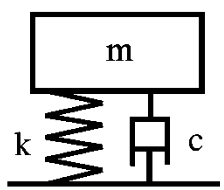
4. Mechanical model

External forces and torques

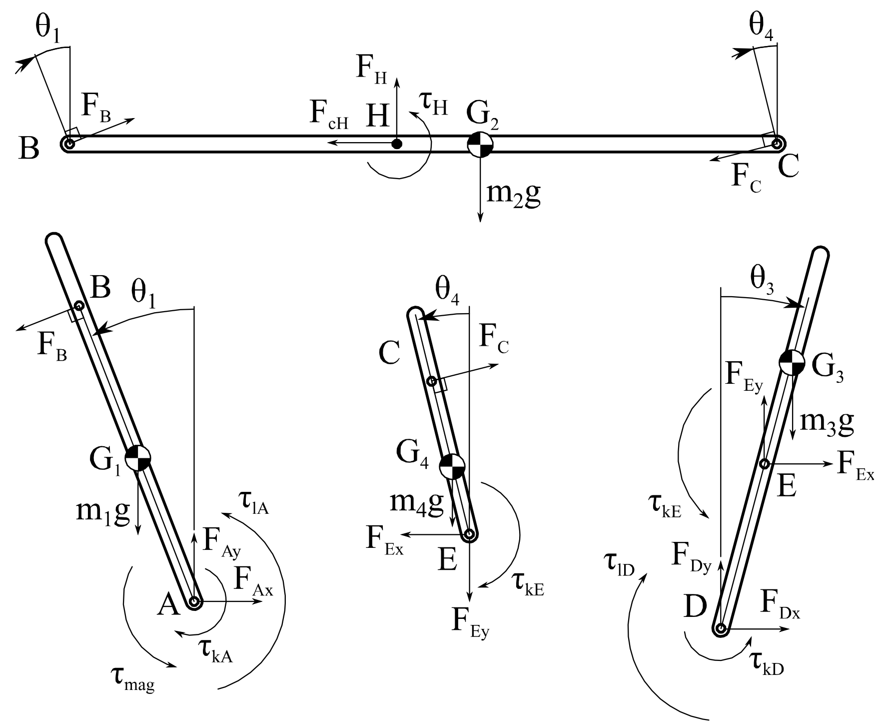
- Magnetic torque
- Bodies weights
- Elastic torques
- Friction
- Spring-damping torques

  → Motion limits

  → Bounces



Free body diagrams



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4. Mechanical model

Newton's second law

$$\sum F_x = m \cdot a_x$$

$$\sum F_y = m \cdot a_y$$

$$\sum \tau_z = I_{xy} \cdot \alpha_z$$

Equations for body 1:

$$F_{Ax} - F_B \cdot cos(\theta_1) = m_1 \ddot{x}_{G_1},$$
$$F_{Ay} - F_B \cdot sin(\theta_1) - m_1 g = m_1 \ddot{y}_{G_1},$$
$$F_B \cdot AB + m_1 g \cdot AG_1 \cdot sin(\theta_1) + \tau_{lA} - \tau_{k_A} + \tau_{mag} = I_1 \ddot{\theta}_1.$$

Equations for body 2:

$$F_B \cdot cos(\theta_1) - F_C \cdot cos(\theta_4) - F_{c_H} = m_2 \ddot{x}_{G_2},$$
$$F_B \cdot sin(\theta_1) + F_H - m_2 g - F_C \cdot sin(\theta_4) = m_2 \ddot{y}_{G_2},$$
$$F_H \cdot BH - m_2 g \cdot BG_2 - F_C \cdot BC \cdot sin(\theta_4) + \tau_H = 0.$$

Equations for body 3:

$$F_{Dx} + F_{Ex} = m_3 \ddot{x}_{G_3},$$
$$F_{Dy} + F_{Ey} - m_3 g = m_3 \ddot{y}_{G_3},$$
$$F_{Ey} \cdot DE \cdot sin(\theta_3) - F_{Ex} \cdot DE \cdot cos(\theta_3)$$
$$- m_3 g \cdot DG_3 \cdot sin(\theta_3) + \tau_{k_D} + \tau_{k_E} - \tau_{lD} = -I_3 \ddot{\theta}_3.$$

Equations for body 4:

$$F_C \cdot cos(\theta_4) - F_{Ex} = m_4 \ddot{x}_{G_4},$$
$$F_C \cdot sin(\theta_4) - F_{Ey} - m_4 g = m_4 \ddot{y}_{G_4},$$
$$m_4 g \cdot EG_4 \cdot sin(\theta_4) - F_C \cdot EC - \tau_{k_E} = I_4 \ddot{\theta}_4.$$

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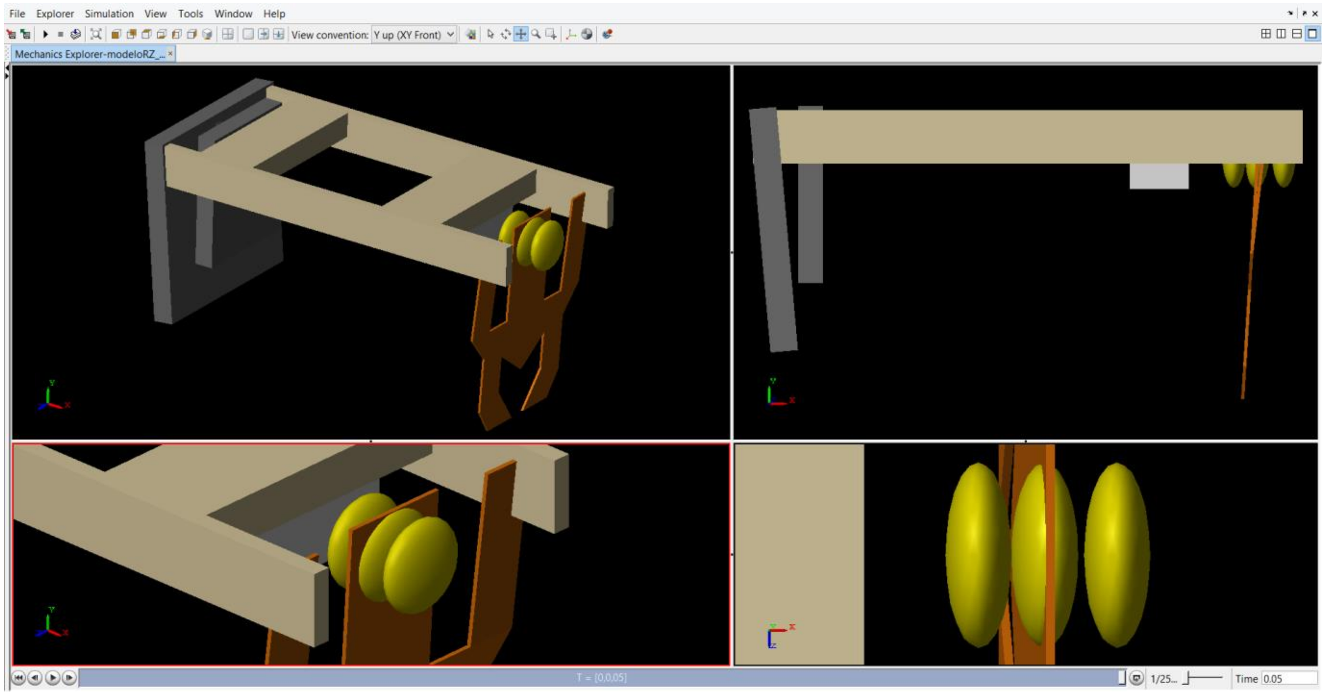
5. Model validation

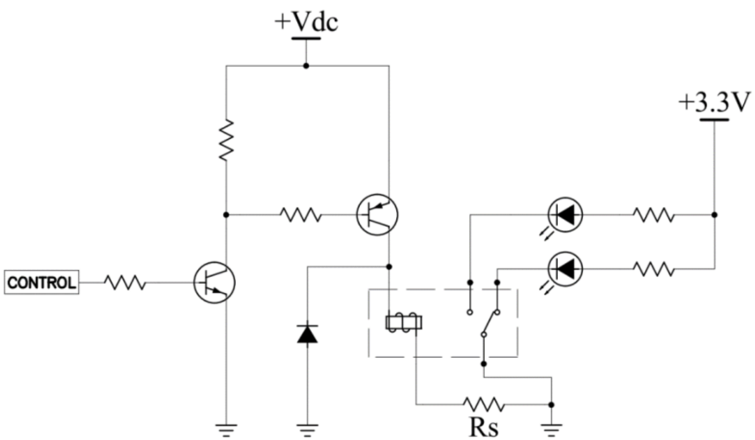
Implementation in MATLAB Simulink

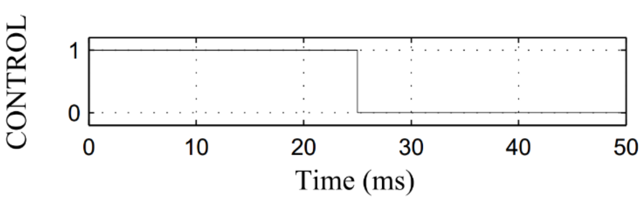
Simmechanics graphical interface

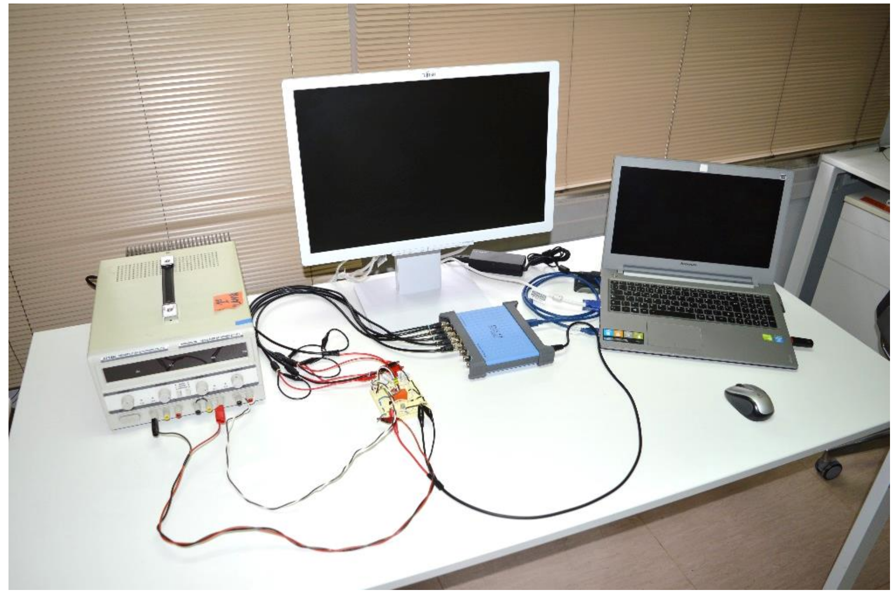


5. Model validation

Test bench







Measured variables:

- Voltage
- Current
- Contacts (1/0)

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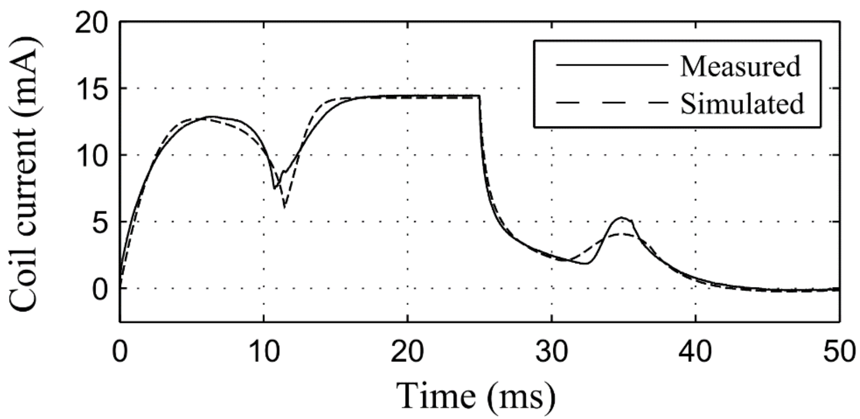
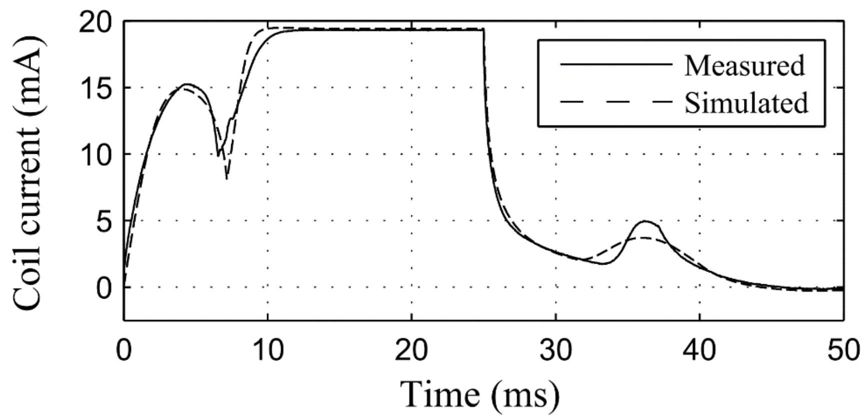
5. Model validation

Current through the coil

24V Supply voltage

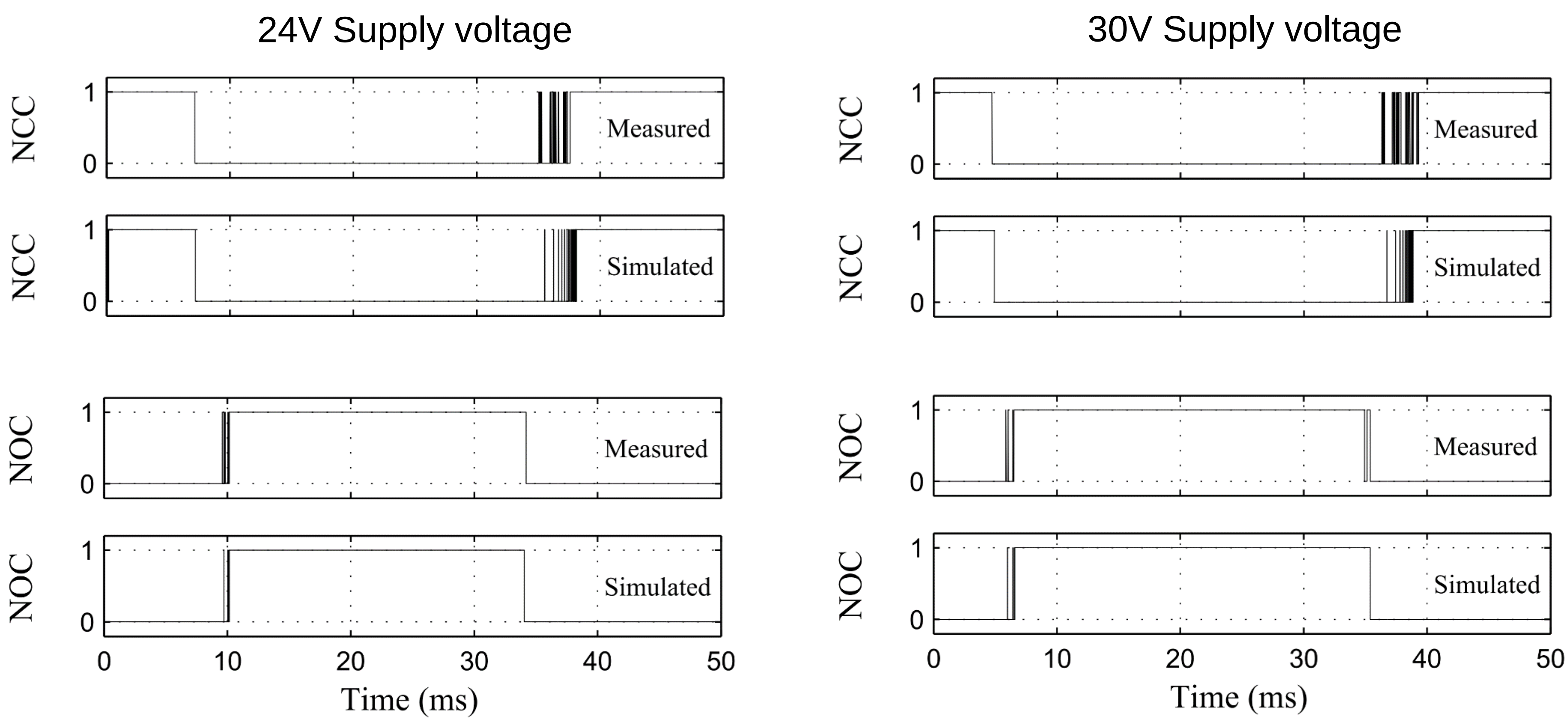


30V Supply voltage



5. Model validation

Contacts (1/0)



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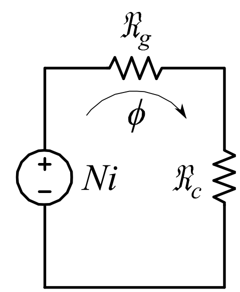
6. Conclusions

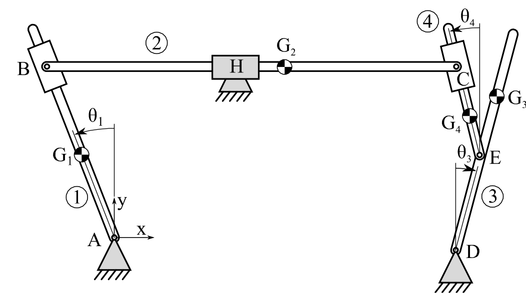
Electromagnetic model → Magnetic equivalent circuit with magnetic saturation

- Low computational needs
- High accuracy
- Angular gap (literature: only linear gaps)
- Improved Froëlich equation
- Flux, current, coil inductance



Mechanical model → Rigid body model

- Two degrees of freedom (literature: only 1DoF)
- Low computational needs
- Angular and linear motions
- Modeling of bounces by spring-damping torques



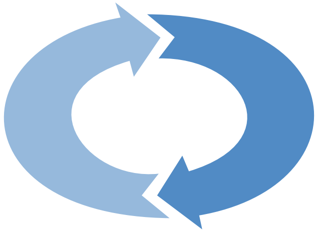
6. Conclusions

Very low computational requirements

- Sensitivity analysis
- Design optimization
- Design of controllers

Fully parametrization

- Stochastic behaviors
- Temperature dependence
- Wear influence



Iterative processes

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