

# Outline

## Model based Design of Physical Systems

Julius Hudec

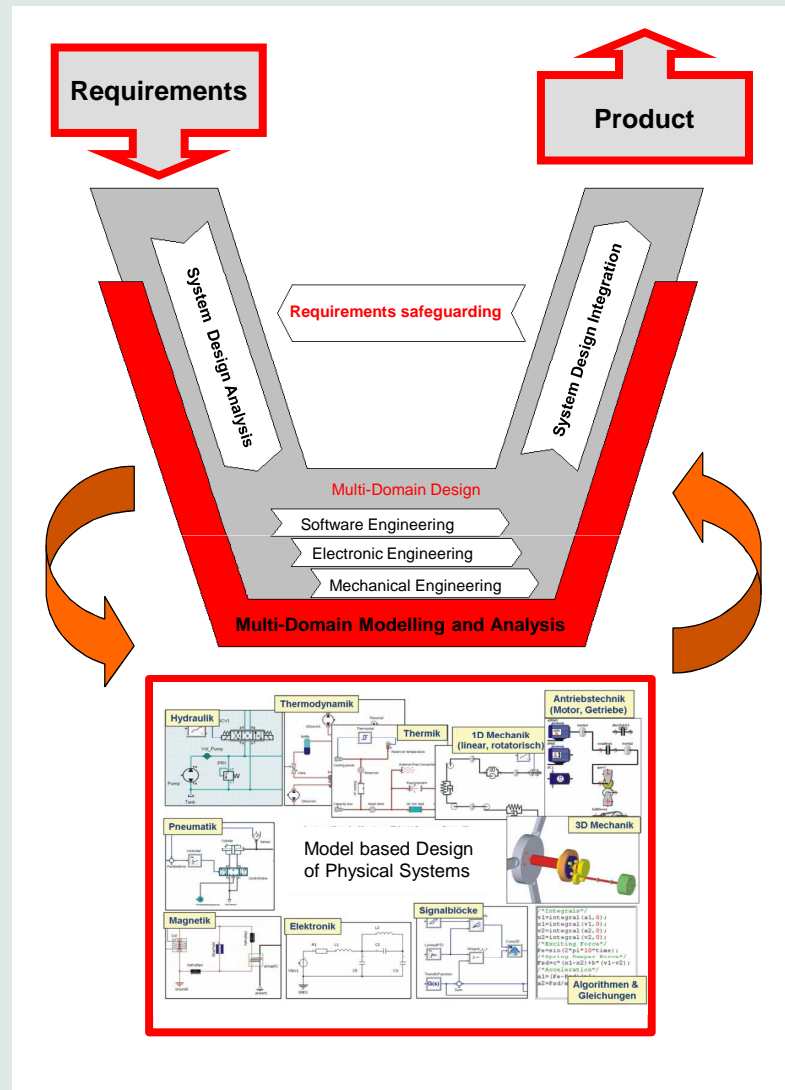
16.01.2012

1. Introduction
2. Physical System Design Process
3. Physical Distributed Parameter Systems
4. Physical Lumped Parameter Systems
5. Virtual Prototyping
6. Conclusion

# 1. Introduction

- Already today more than 70% of all industrial products include IT components and this tendency is heavily increasing
- Product development nowadays is functional and spatial integration of classical domains with IT technology and control systems
- Following this way permits new principal solutions to improve the cost-benefit ratio and approach to new high-quality products
- Lots of product families are improved to the limits of physical and technological producibility
- Multi-domain simulation tools are required to master growing complexity and heterogeneity of innovative systems
- The most capable cross-domain development tools feature a scalable, clearly arranged structure and offer a lot of application-relevant domain-specific libraries

## 2. Physical System Design Process



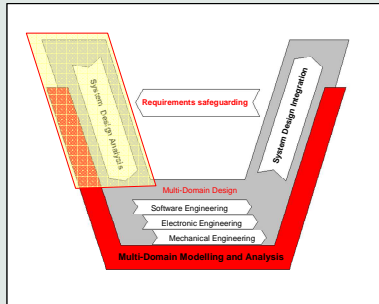
### Advantages of a Multi-domain Design

- Mastering the complexity and heterogeneity of today's demanding products
- Abbreviation of the development periods while reducing the costs
- Design openness, flexibility and reusability

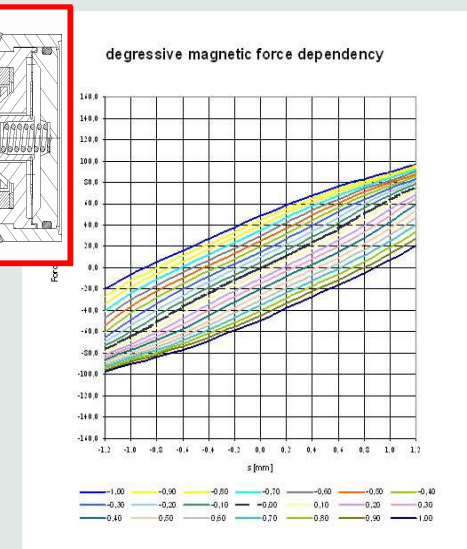
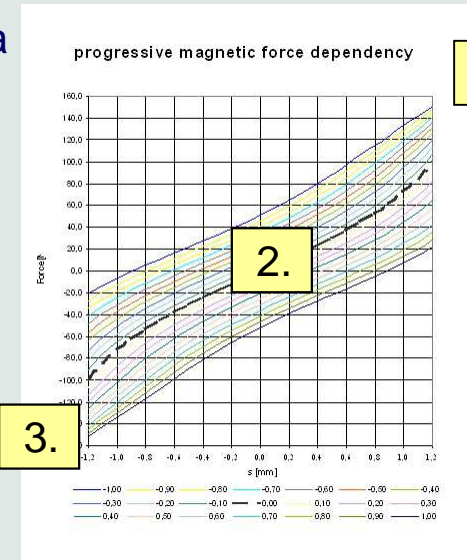
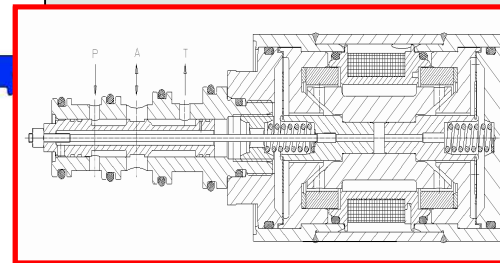
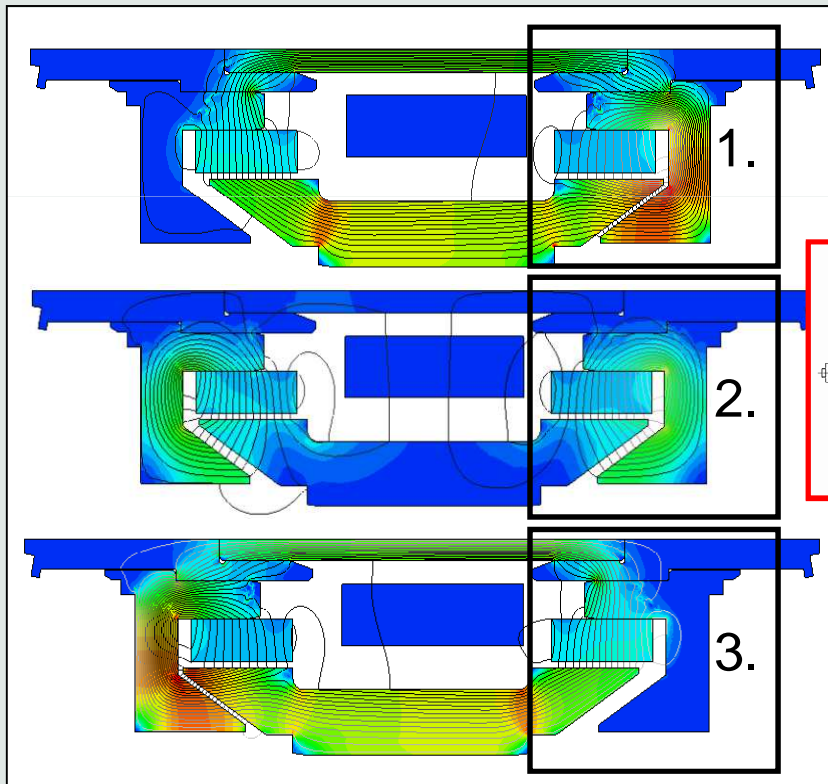
### Optimization of Multi-domain Systems

- Increase of complexity and heterogeneity to improve functionality
- Cross-domain models permit complex design, reduction of overall size and simplification of the structure
- Spatial integration of functions
- Improvement of producibility
- Flexible functional adaptation through software
- Fulfilment of reliability requirements

# 3. Physical Distributed Parameter System

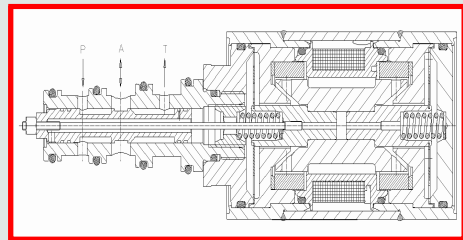


- Spatial distribution of physical Phenomena is described by PDE's
- FEM is one of the most widely used engineering analysis methods for solving PDE's today

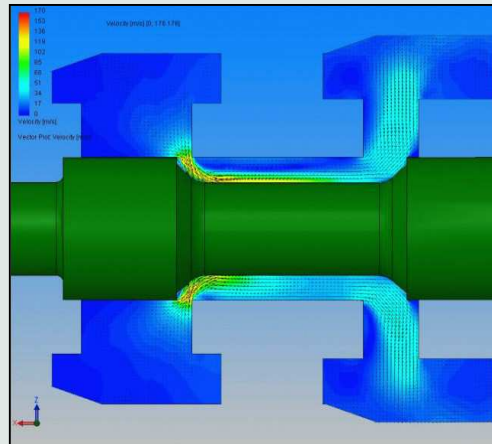


# 3.1 Physical System Optimisation using FE Analysis

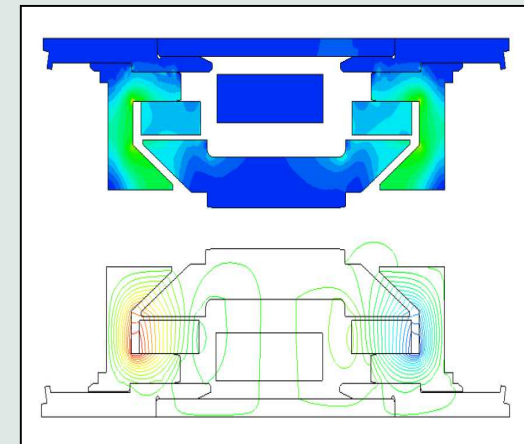
Initial CAD concept Design of a hydraulic Control valve



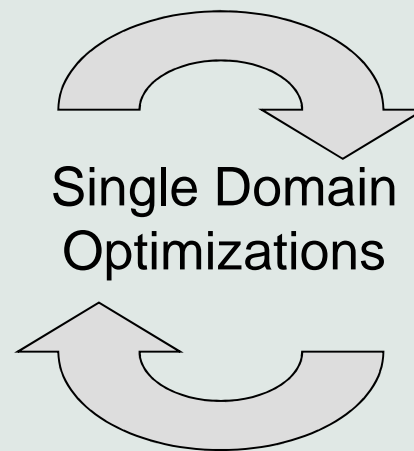
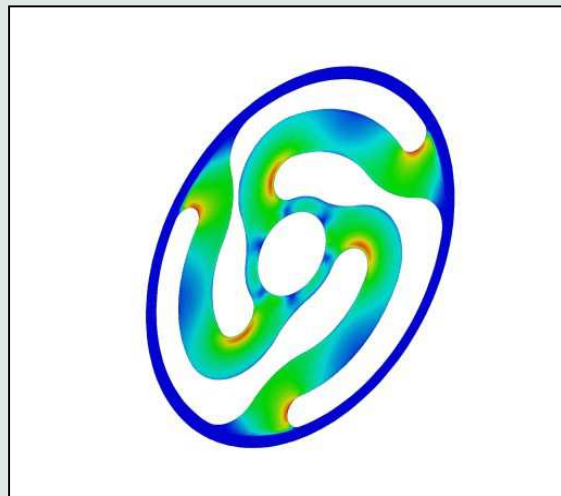
CFD Simulation



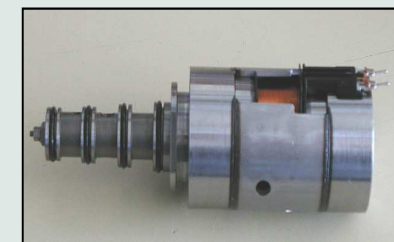
FEM Magnetic Field Analysis



FEM Structural Analysis

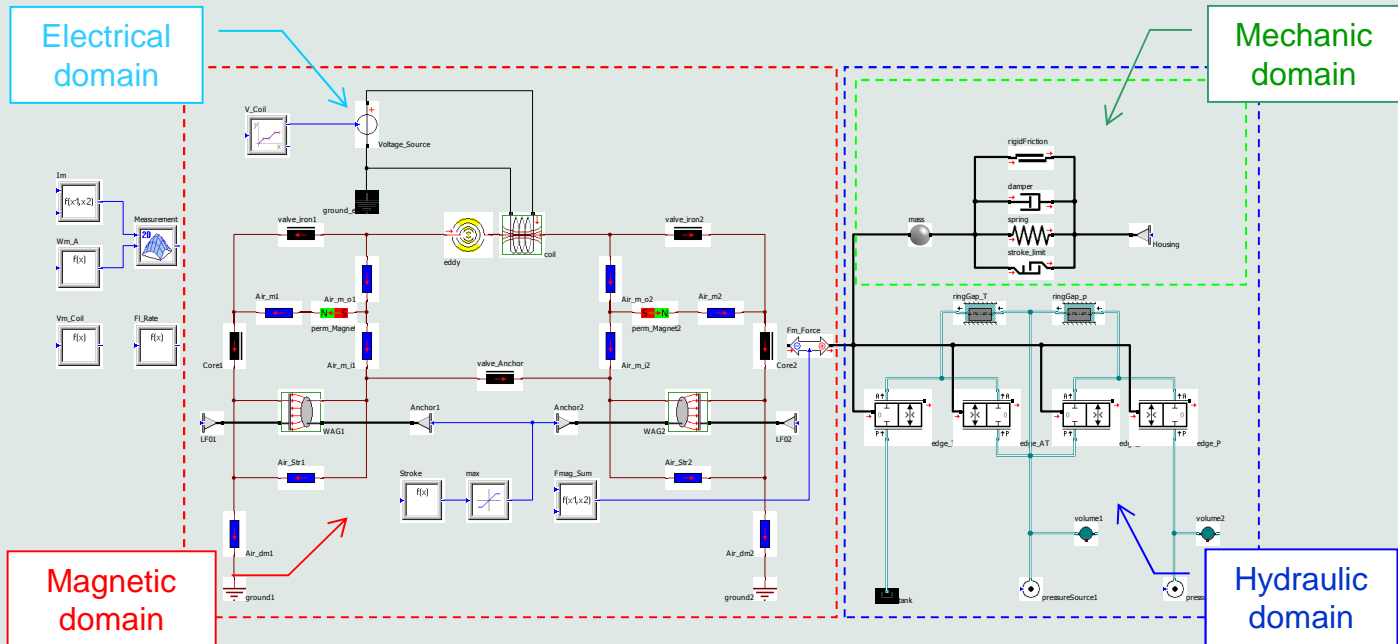
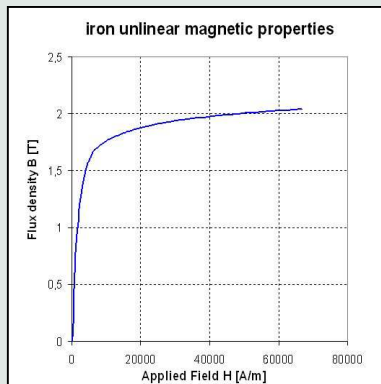
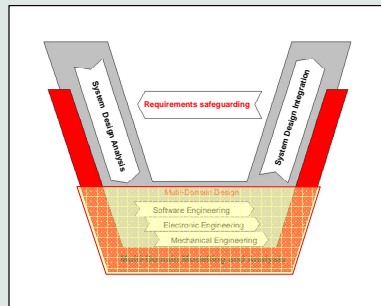


Final product

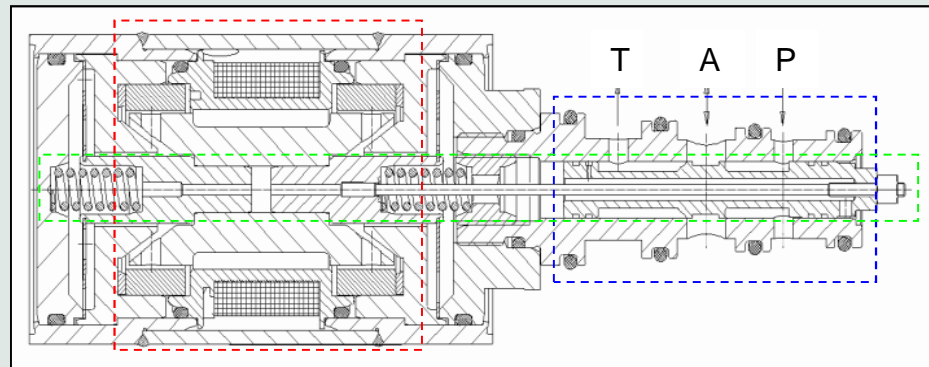
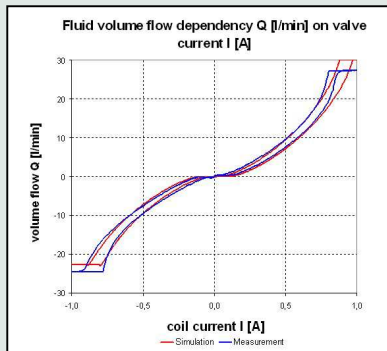
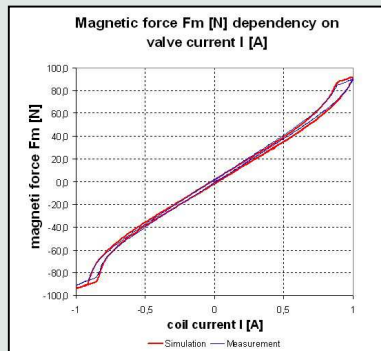


# 4. Physical Multi-domain Lumped Parameter System

Detailed nonlinear multi-domain model of a hydraulic control valve

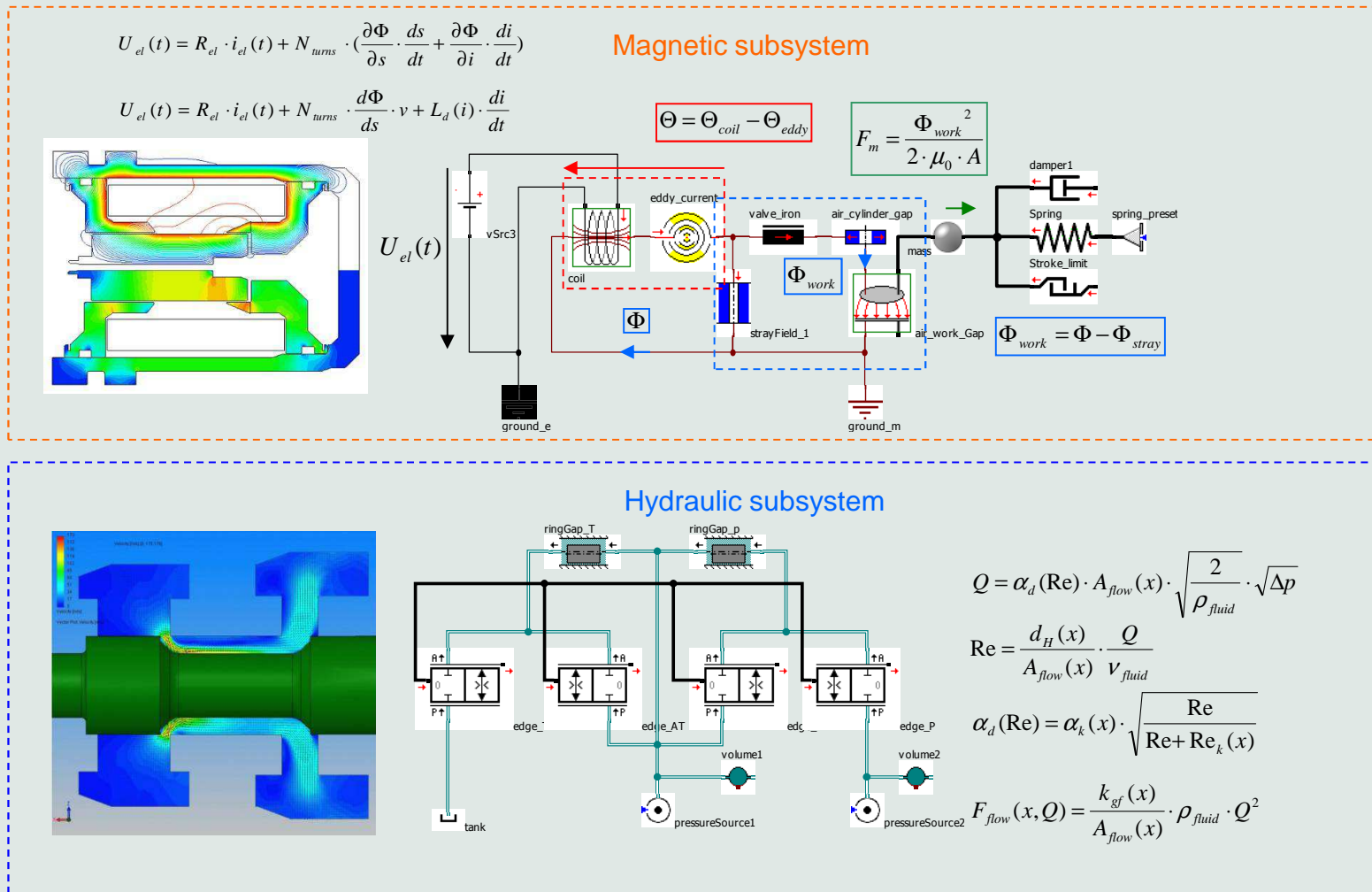


Design Mapping to a Physical Multi-domain System



# 4.1 Design Mapping to a Physical Multidomain System

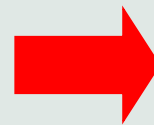
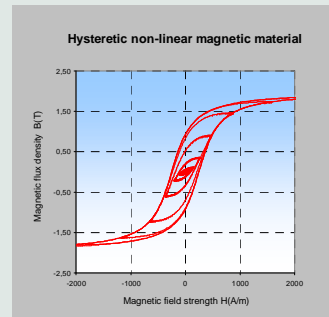
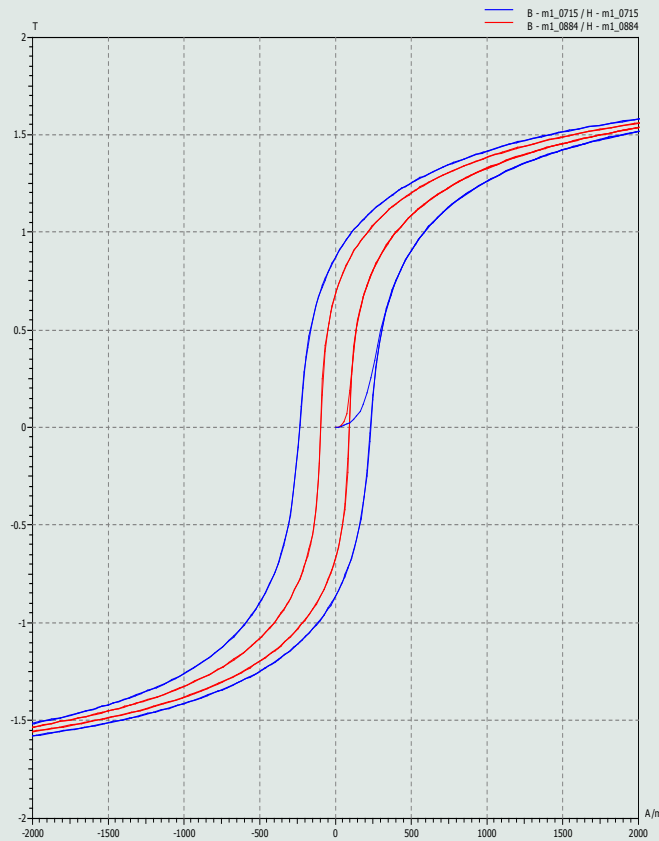
## FEM Results transferred to a parameterised Physical Multi-domain Model



# 4.2 Physical Simulation of Non-linearity

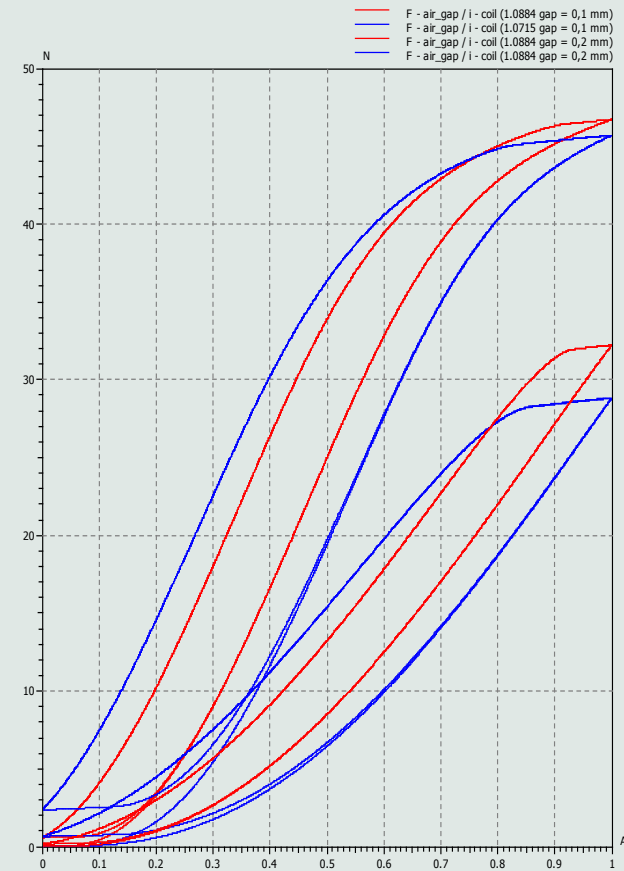
Simulation of non-linear physical material behaviour ( 1.0715 and 1.0884 )

B-H characteristics



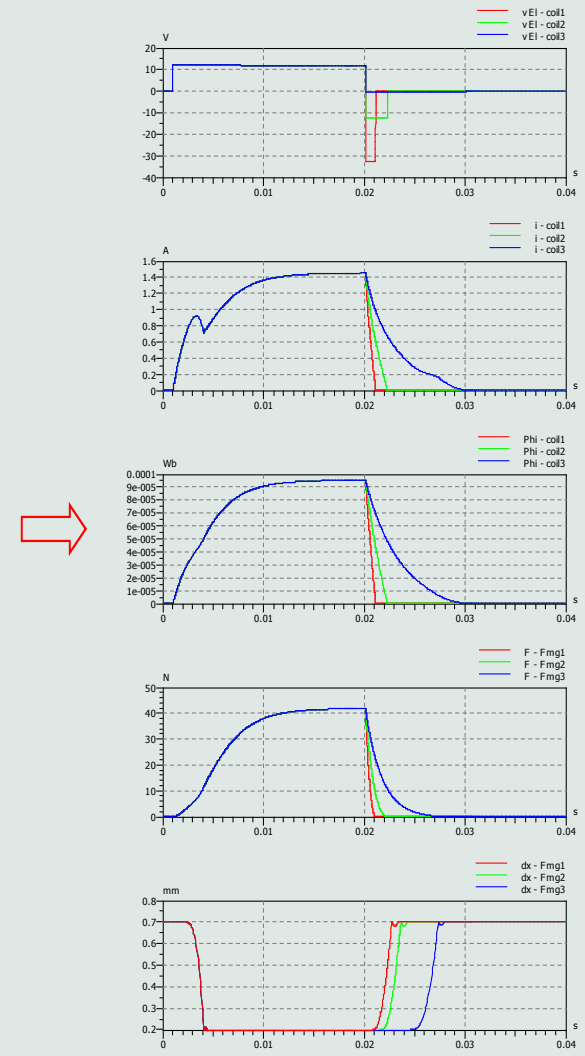
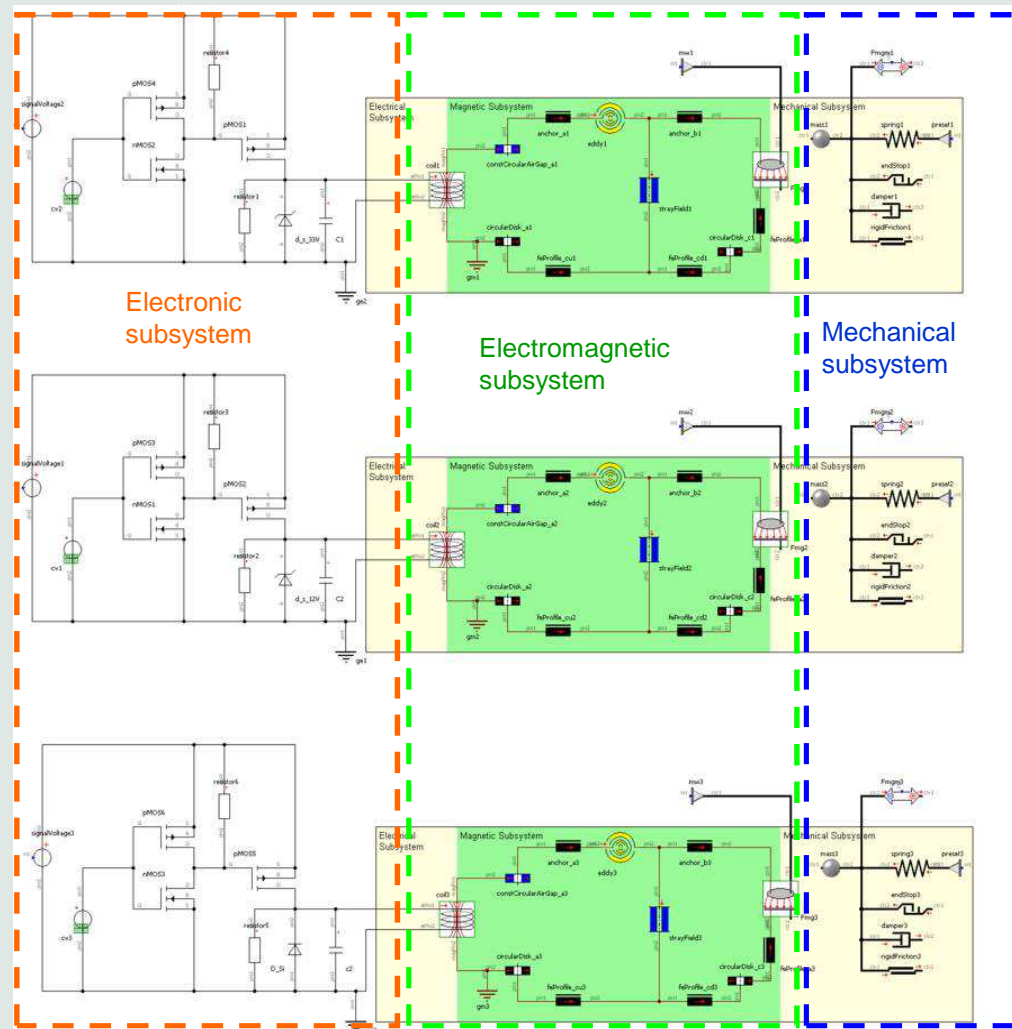
Static characteristics influenced by physical material behaviour

Actuator Force-current characteristics



# 4.3 Simulation of a Multidomain Overall System Design

## Simulation of clamping voltage influence on actuator dynamics

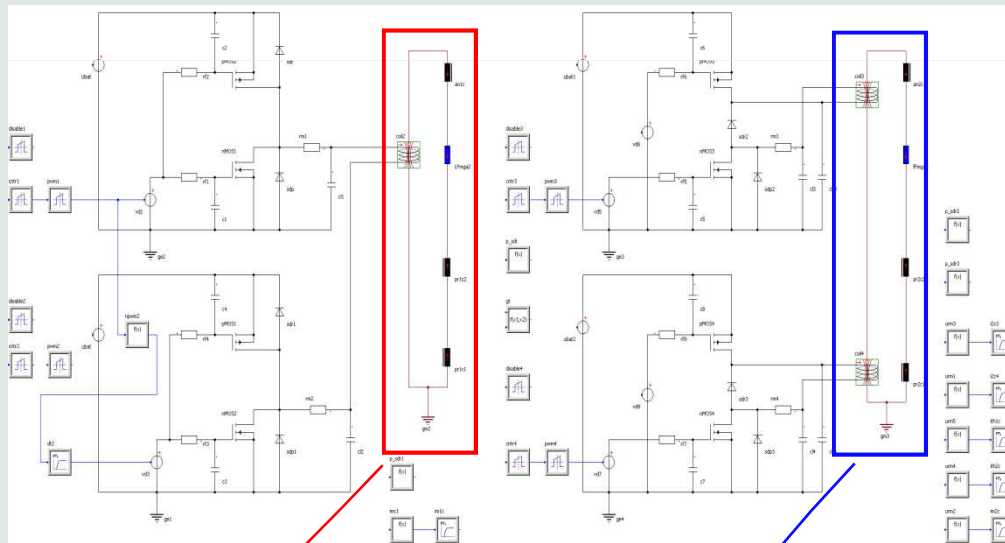


# 4.5 Transient Simulation of PWM Modulation

## Comparison of bipolar and unipolar power driver Design

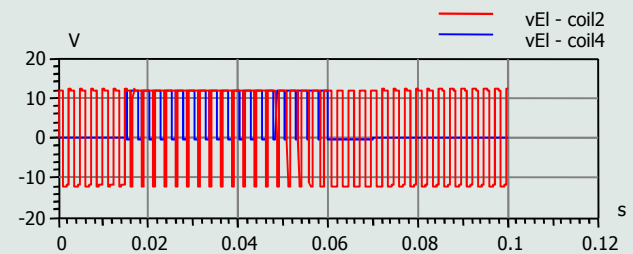
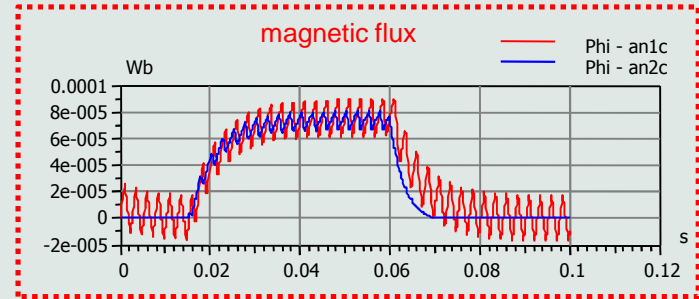
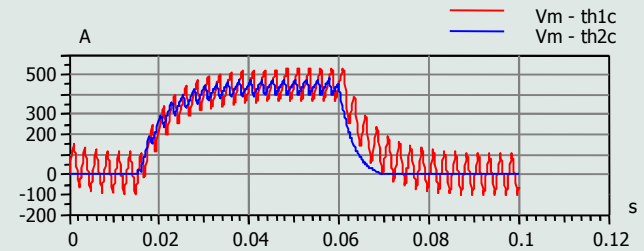
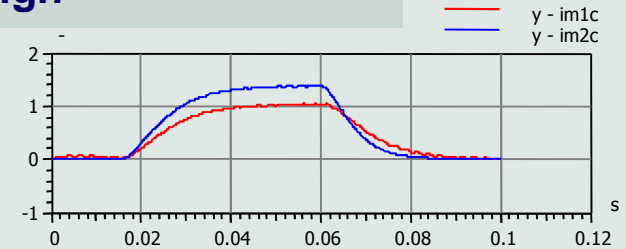
- increase of coil current up to 31% depending on deviation of turns between dual coil and single coil actuator design

- equal magnetic flux linkage of an actuator



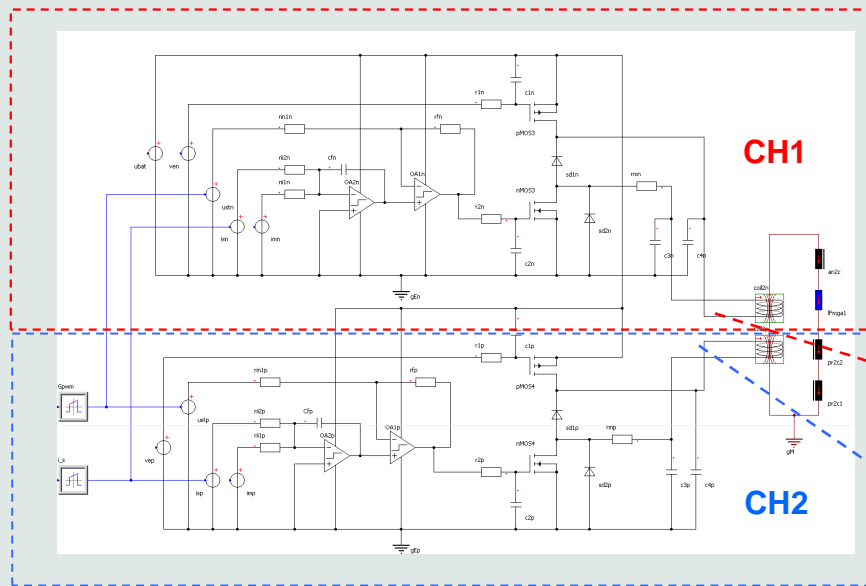
Full-Bridge

2 x Half-Bridge

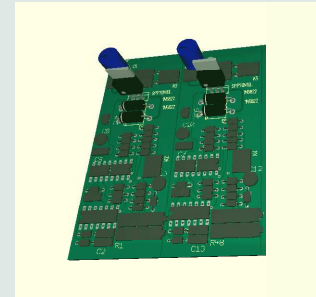


# 4.6 Multidomain Simulation of a Power Driver

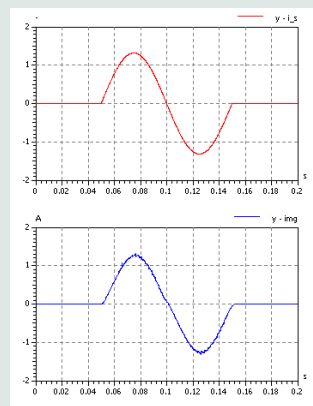
## Simulation of an embedded closed loop PWM Controller



PCB Design

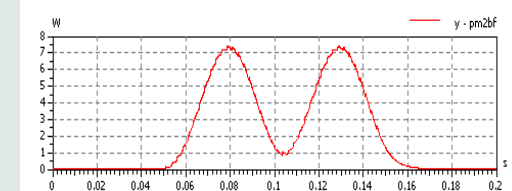
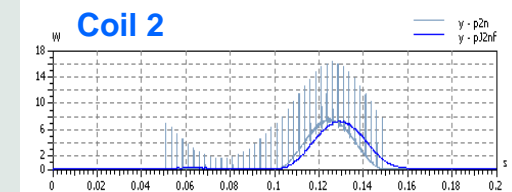
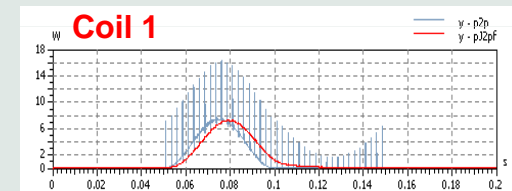


Hardware Prototype



Demanded bipolar current signal

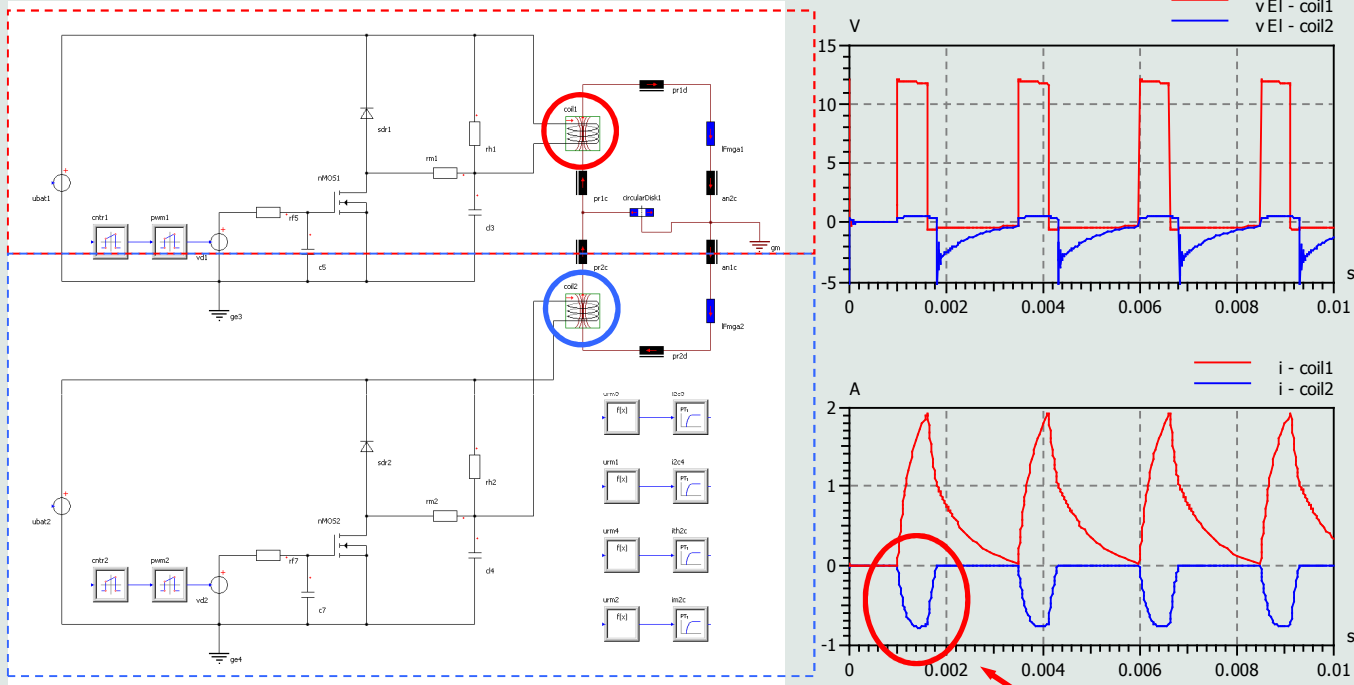
Resulting current calculated from magnetic field



# 4.7 Physical Simulation of System Imperfections

## Double solenoid Low-Side Switch induced disturbances investigation

Acting on positive current polarity

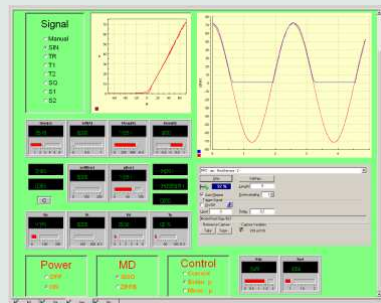
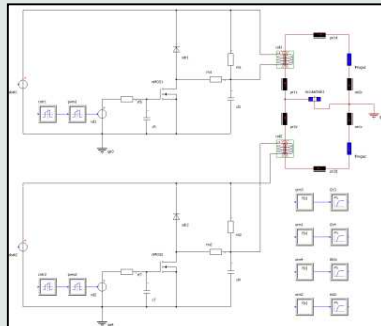
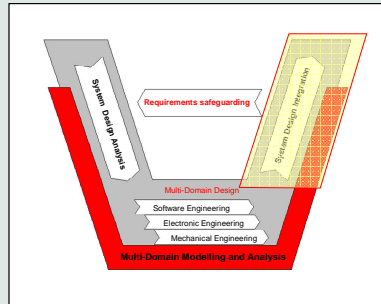


Acting on negative current polarity

induced disturbance

- dSpace RapidPro LS Switch Driver
- magnetic double solenoid coupling
- induced disturbances must be compensated

# 5. Virtual Prototyping



## Virtual Prototyping model

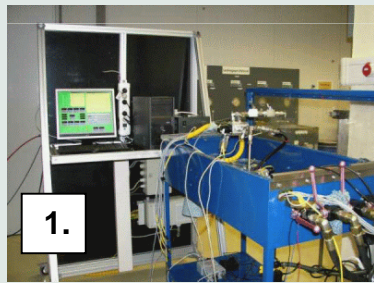
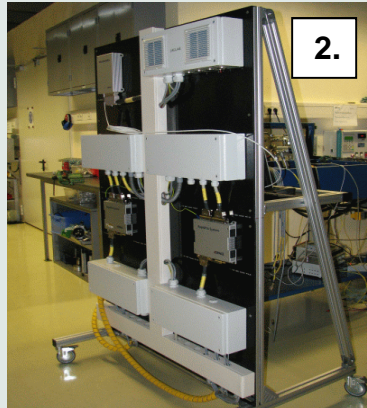
- includes the geometrical, physical and any quantitative or qualitative data from the real system

## Virtual Prototyping environment

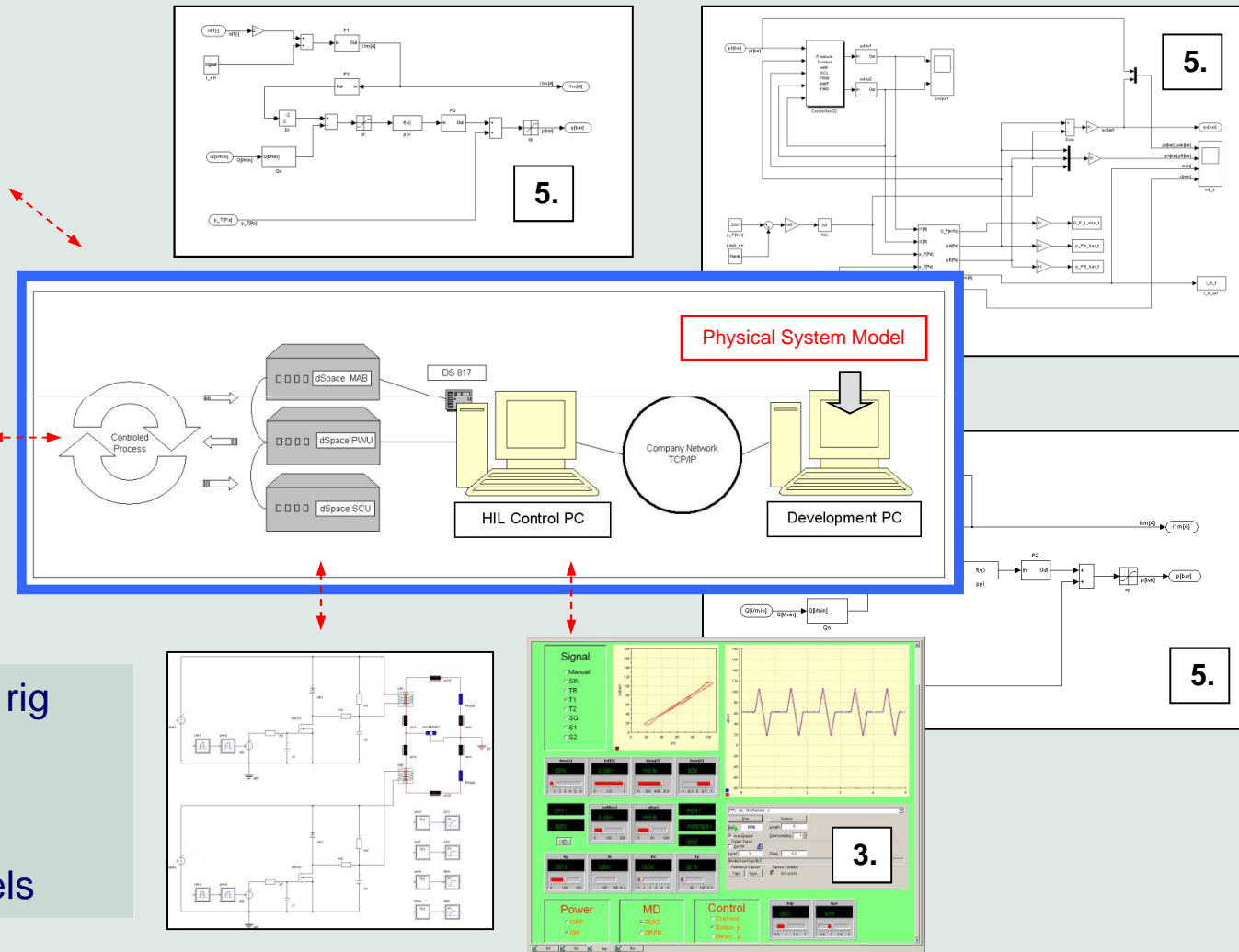
- enables users to naturally interact with the investigated system
- the user should be able to explore and discover unexpected but critical details about the system's behaviour
- the user should be able to observe the tested system, how it works and how it responds to changes in design, operation, or any other engineering modification
- Interaction within the virtual environment should be provided by an easily understood interface, appropriate to the user's technical background and expertise

# 5.1 Physical HIL System Simulation

## Virtual Prototyping Architecture of an Automotive RT HIL Test System



1. Hydraulic Test rig
2. RT Hardware
3. Control-Desk
4. Power Units
5. Simulink Models



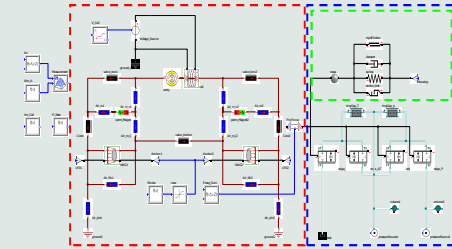
# 5.2 RT Code Generation from Virtual Model

SimX-Model

### 3500 Lines Modelica

- implicit physical formulations
- the highest fidelity, very complex model
- system is very stiff with algebraic loops

Parameter extraction

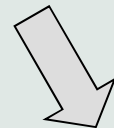


Simulink-Model

### FIRST LEVEL ( Explicit formulated Component Model )

#### Block based Representation

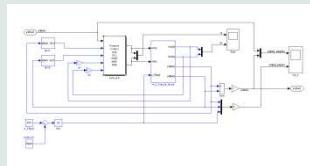
- continuous time model, based on design parameters
- explicit formulation
- no algebraic loops
- ode (45 ) auto step
- smaller



Model Download



Simulink-Model



### SECOND LEVEL ( reduced Model )

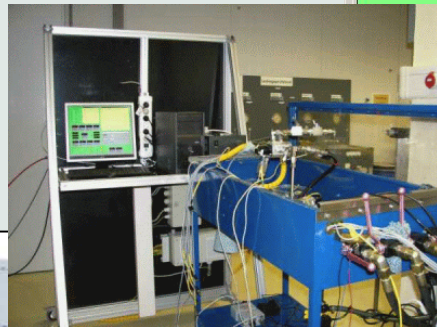
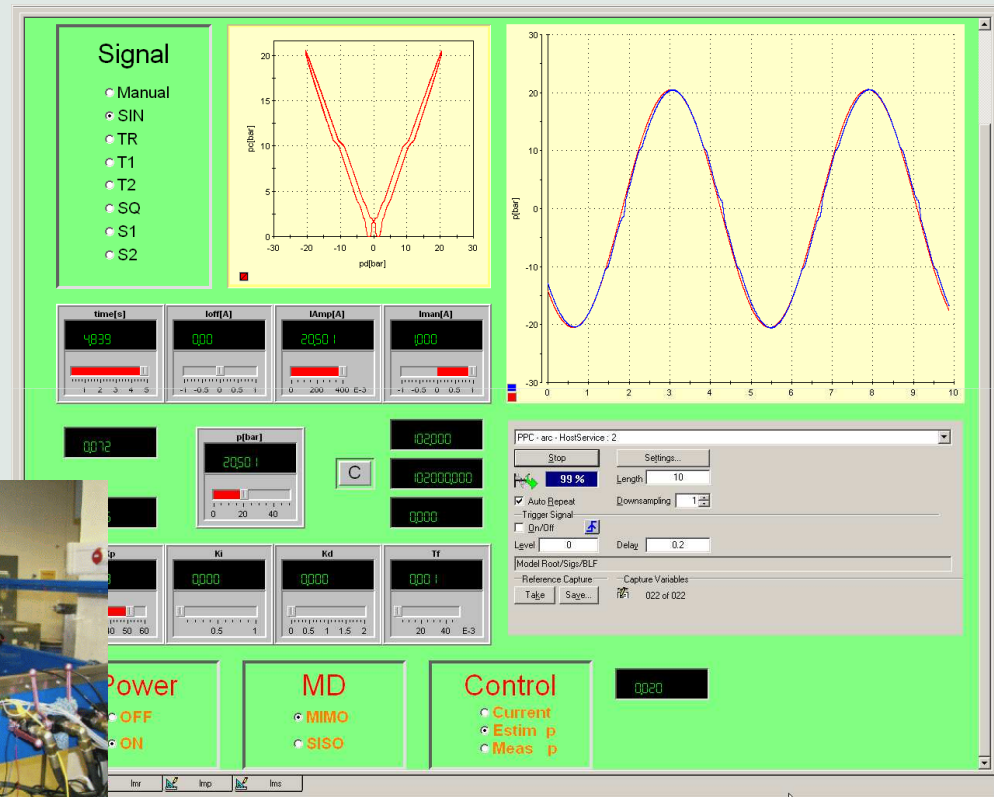
#### Discrete Controller Representation

- powerful, efficient model
- fixed time step 1ms
- small explicit solver ( or discrete function )
- RT Workshop code generation

# 5.3 MIMO Pressure Controller Design

## MIMO double solenoid Pressure Controller

- Dead Band compensation
- Nonlinearities compensation
- Fluid Flow compensation
- Pressure drop compensation
- Hysteresis compensation
- On-the-fly tuneable
- Virtual Simulink Model
- MATLAB / Simulink RTW generated

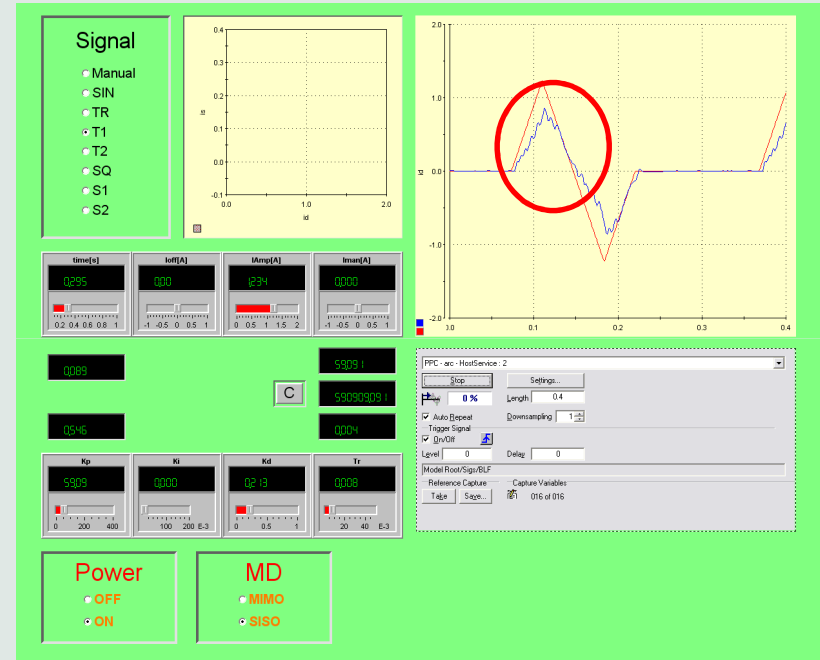


# 5.4 Comparison of SISO and MIMO Controller Design

## MIMO Design



## SISO Design



- SISO Design uses information only from a single acting channel
- MIMO Design can use the induced error current for Disturbance Compensation

## 6. Conclusion

- FEM simulation results helped optimize leakage, reliability, power consumption and the total weight of the magnetic actuator
- Purely physical domain-coupled fully parametrical simulation model has been used in the examples
- Virtual prototypes can notably save time and costs
- Multi-domain components enormously support the fluent creation of virtual prototypes
- Model based virtual prototyping method used in this work presents a new level of flexibility in System Design
- All system parameters of the virtual prototype model are adjustable on-the-fly
- MIMO Design of a superior controller optimally compensates the induced error current in the double-coil actuator