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Bondgrafen als Mechatronisch Modelleergereedschap.

Willem Minten, Bart De Moor, en Joos Vandewalle
ESAT-SISTA-K.U.Leuven-Belgium
Email: `Willem.Minten@esat.kuleuven.ac.be`
Internet URL: `http://www.esat.kuleuven.ac.be/~minten`

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Overview

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  - o Short Description of the Bond Graph Language
- Modeling Classes
- Bond Graphs and Mechatronic Design
  - o Intrinsic Values
  - o Other Capabilities
- Conclusion

Introduction

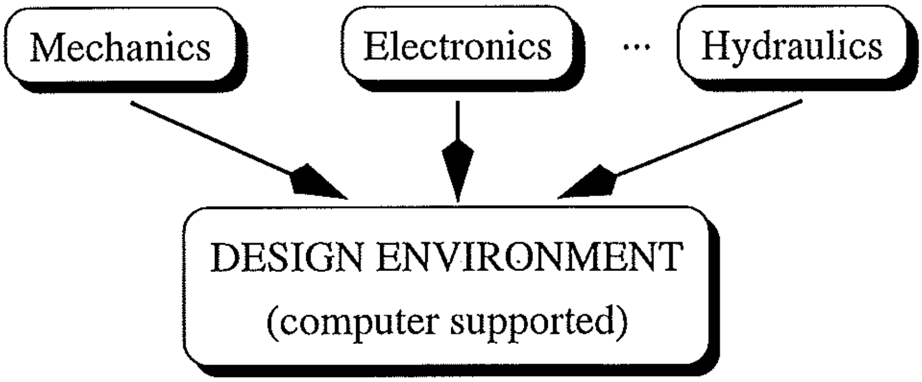
Aim

No

comparative study of different modeling methods

Yes:

how can we answer to some questions in *mechatronic modeling* problems?



Mechanics

Electronics

···

Hydraulics

DESIGN ENVIRONMENT
(computer supported)

$\Longrightarrow$ **Added value:**

- shorter *time to market*
- *better* products
- *reduction* of the development cost

Introduction

Short description of Bond Graph Language

Contains aspects of:

1. **System Theory:** seeking for analogies to ease domain independent representations and interpretations.

   Dissipation:

$$F = c \cdot \frac{dx}{dt} = c \cdot v \longleftrightarrow e = R \cdot \frac{dq}{dt} = R \cdot i \longleftrightarrow \ldots$$

   Storage (direct analogy):

$$F = \frac{x}{1/k} = \frac{1}{1/k} \cdot \int v \cdot dt \longleftrightarrow e = \frac{q}{C} = \frac{1}{C} \cdot \int i \cdot dt \longleftrightarrow \ldots$$

or

$$F = m \cdot \frac{d^2x}{dt^2} = m \cdot \frac{dv}{dt} = \frac{dp}{dt} \longleftrightarrow e = L \cdot \frac{d^2q}{dt^2} = L \cdot \frac{di}{dt} = \frac{d\Phi}{dt} \longleftrightarrow ..$$

   Transducing:

$$F = B \cdot l \cdot i \quad ; \quad e = B \cdot l \cdot v$$

$$\vdots$$

Introduction

$\Longrightarrow$ behavior described with generalized quantities and effects:

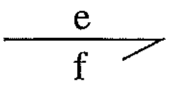
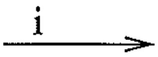
VARIABLES	effort variable e	flow variable f	momentum $p = \int e \cdot dt$	displacement $q = \int f \cdot dt$
1D transl.	F	v	p	x
1D rot.	M	ω	h	θ
electrical	e	i	Φ	q
		$\vdots$		

EFFECTS	dissipation	energy storage		power transducers			
		kinetic p	potential q	transformer $e_1 = \mu(e_2)$	gyrator $e_1 = \rho(f_2)$	common effort $\forall e_i : e_i = e$	common flow $\forall f_i : f_i = f$
1D transl.	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
1D rot.	R	I	C	TF	GY	0	1
electrical	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
				$\vdots$			

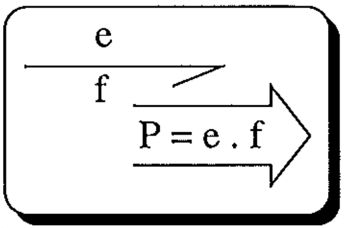
2. **Physical System Theory:** observe the main physical laws: Thermodynamics (energy, entropy).

Introduction

3. Graphical Visualization: Graphical primitives:

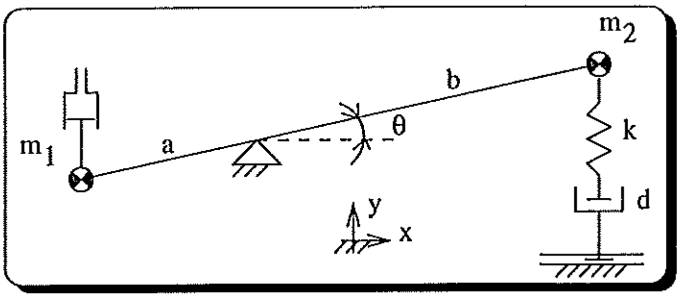
Disspative field (energy loss)	R:r	
Storage field (energy conservation)	C:1/k I:m	
Transducers (power continuity)	TF:m GY:r	
	0:e	(K.C.L.)
	1:f	(K.V.L.)
Sources	S:s	
Energy flow		
Information flow		

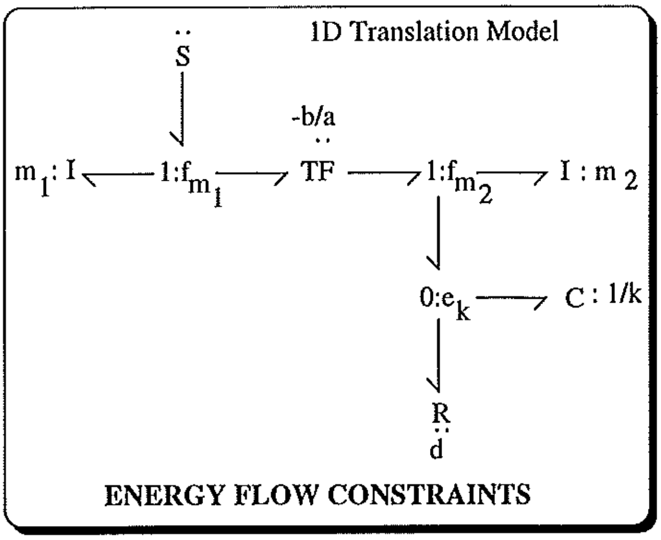
Main idea: visualize the energy distribution:



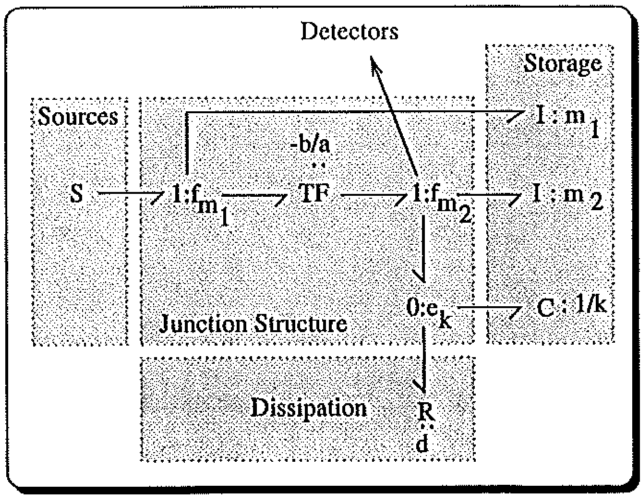
Introduction

Example: a lever mechanism





$\Longrightarrow$ energy based classification possible

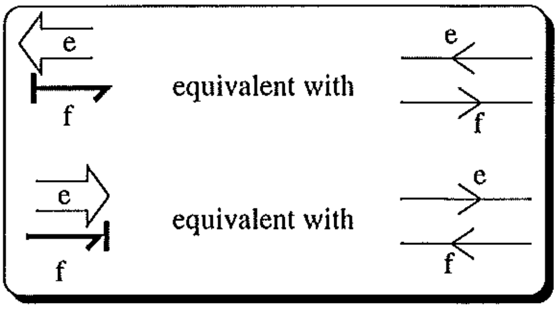


Introduction

4. Mathematical Formulation:

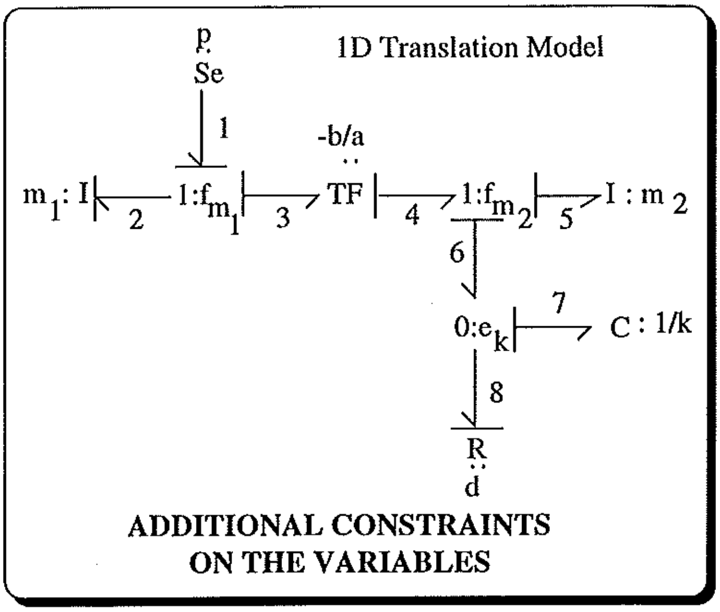
Used Tool: Causality assignment

- *conversion:* constituent relations ⟶ assignment statements
- *sorting* of the statements: causal propagation



Introduction

Example of SCAP:



Other procedures: LCAP, D-SCAP, RCAP, Bi-SCAP, ...

Conclusion:

- graphical visualization of constraints on the variables
- BGM is independent of the desired mathematical formulation
- BGM is behavioral, like reality

$\Longrightarrow$ higher model quality than a set of equations or a block scheme

Modeling Classes

Dedicated Modeling for Design

Mechanical Structure design: geometric design, strength design, vibration design.
Modeling tools:

- wires, volumes in CAD
- finite elements in FEM

System Design: (CA)SD.
Modeling tools:

- algebraic equations for equilibrium point design
- algebraic and differential equations for transient behavior
- block diagrams in nonlinear simulations

Control Design: (CA)CSD.
Modeling Tools:

- block diagrams in nonlinear simulations
- transfer functions in classical control
- state space models, neural nets, fuzzy models in modern control

$\Longrightarrow$ iterative process for *mechatronic* products

Modeling Classes

Consequences:

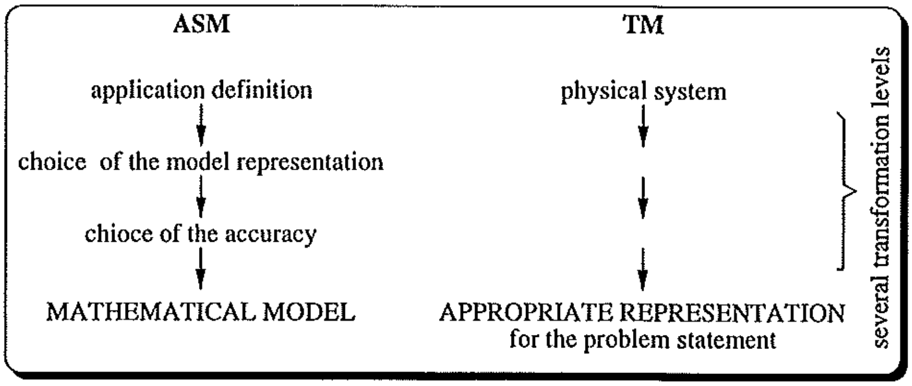
- backtracking traces
- not achieved goals

Reasons:

- modeling methods are *application specific* (ASM)
- *queue integration* of the design process

Solution:

- use *transformation modeling* (TM)
- invoke an *optimization* for the applications that coincide together



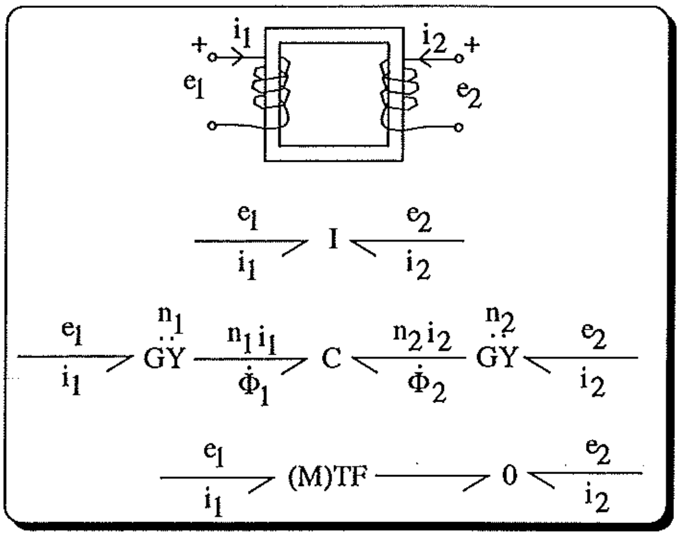
⟹ Mechatronic Design

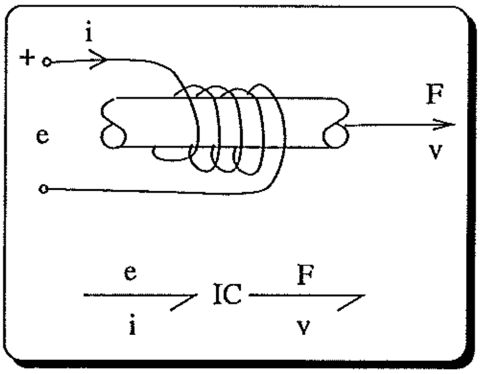
Example: the lever mechanism

Bond Graphs and Mechatronic Design

Intrinsic Values

- *domain independent*, modeling focuses energy considerations.
  Example: electrical transformer and door bell



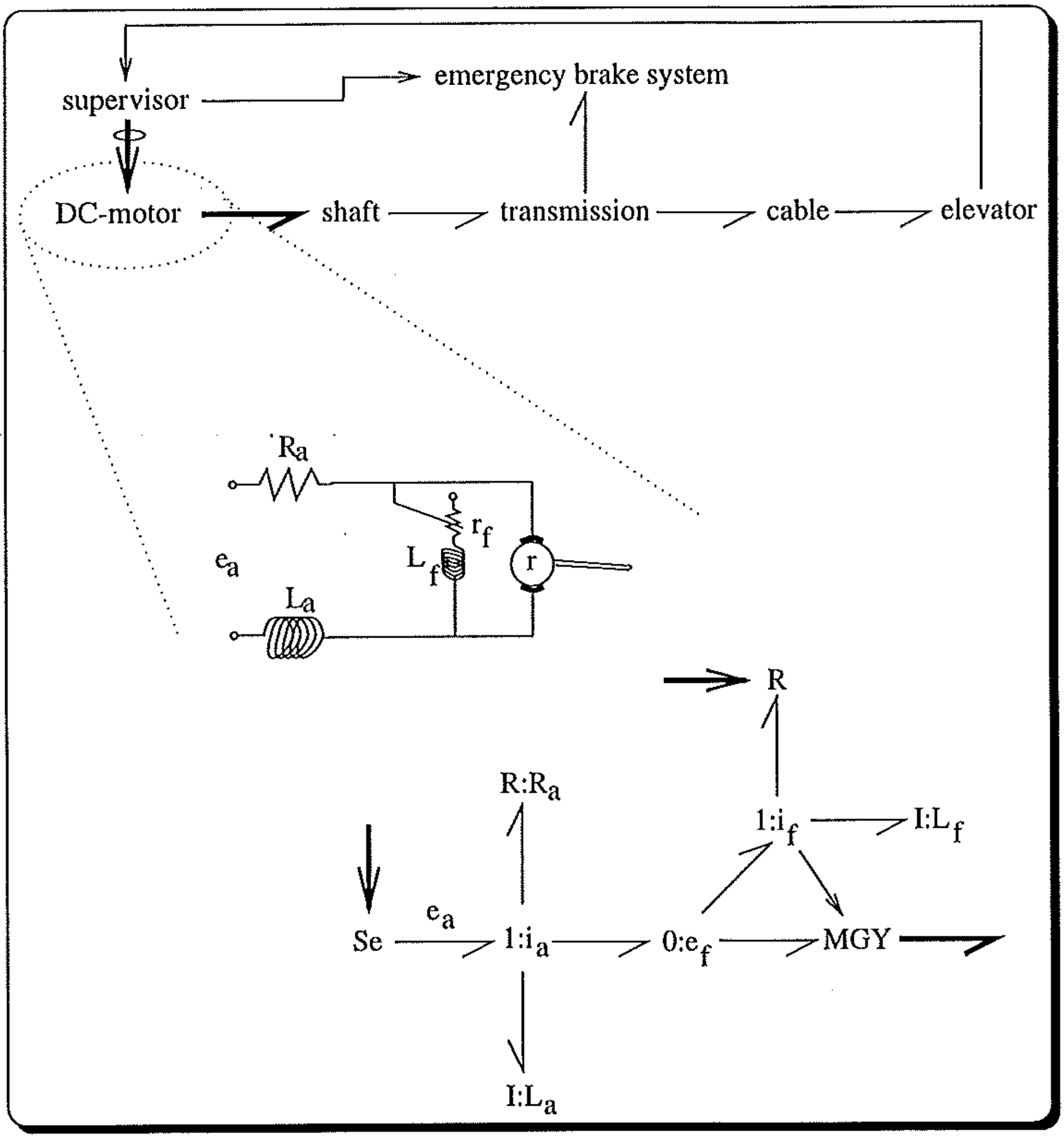


- advanced software support possible due to
  - *object orientation* of the a-causal primitives
  - *structured* method that can highly be automated

Bond Graphs and Mechatronic Design

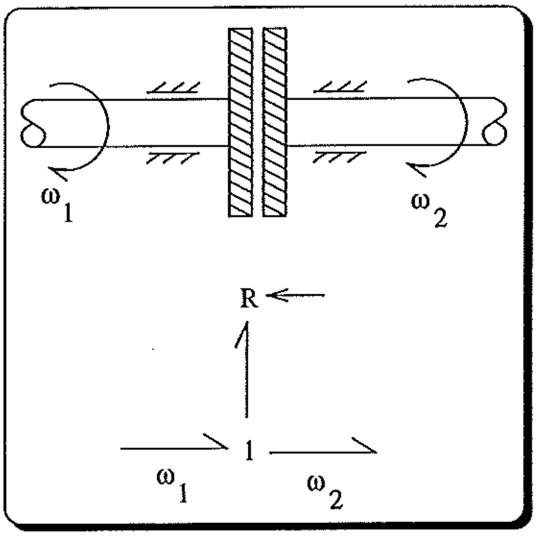
- fully support of abstraction level due to hierarchical modeling facilities
- multi-bonds support fully vector quantities in mechanics

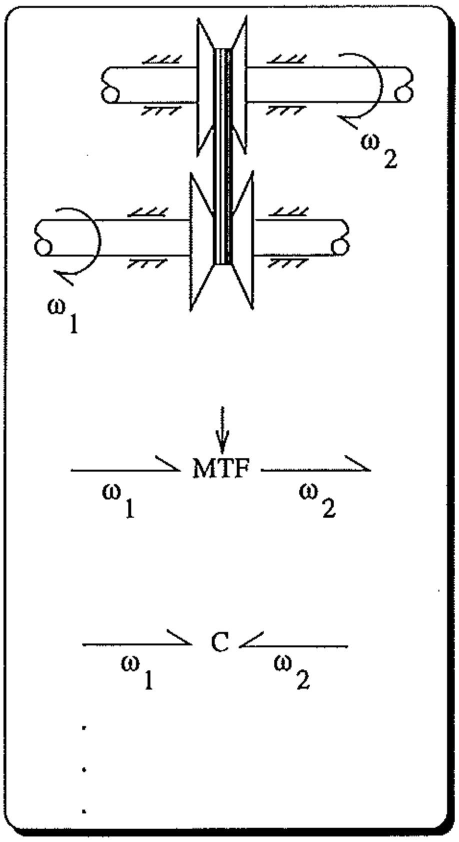
Example:



Bond Graphs and Mechatronic Design

- makes design with concepts explicit.
  Example: clutch and transmission



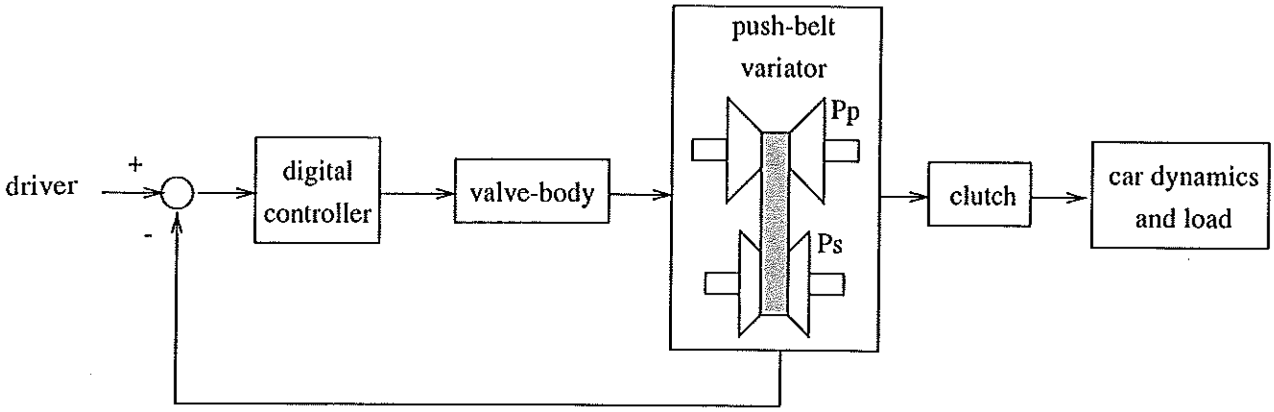


Bond Graphs and Mechatronic Design

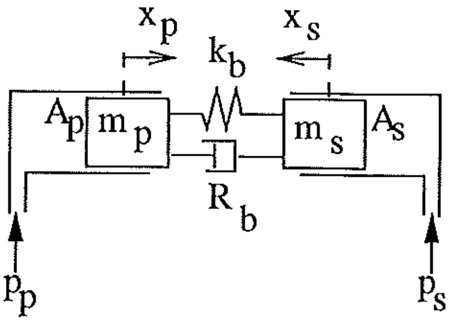
Other Capabilities towards

- physical system design aspects
- control system design aspects

by example of a CVT transmission:



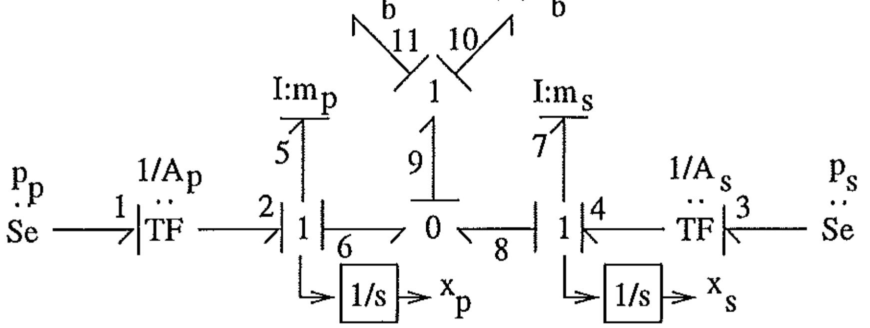
I.P.M.



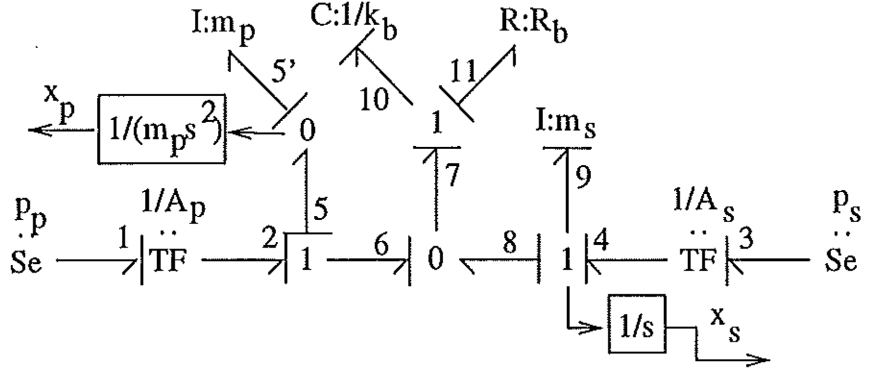
Bond Graphs and Mechatronic Design

General mathematical structure: causal assignments

SCAP:



(All-Derivative)
SCAP:



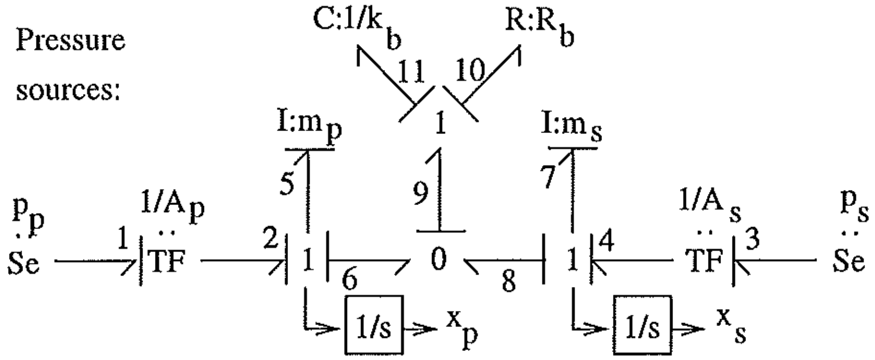
o set of explicit ODE's ($\dot{x} = \varphi(x, u)$)

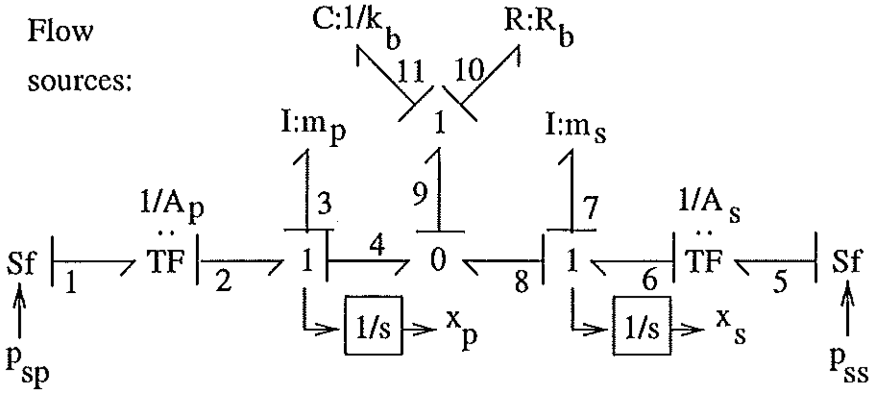
o dependency between the state velocities

o transfer function $\frac{\dot{x}_s}{p_p}$ has one zero and three poles (of which one in the origin)

Bond Graphs and Mechatronic Design

Impact of sources on the (controller) design



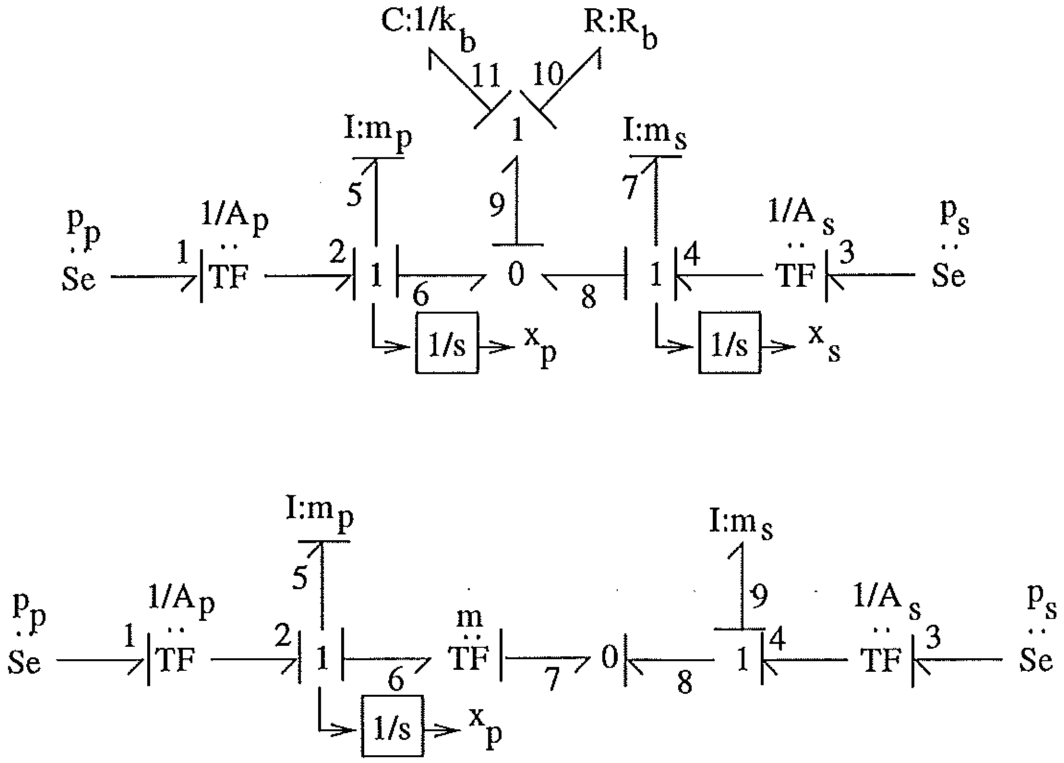


- o transmission ratio control
- o robustness issues
- o quality of the sources

Bond Graphs and Mechatronic Design

Modularity

Push-belt dynamics:

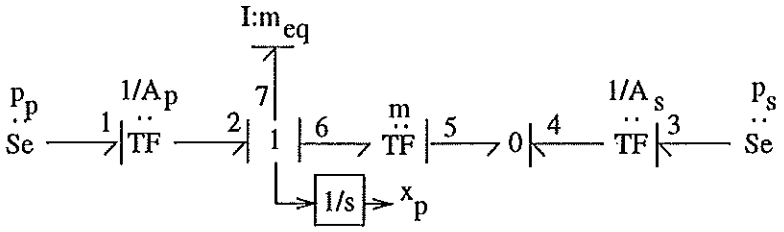


- o invoking different abstraction levels
- o questioning some (over-)simplifications

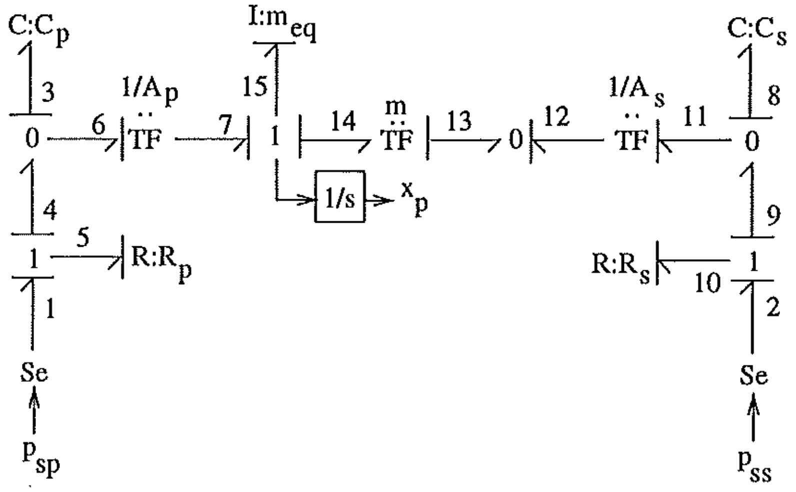
Bond Graphs and Mechatronic Design

Model for control

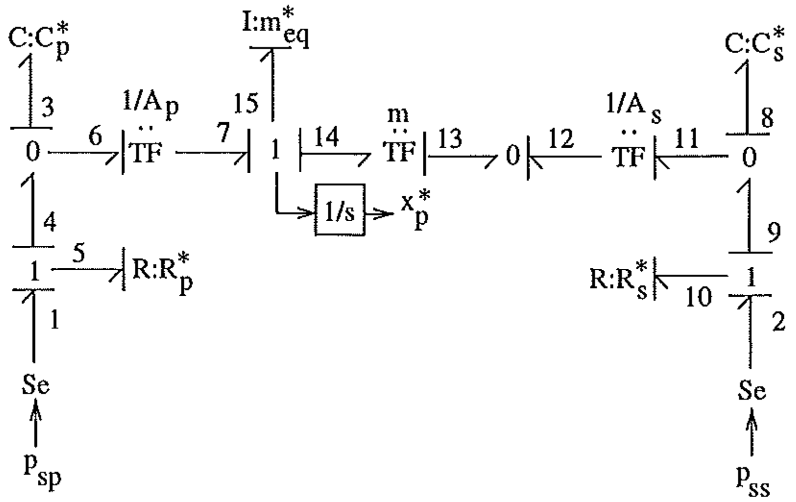
First model for control:



Important oil dynamics



Linear model:



- o Model transformation on the physical level
- o Linearisation on the physical level

Conclusion

- Bond graph models serve in *Mechatronics* as an important knowledge data-base:
  - graphical
    ⟶ makes really a first design *by sketching* possible
  - structured, modular and unified methodology (energy based)
  - revealing structural characteristics of physical models and controller schemes *at the very first beginning of the modeling phase* (causality)
    - \+ ODE - DAE - structural singularities
    - \+ formal transfer function determination
    - \+ optimal design of transmission ratio control
    - \+ robustness issues
    - \+ issues on the desired quality of the sources
    - \+ questioning (over-)simplifications

    ⟶ Forecasting design issues results in fewer backtracking traces
  - model transformations possible
    ⟶ on the physical level (gaining insights of the modeler)
    ⟶ towards physical structure and controller design
    - \+ Linearisation
    - \+ direct derivation of the desired mathematical form
- Aspects not shown:
  - parameter identification aids
  - aids for physical state estimator design
  - ...