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Digital Hydraulic System using pumps and on/off valves controlling the actuator

Cristiano C. Locateli
Paulo L. Teixeira
Edson R. De Pieri
Petter Krus
Victor J. De Negri

LASHIP – Laboratory of Hydraulic and Pneumatic Systems
Federal University of Santa Catarina
Florianópolis - S.C. – Brazil

Flumes - Fluid and Mechatronic Systems
Linköping University
Linköping, Sweden1

Fluida och Mekatroniska System
FluMeS
Fluid and Mechatronic Systems

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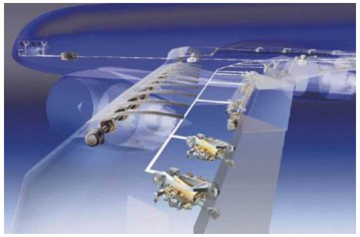
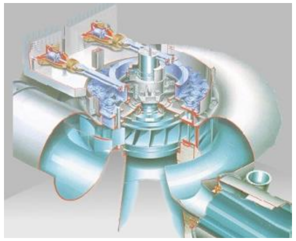
Introduction

- Hydraulic systems have important features, such as **high robustness, power density and power/weight ratio**;

- They have a **market niche** which other technologies can hardly compete;



- Despite **the components** generally present a **high efficiency**, the **hydraulic systems** have **low efficiency**;

- **Digital hydraulics:** approach with potential to increase the **efficiency of hydraulic systems**..

Introduction

Digital hydraulic advantages:

- Efficiency:
- Redundancy:
- Robustness:
- Capacity of component standardization.

Digital hydraulic challenges:

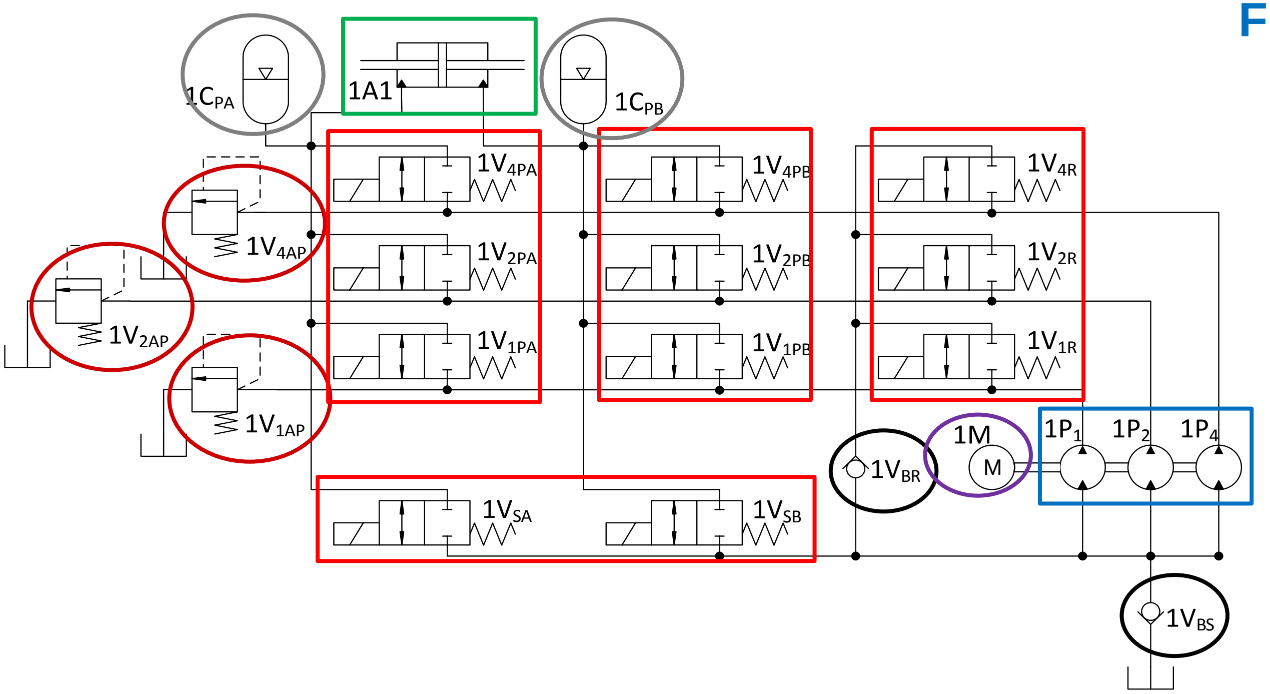
- Size and price of components:
- Noise:
- Pressure peaks:
- Unconventional control.

Contributions

- **New concept of a hydraulic circuit**.
- Focuses on the use of digital pumps and valves for direct control of the actuator;

Proposal of a Digital Hydraulic System

Symmetric actuator - Components



On/off Valves

Fixed Displacement Units

FDU

Actuator

Relief Valves

Check valves

Accumulators

Prime motor

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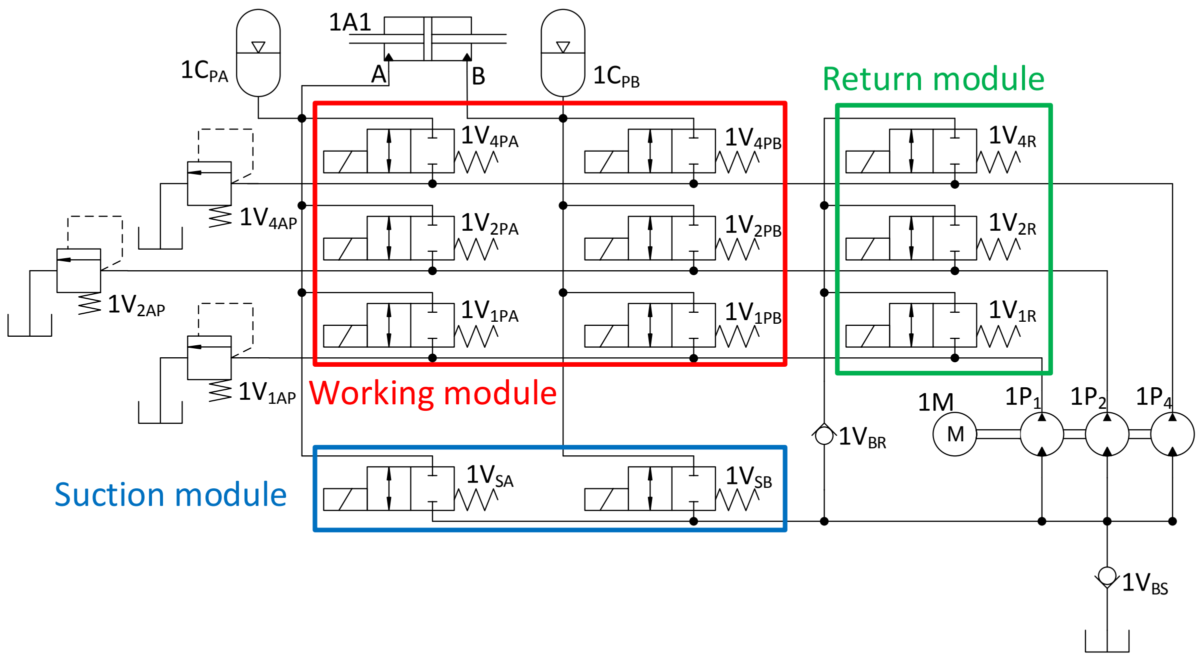
Symmetric actuator - Module



Working module

It is responsible for directing the flow rate from the FDUs to the actuator chamber

Suction module

It allows flow from the actuator chambers to the digital pump

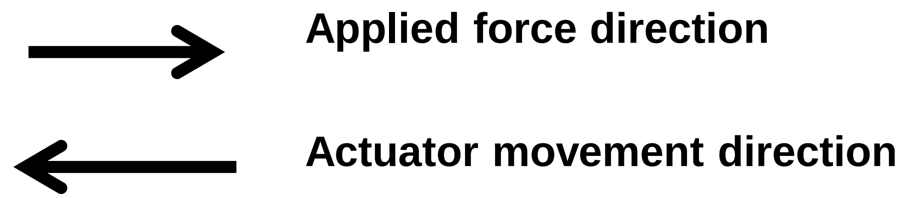
Return module

It allows the idle operation of the FDUs when they are not providing flow rate to the actuator chamber

FDU – Operating mode

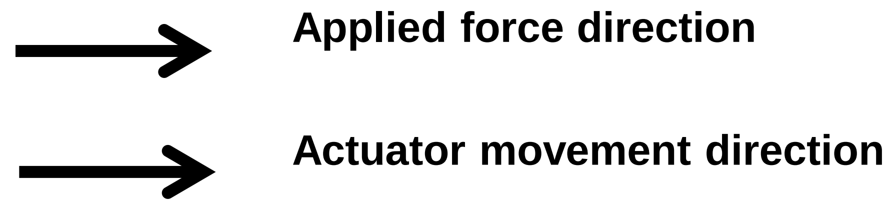
Pump mode

When the applied force on the actuator is in the **opposite direction** of movement



Motor mode

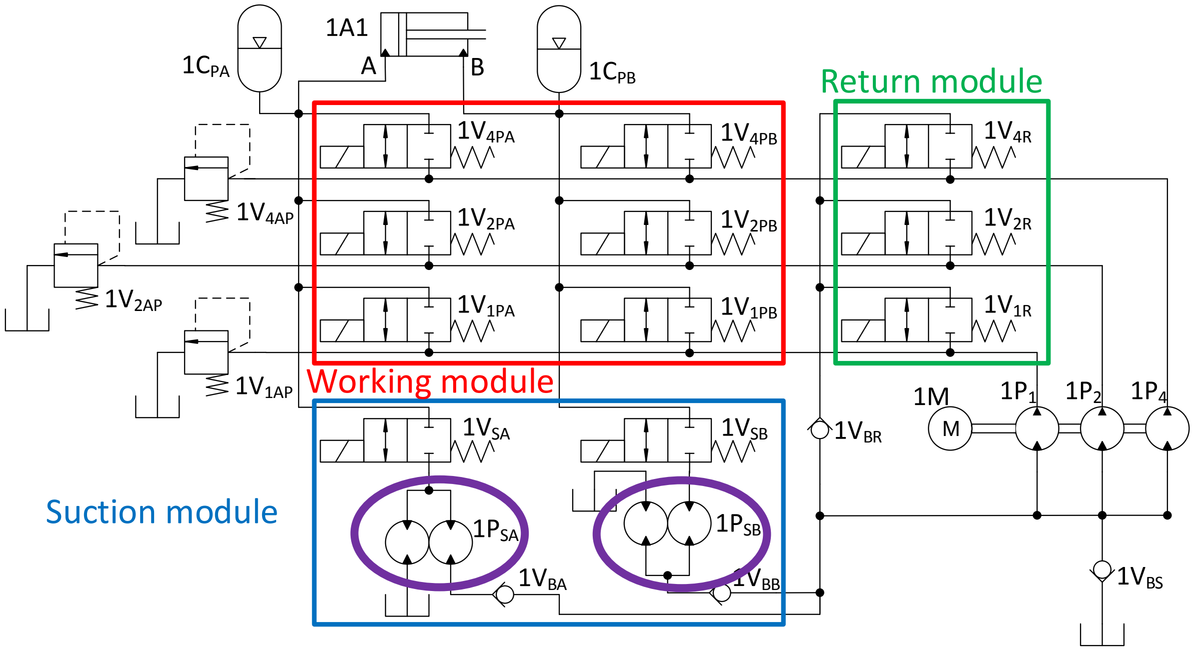
When the applied force on the actuator is in the **same direction** of movement



Idle mode

When the FDU is in idle condition

Asymmetric actuator



Distinct chamber **areas**, different **flow rates**

but...

The flow rate that leaves and enters the digital pump must match

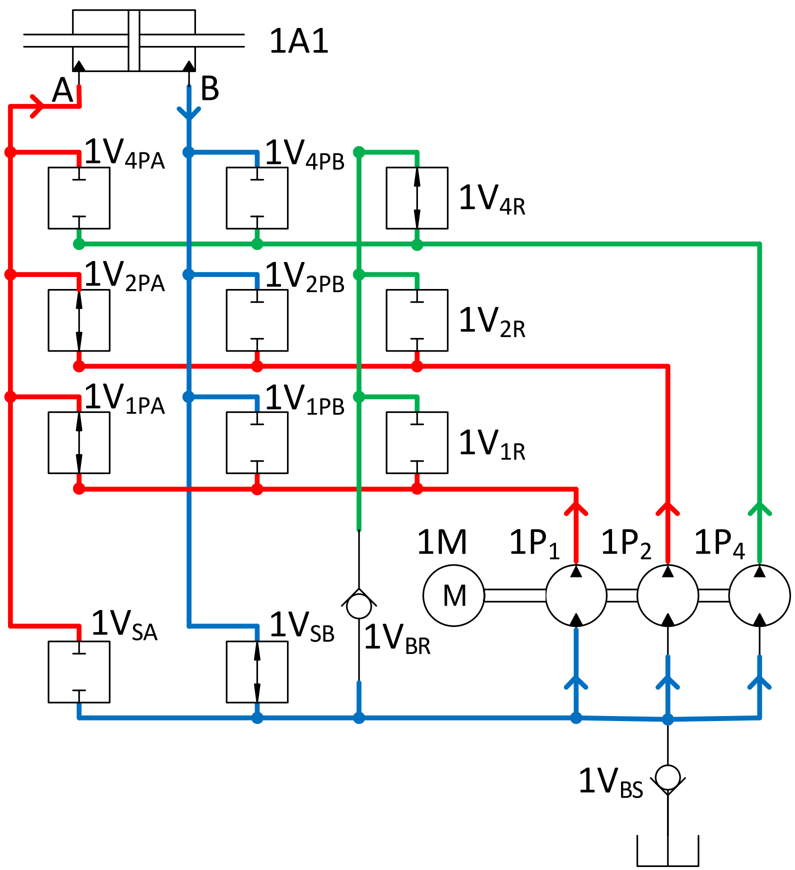
Flow divisor

Control Method

- The actuator speed is function of which **on/off valves are active**, **prime over speed** and **system loads;**
- **Seven different speeds**;
- The **size** of digital pump units are defined by **mathematical sequence** of power of two (1, 2 and 4).

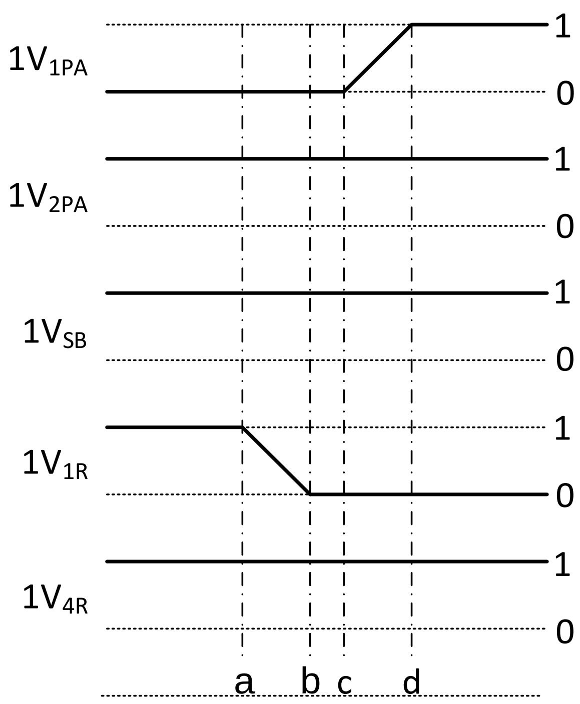
Example: Third actuator speed level.

- **The red line** represents the FDU operating in pump/motor mode.
- **The blue line** represents the flow that leaves chamber B,
- **The green line** shows FDU $1P_4$ operating in idle mode



Control Method

- The **transient state** behaviour comprises the **transition between speed levels;**
- **Delay time** between the changes of speed levels;
- **Delay time** is applied **to minimize hydraulic short circuits;**

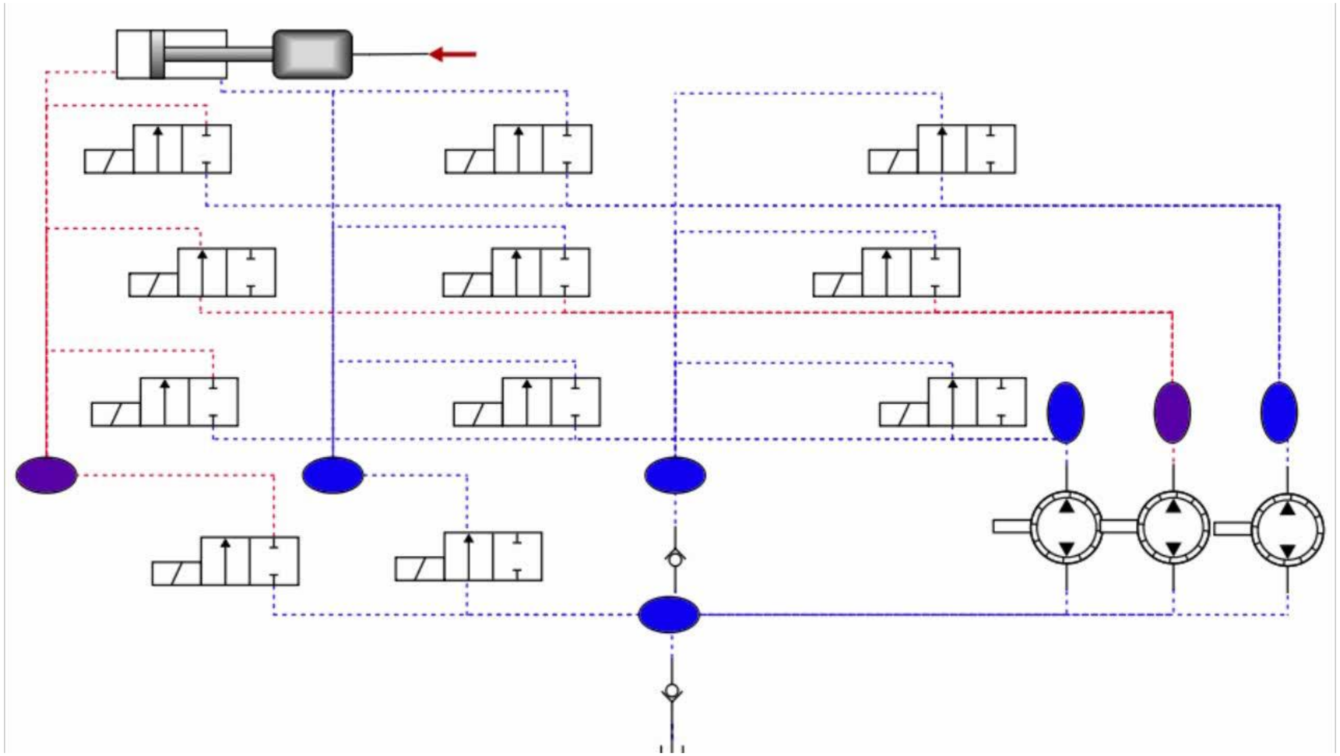


Example: Diagram related to changing between the **second and third speed levels**.

- A control signal is initially sent to close the $\mathbf{1V_{1R}}$ valve of the return module;
- After a specific delay time, a control signal is sent to open the $\mathbf{1V_{1PA}}$ valve of the working module;
- During this process, the $1V_{2PA}$, $1V_{SB}$ and $1V_{4R}$ valves remain activated.

Operating example

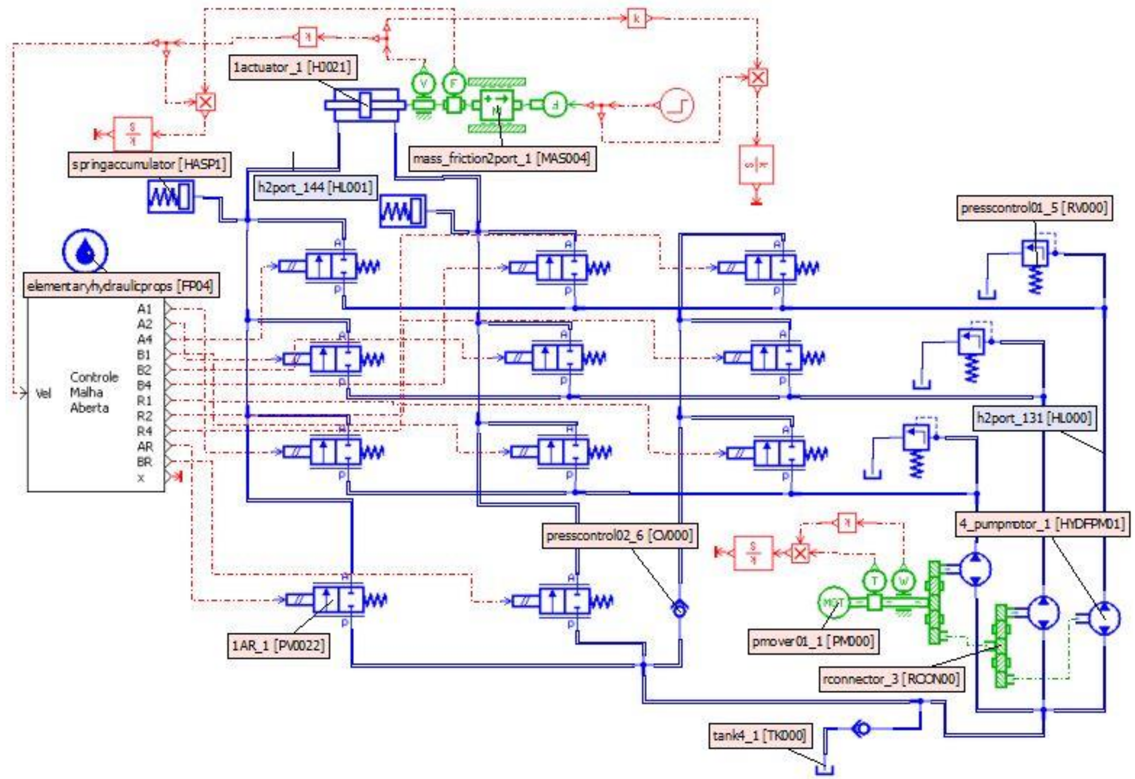
Symmetric actuator



Transition between the **second** and **third** speed levels (slow motion).

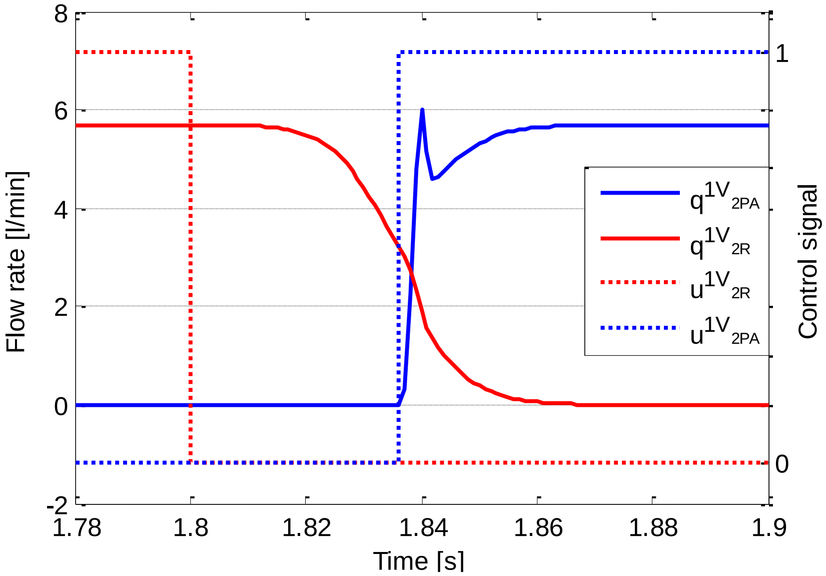
System Modelling

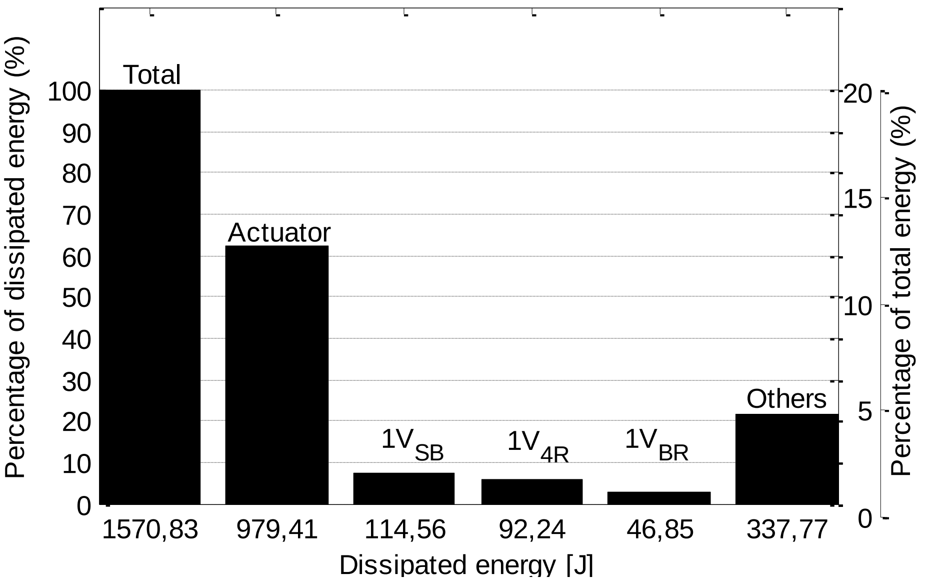
- Co-simulation technique;
- The hydraulic circuit was modelled in **AMESim**;
- The control strategy was implemented using **MATLAB/Simulink**.



Preliminary Results

Symmetric actuator

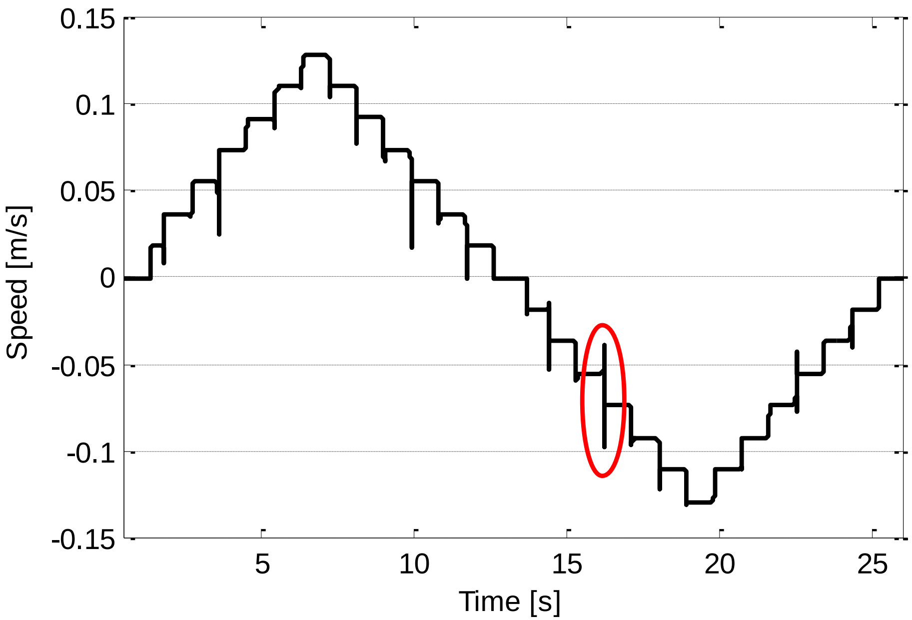


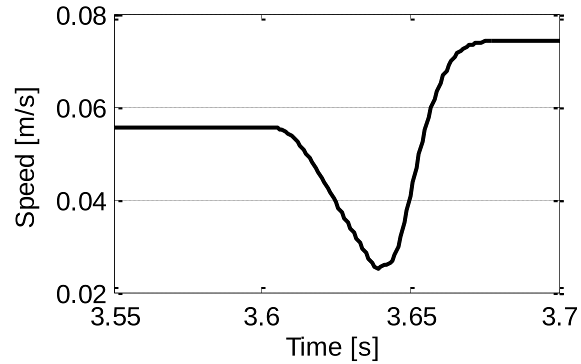


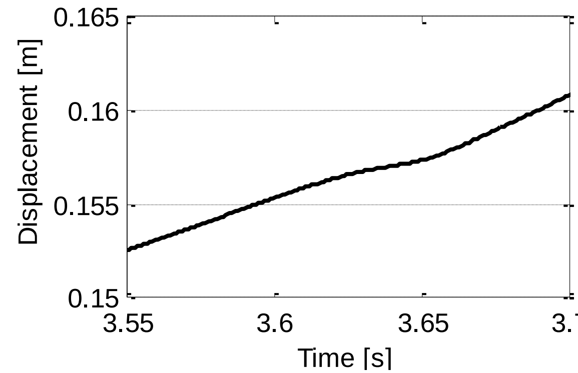
- The **flow rate** and **control signal** behaviour of the $1V_{2PA}$ and $1V_{2R}$ valves.
- The simulation result **does not exhibit significant short circuit**.
- **The total energy dissipated** is nearly **20%** of the **total energy used** by the system.
- The main dissipations take place on the $1V_{SB}$, $1V_{4R}$ and $1V_{BR}$ valves beyond the friction losses on the actuator.

Preliminary Results

Symmetric actuator



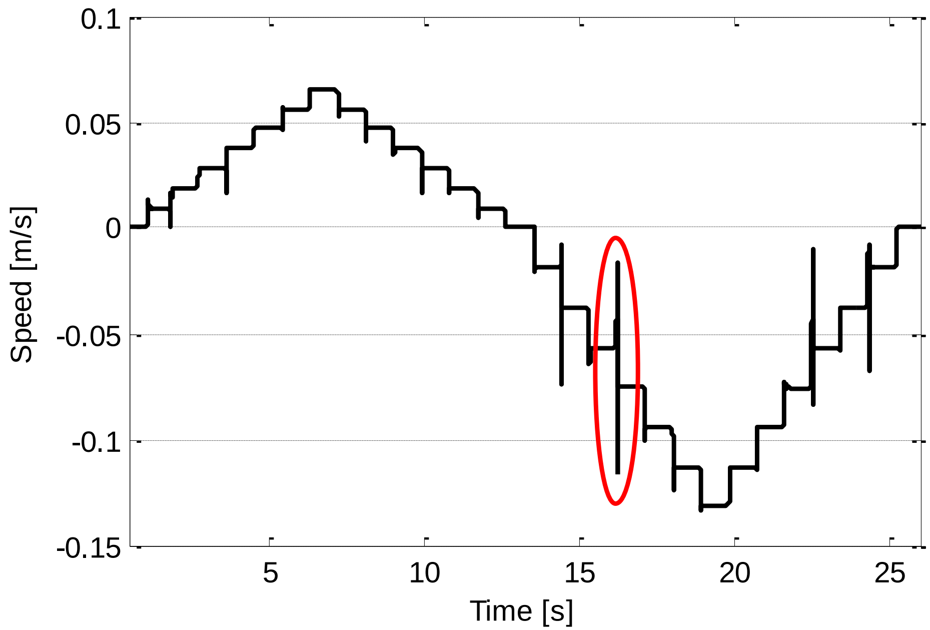


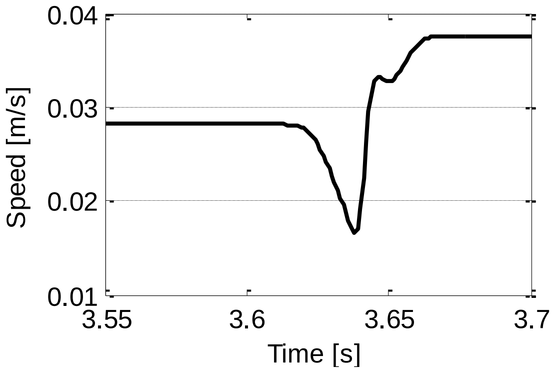


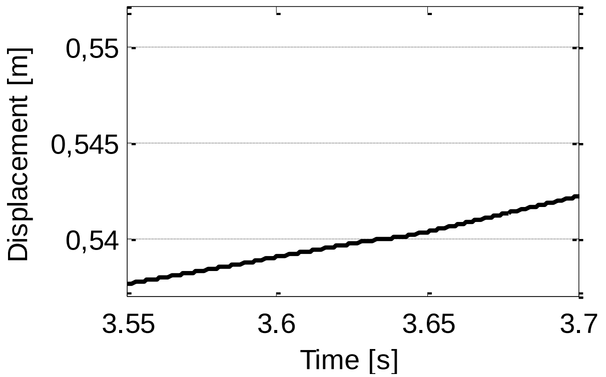
- The **highest speed oscillations** occur between **the third and fourth** levels.
- The oscillations was **reduce** with the use of **delay time** and the use of **accumulator**.
- The oscillation **does not cause** an abrupt movement in actuator positioning.

Preliminary Results

Asymmetric actuator







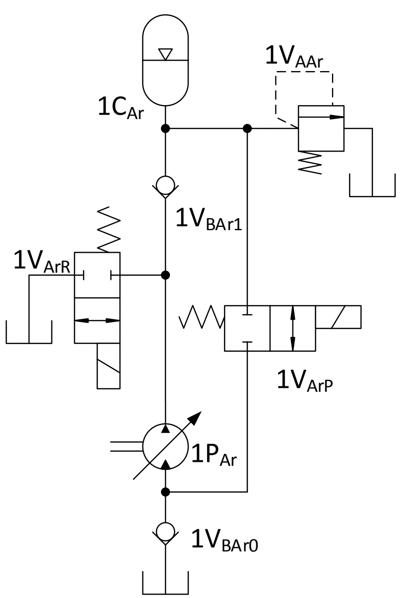
- **The most ocilations** occurs in the **retreat movement**
- The oscillations occur due to the **short circuit** in the lines.
- Despite the **high speed oscillation** in this transition, **there is not a large** effect on the position.

Conclusions

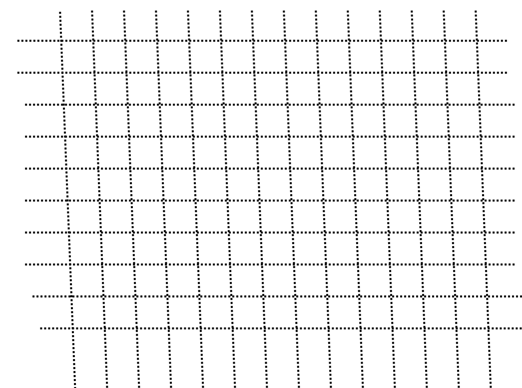
- This paper discusses **a new concept of hydraulic system** that aims **to increase energy efficiency** using **digital hydraulic** principles.
- Preliminary results show **smooth displacement transition** in the speed level transitions and low power dissipation.
- The **motor mode** can be an alternative to supply energy or store it for later use.

Future Work:

Energy management device



Digital Pump



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Thank you !

Questions?

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cristiano@laship.com.br

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