ASME/BATH 2014 Symposium on Fluid Power & Motion Control
September 10-12, Bath, United Kingdom

Actuator Speed Control using Digital Hydraulics

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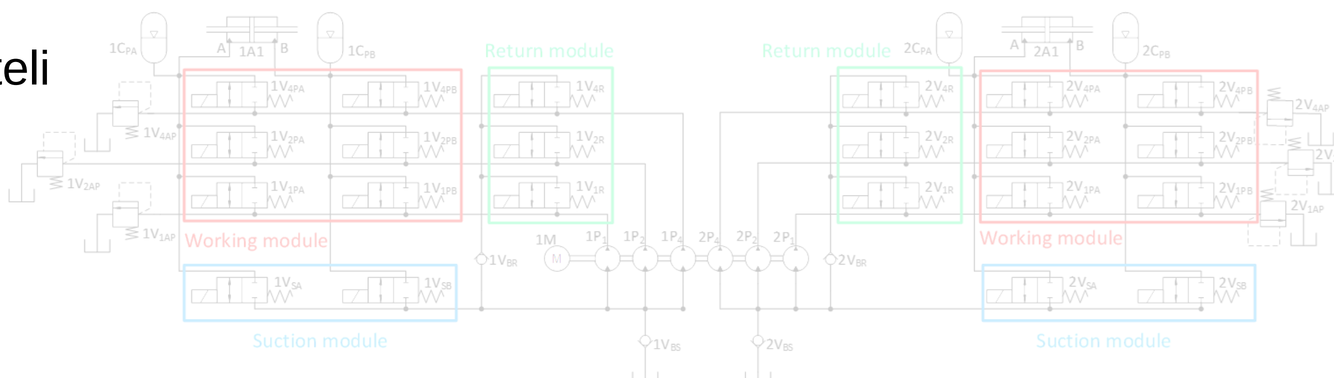

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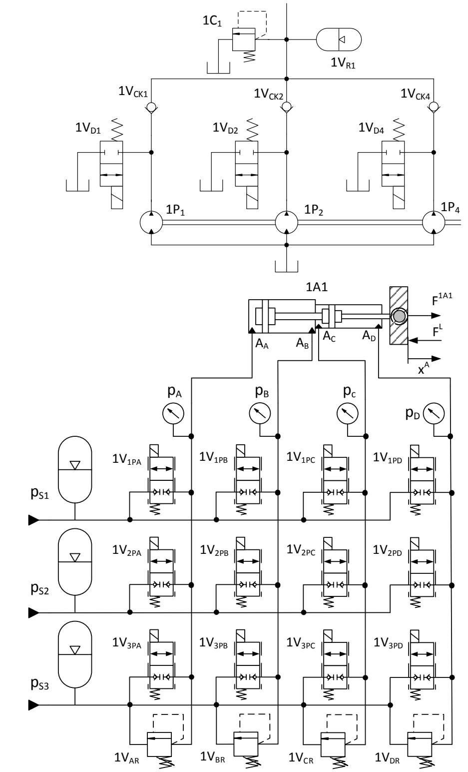
Introduction

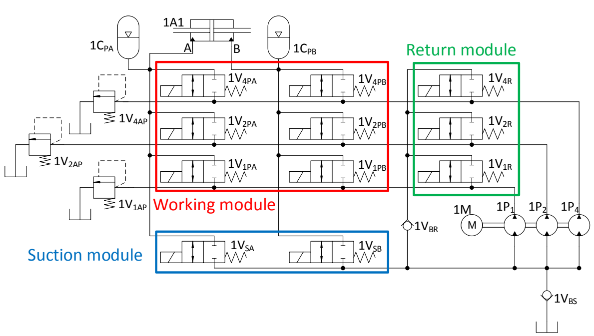
In the last few years, the **energetic efficiency** of hydraulic systems has been widely discussed...

One approach that has a particular potential is **digital hydraulics**.

Digital hydraulics has several potential advantages when compared with traditional technology.



Contributions



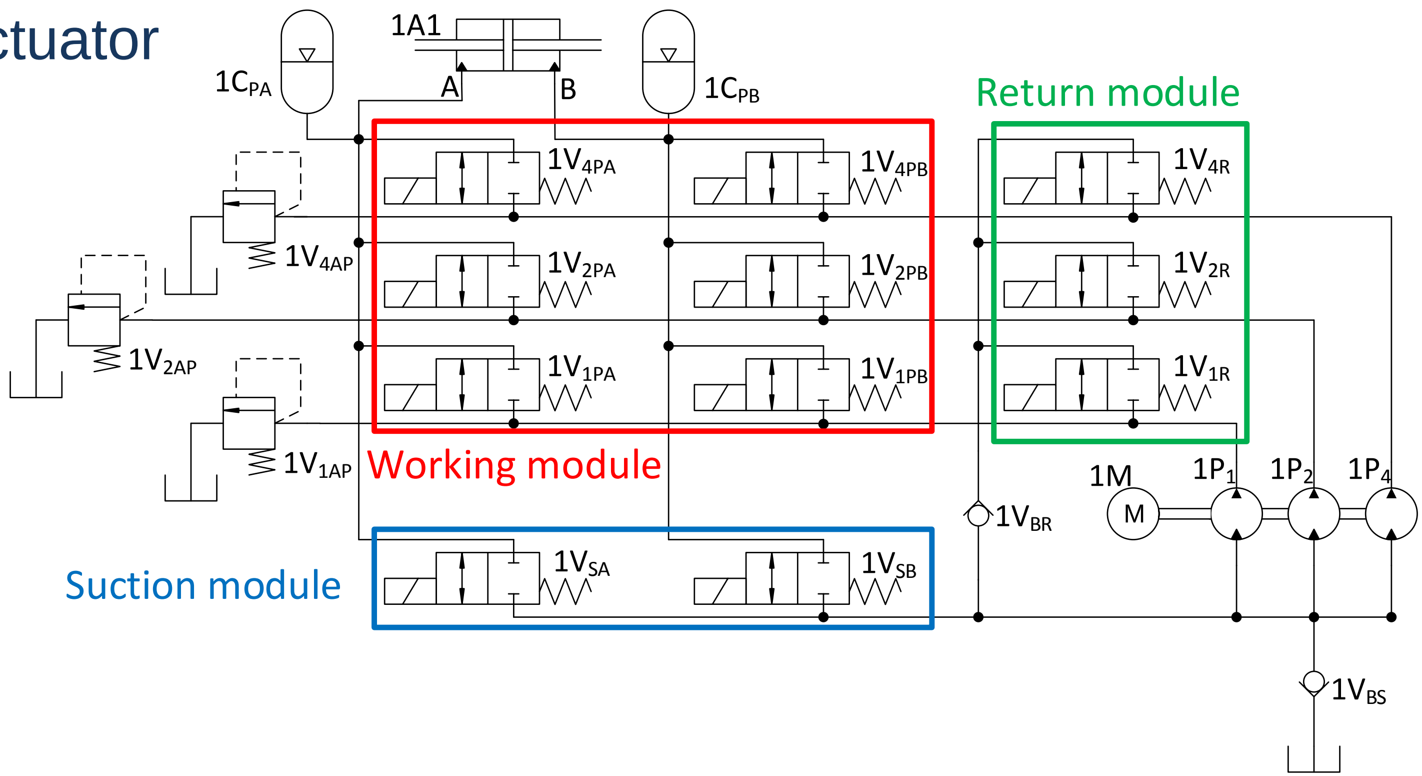
The **main objective** of this paper is to discuss the speed control of symmetrical actuators using digital hydraulic principles

It is proposed a **hydraulic circuit configuration** based on use of **several fixed displacement** and **on/off valves**.

An **energy management device** is also proposed.

Proposal of a Digital Hydraulic System

Symmetric actuator



Working module

It is responsible for directing the flow rate from the fixed displacement units (FDUs) to the actuator chambers

Suction module

It allows flow from the actuator chambers to the digital pump

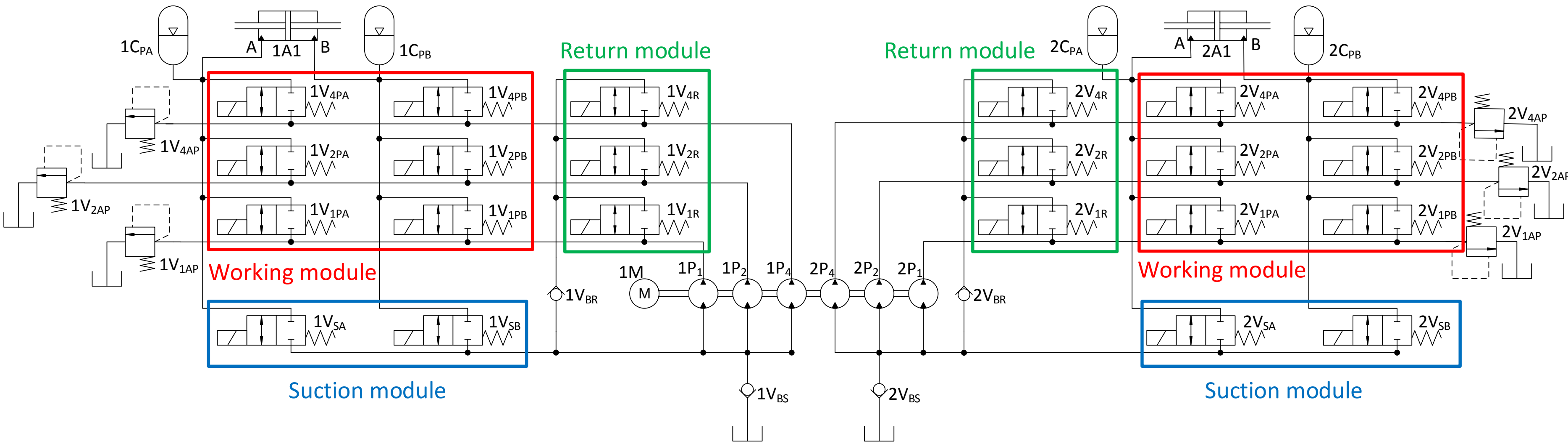
Return module

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

A preliminary discussion and results, using one symmetrical cylinder, were presented in FPNI PH.D Symposium 2014, Finland (Locateli et al., 2014)

Proposal of a Digital Hydraulic System

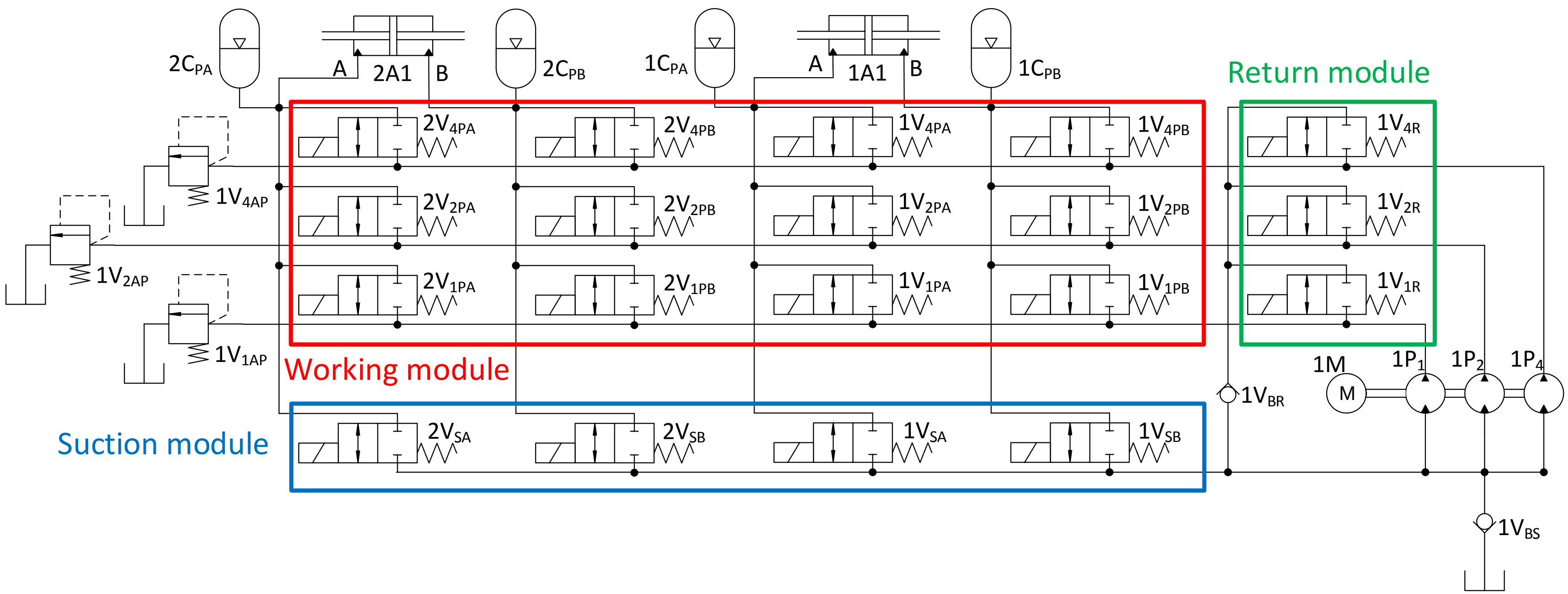
Two actuators not sharing the same FDUs



- **Independent FDU** for each actuator;
- **Larger** number of components;
- The actuators can be used **simultaneously**;
- Capacity to **reuse energy** when moving load applied on the direction of the movement

Proposal of a Digital Hydraulic System

Two actuators sharing the same FDUs



- Actuators **must not use** the same FDU at the same time;
- **Lower** number of components;
- **Reduction in the availability** of speed levels for the actuators;
- Capacity to **reuse energy** when moving load applied on the direction of the movement

Proposal of a Digital Hydraulic System

FDU – Operating modes

Pump mode

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

→ **Applied force direction**

← **Actuator movement direction**

Motor mode

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

→ **Applied force direction**

→ **Actuator movement direction**

Idle mode

When the FDU is in idle condition

Control Method

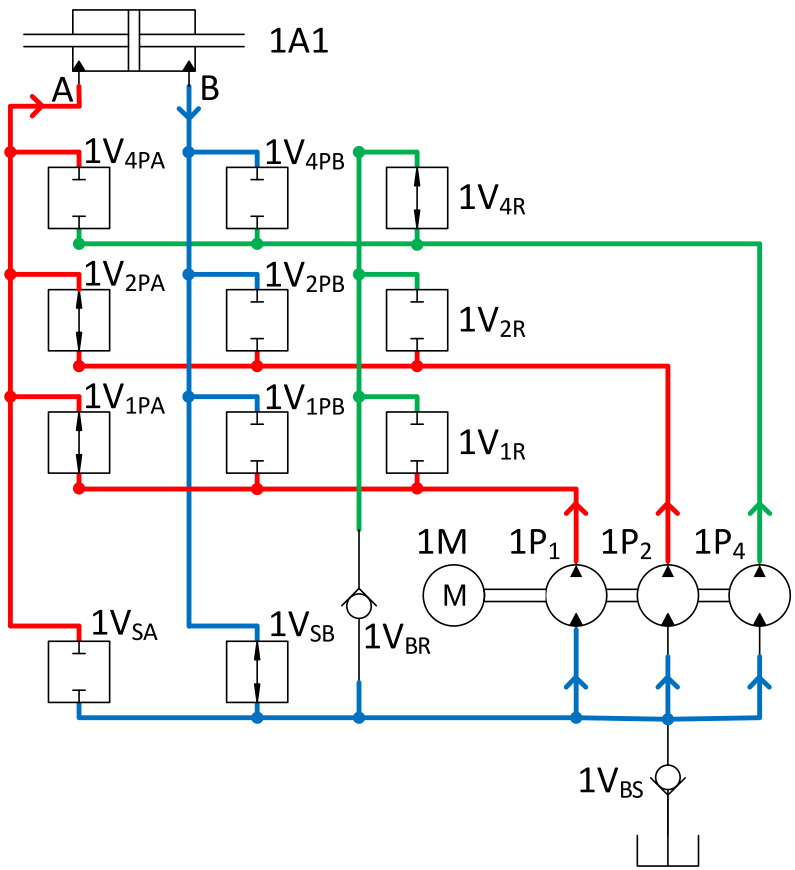
- The actuator speed is function of which **on/off valves are active**, **prime mover speed** and **system loads;**

- **Seven different speeds**;

- The **size** of digital pump units are defined by **mathematical sequence** of power of two (1, 2 and 4).

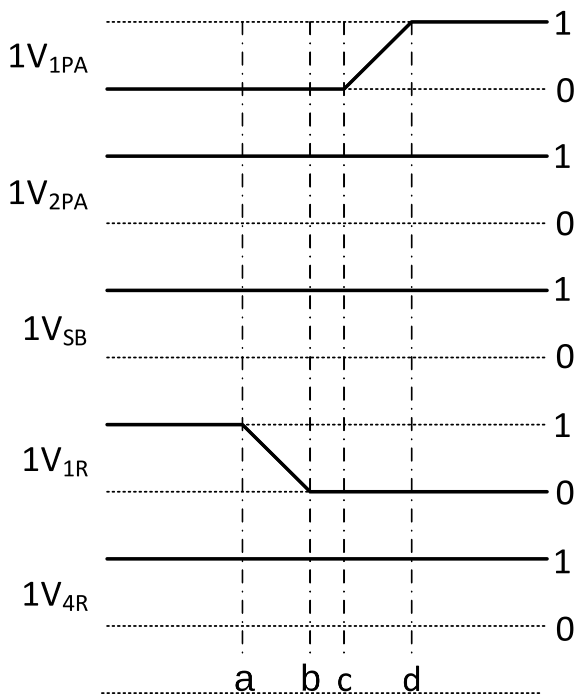
Example: Third actuator speed level.

- **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;**
- The valve opening time is **40 ms.**



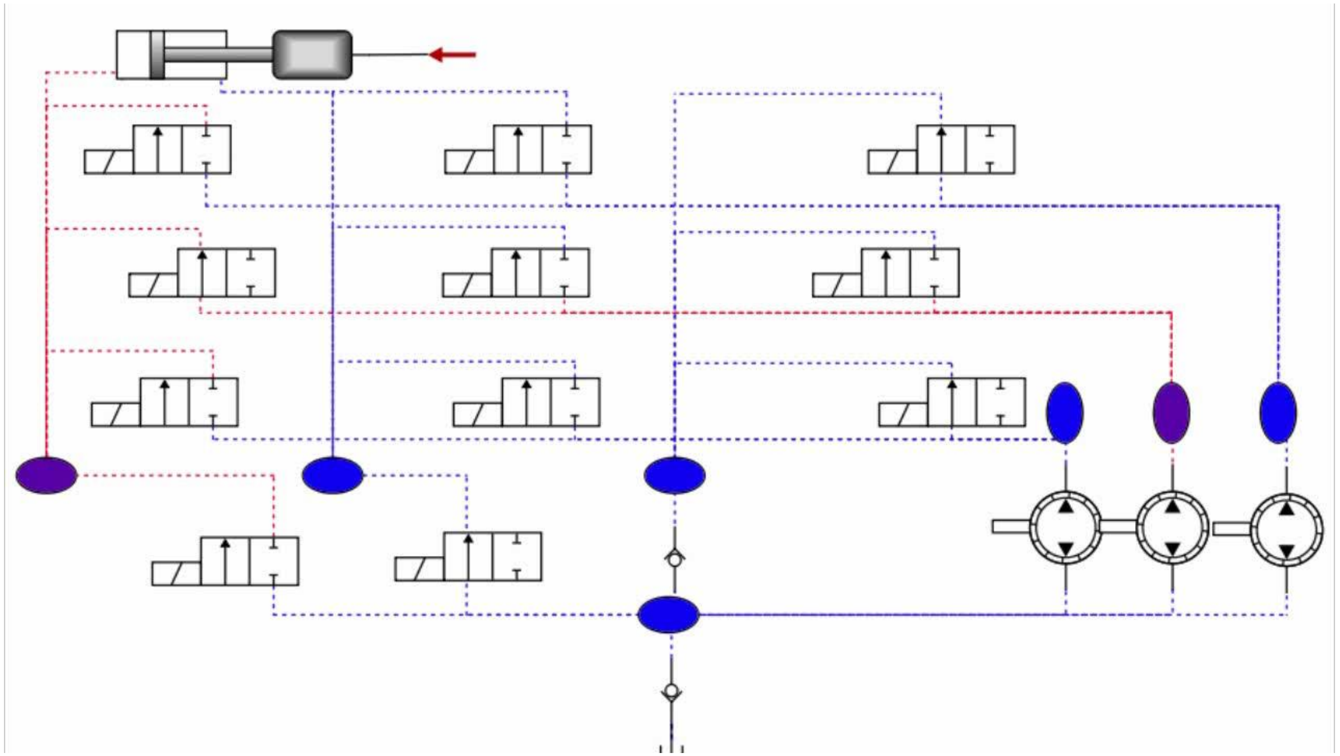
Example: Diagram related to speed changing between the **second and third levels**.

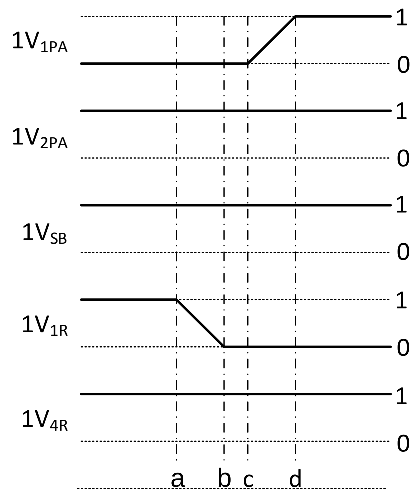
- A control signal is initially sent to close the $\mathbf{1V_{1R}}$ valve of the return module;
- After a specific delay time, a control signal is sent to open the $\mathbf{1V_{1PA}}$ valve of the working module;
- During this process, the $1V_{2PA}$, $1V_{SB}$ and $1V_{4R}$ valves remain activated.

Operating example

Symmetric actuator

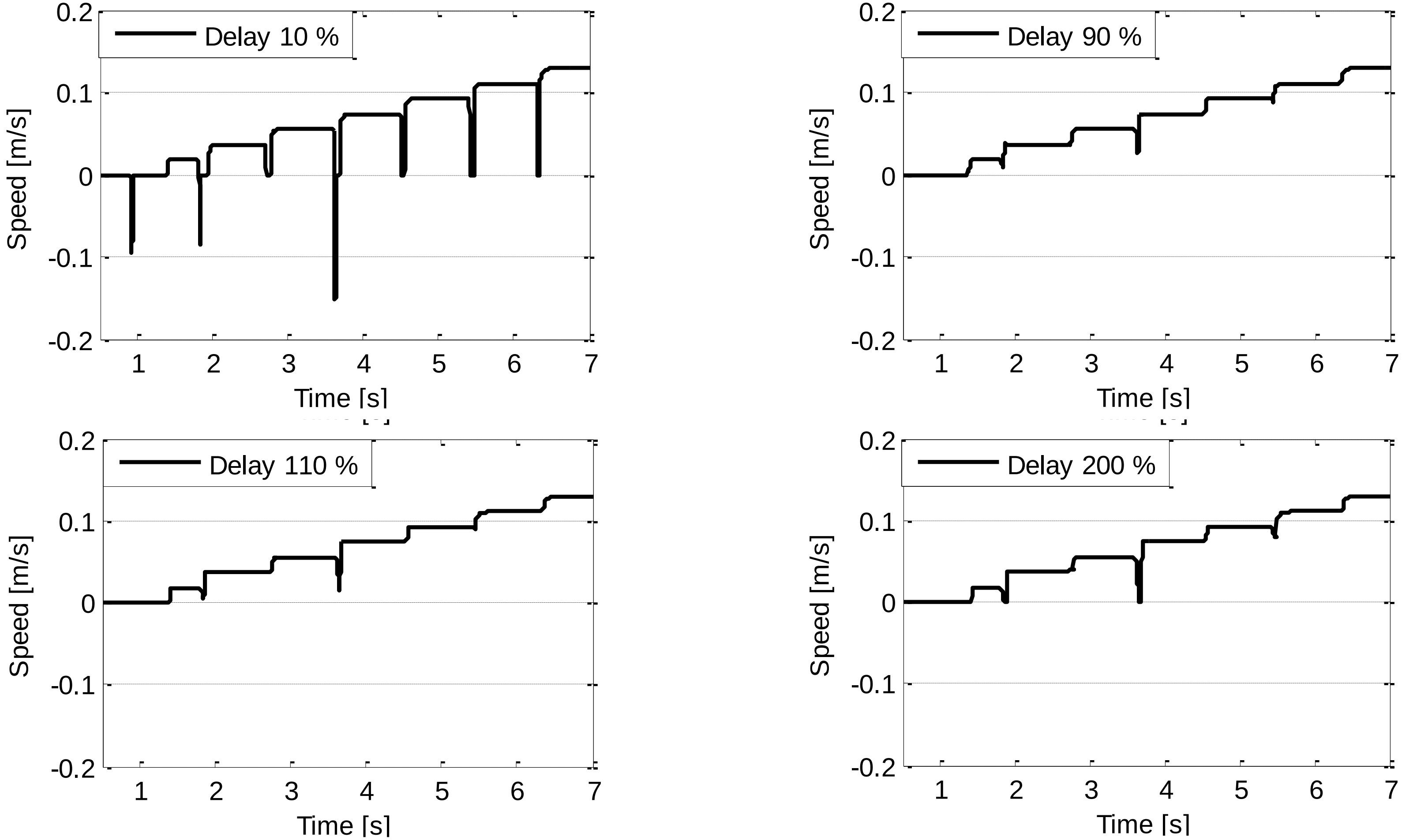
Transition between the **second** and **third** speed levels (slow motion).





Results

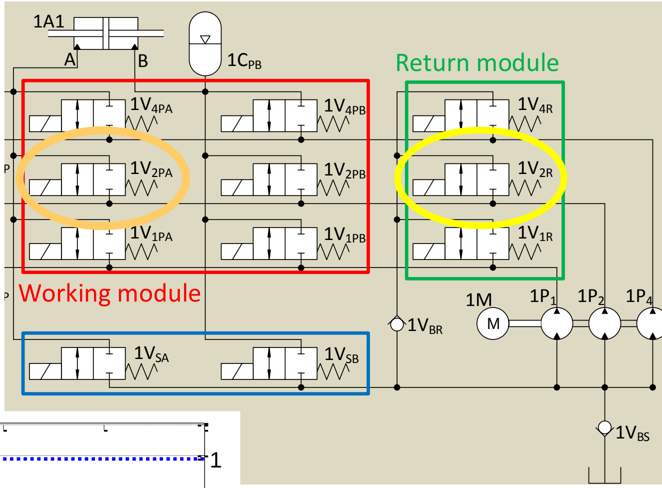
Delay times in the digital hydraulic system



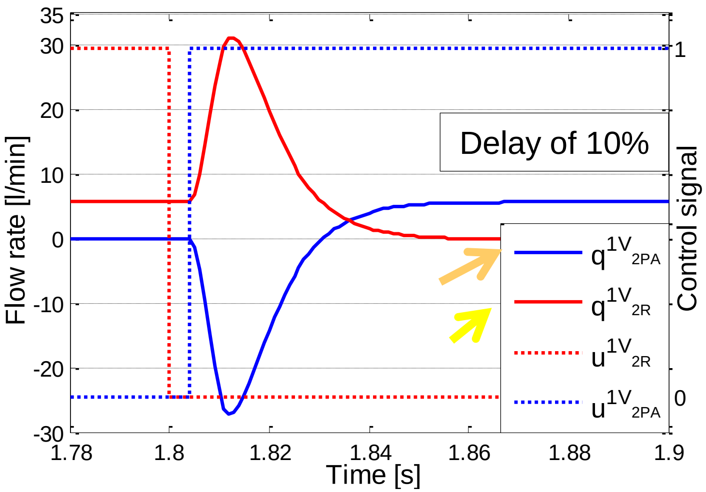
Actuator speed for four different delay times of the valve input signal

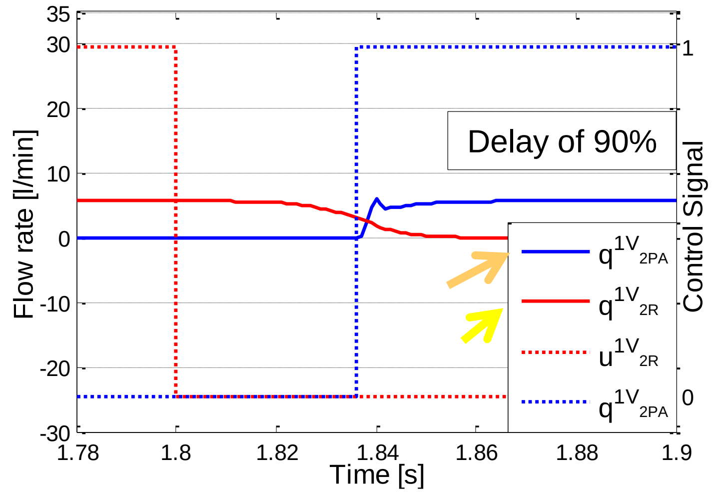
Results

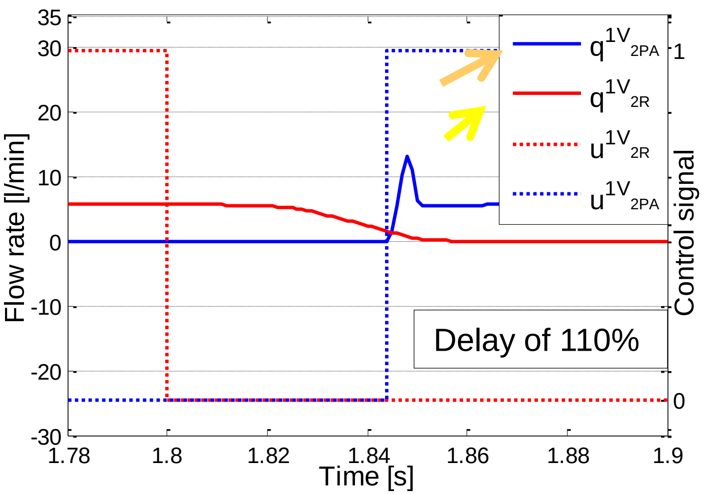
Delay times in the digital hydraulic system

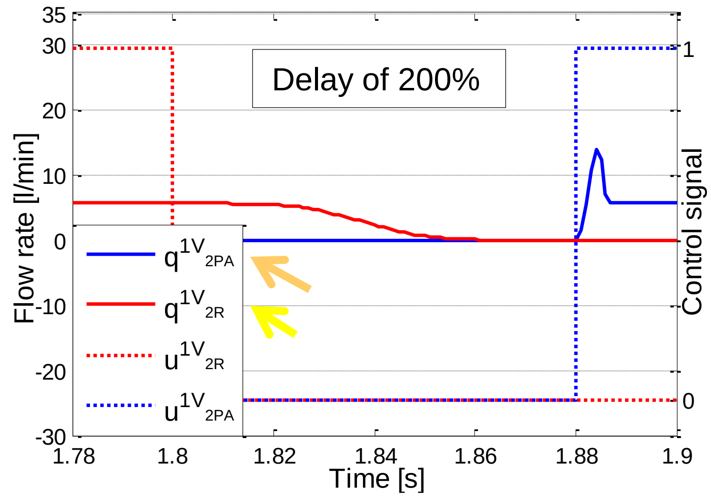


Flow and control signal on the $1V_{2PA}$ valve





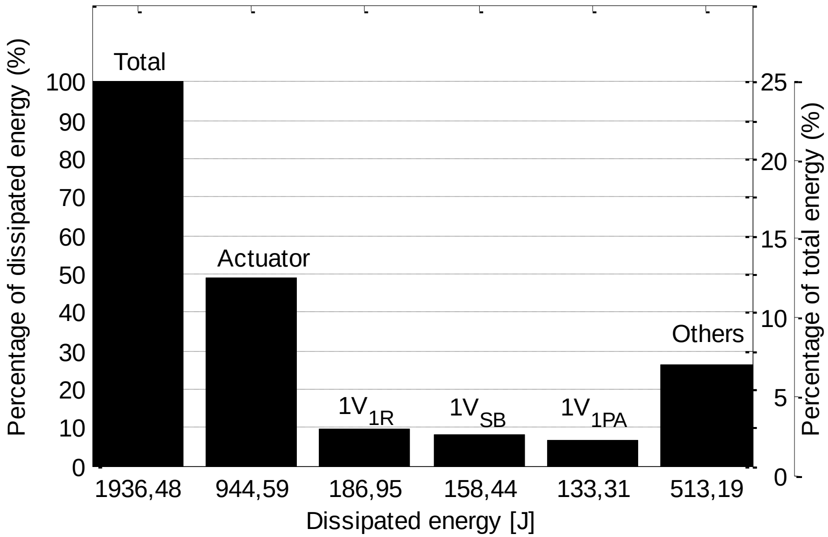




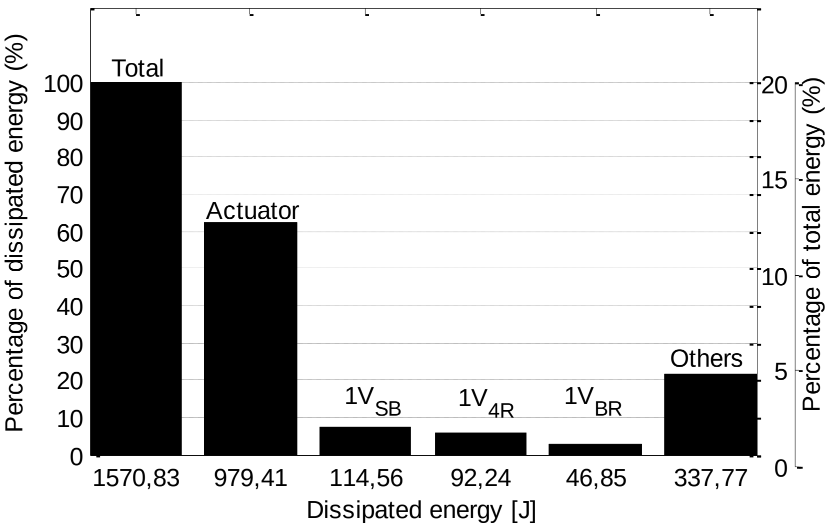
Preliminary Results

Energy dissipation

Energy dissipation with a delay of 10%.



Energy dissipation with a delay of 90 %.



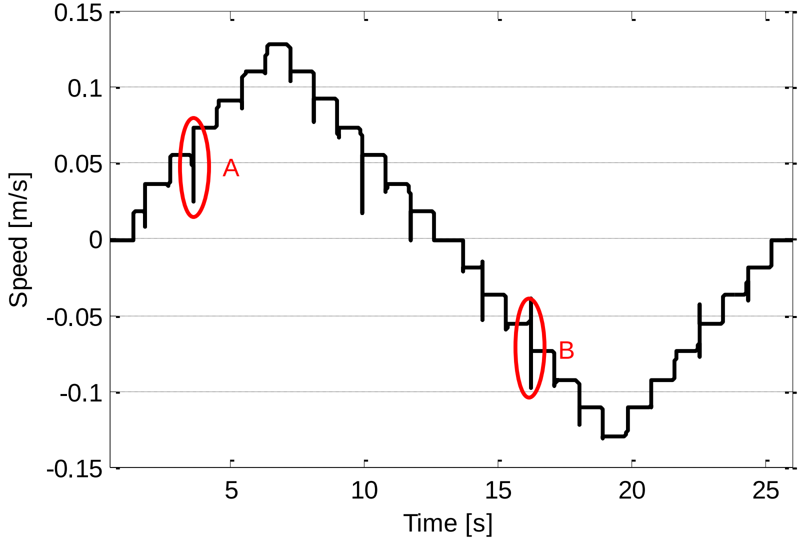
- **The total energy dissipated** is nearly **25%** of the **total energy used** by the system.
- The main dissipation occurs in the $1V_{1R}$, $1V_{SB}$ and $1V_{1PA}$ valves

- **The total energy dissipated** is nearly **20%** of the **total energy used** by the system.
- The main valve dissipations occur on the $1V_{SB}$, $1V_{4R}$, and $1V_{BR}$

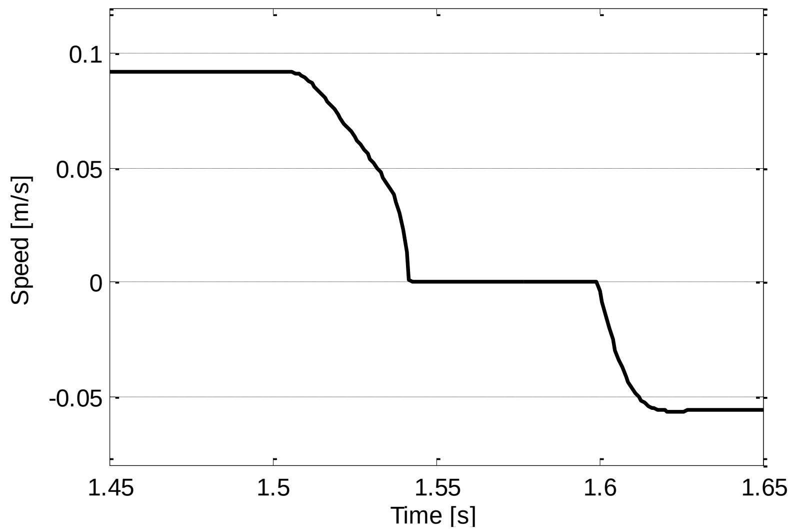
Preliminary Results

Speed control in an open loop

Speed response of the symmetrical actuator for step inputs



Actuator speed from fifth level on advance movement to third level on retreat



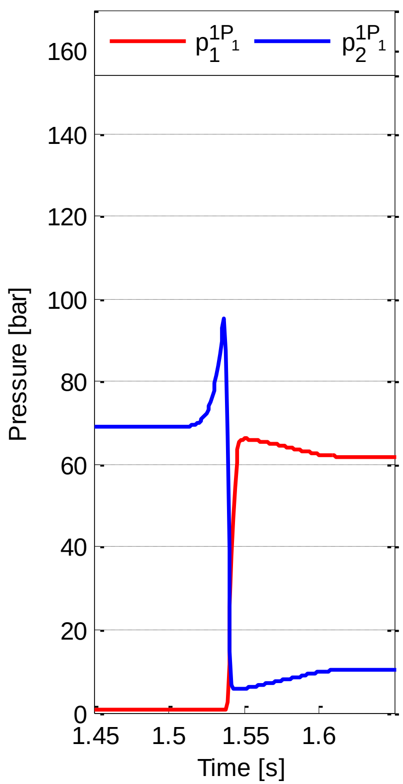
- The higher speed oscillations, both in advance and return movements, take place between **the third and fourth levels**.

- The **accumulator** smooths the changes in the actuator speed, despite of causing a **delay** in the response.
- Short time interval of **150 ms**.

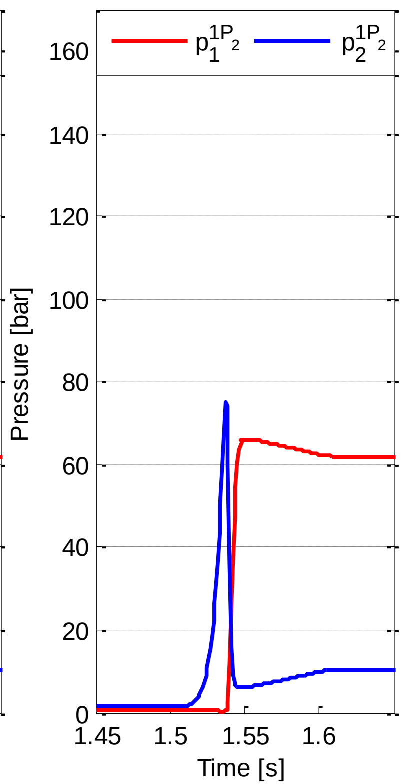
Preliminary Results

Speed control in an open loop

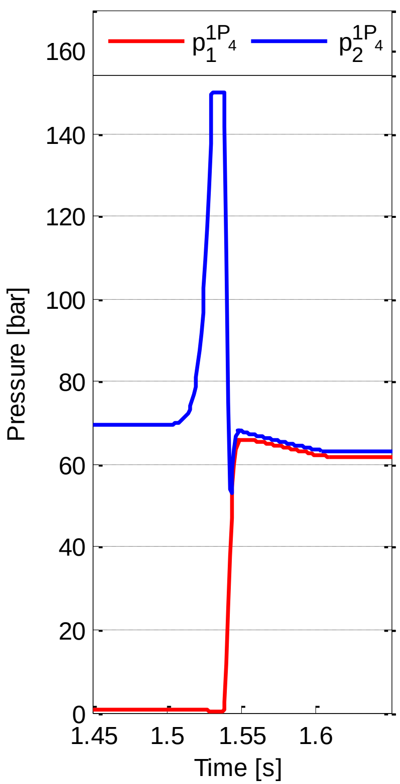
Pressures in the fixed displacement units for a variation of actuator speed from the fifth level of advance to the third level of retreat



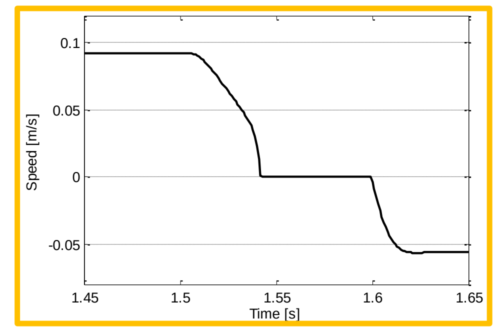
FDU 1 ($1P_1$)
From pump mode
to motor mode



FDU 2 ($1P_2$)
From idle mode
to motor mode



FDU 4 ($1P_4$)
From pump mode
To idle mode



Proposal of an energy management device

Fluida och Mekatroniska System FluMeS Fluid and Mechatronic Systems

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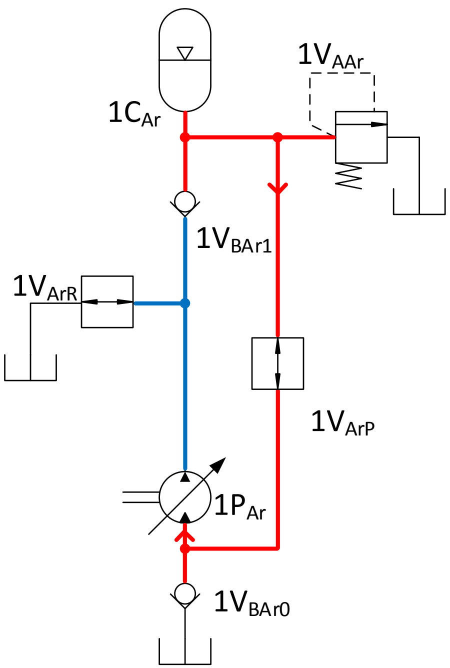
Operational modes

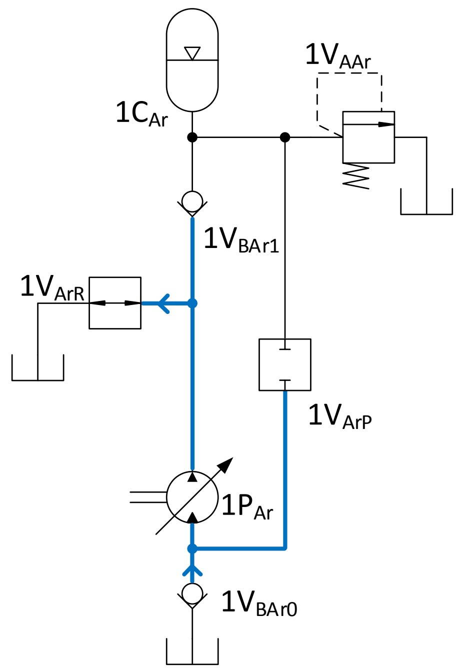
Red line indicates **high pressure**
Blue line indicates **low pressure**
Arrows show the **flow direction**



Motor mode

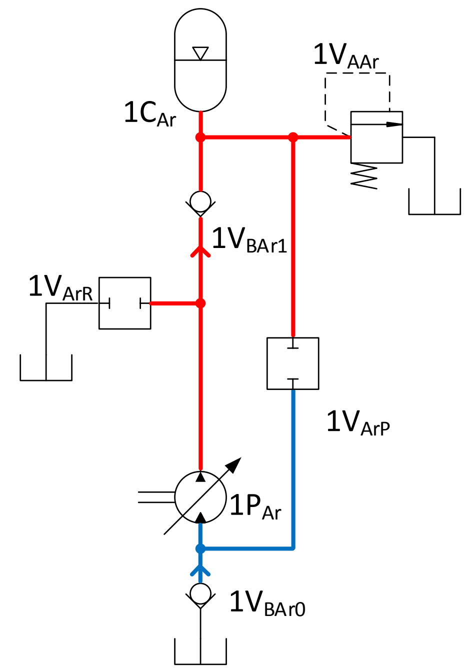
- Tends to **reduce** the energy consumed by the prime mover;

- It can be used when the DHS operates in pump mode.



Idle mode

- It can be used when the DHS operates in pump mode or idle mode.



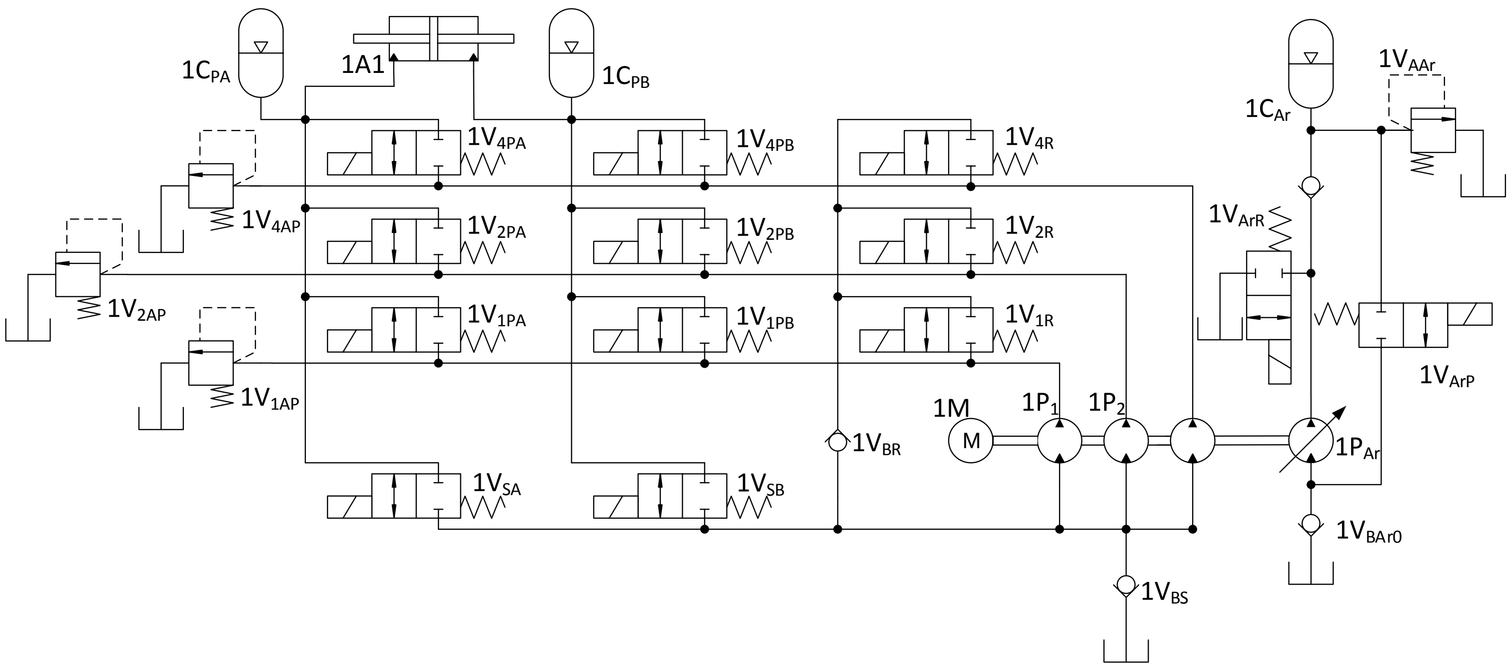
Pump mode

- It is able to **store energy;**

- It can be used when the DHS operates in motor mode.

Proposal of an energy management device

Digital hydraulic system with an energy management device



- The **control action** acts on the variation of the volumetric displacement of the VDU and on the states of the $1V_{ArR}$ and $1V_{ArP}$ valves.

- **Challenge**: Achieving an effective energy management is related to the control strategy.

Advantages, Disadvantages, and Challenges of the proposed digital hydraulic system

- The hydraulic system losses, due to **flow throttling**, are **reduced** and, thus, the **efficiency is increased** due to the replacement of the continuous directional control valve sor flow control valves by **on/off valves**;

- **Possibility to reuse or store** the energy when any FDU operates in motor mode due to the use of a closed circuit;

- The use of on/off valves in the hydraulic system guarantees a **smaller contaminant influence and greater robustness**. However, the use of a large number of valves can present problems related to the **system physical size and synchronization.**

Conclusions

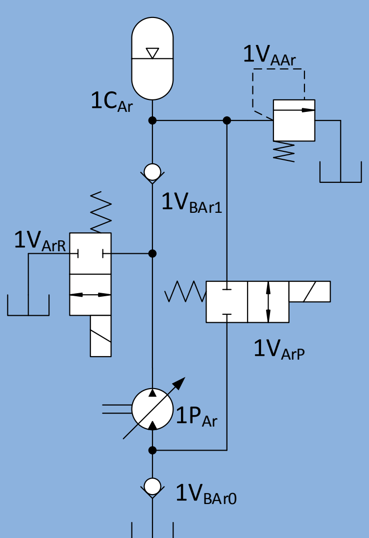
- This paper has discussed a concept of a hydraulic system that aims **to increase energy efficiency** using **hybrid hydraulic principles**;

- Preliminary results show the importance of a **apropriated control strategy** for the opening and closing the on/off valves. A suitable choice enables **low actuator speed oscillations** and **low energy dissipation**;

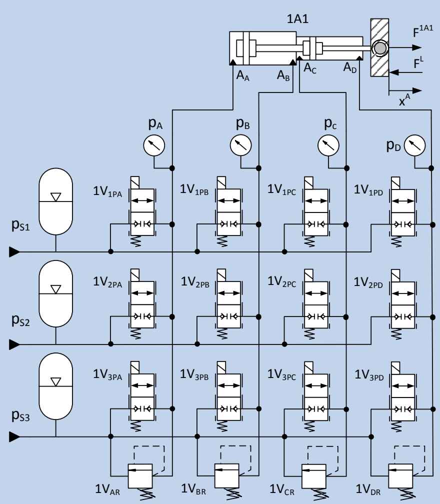
- The **energy management device** enables to store energy in the motor mode **reducing the spend energy** by the prime motor when the digital hydraulic system operates in pump mode.

Ongoing activities by the research groups:

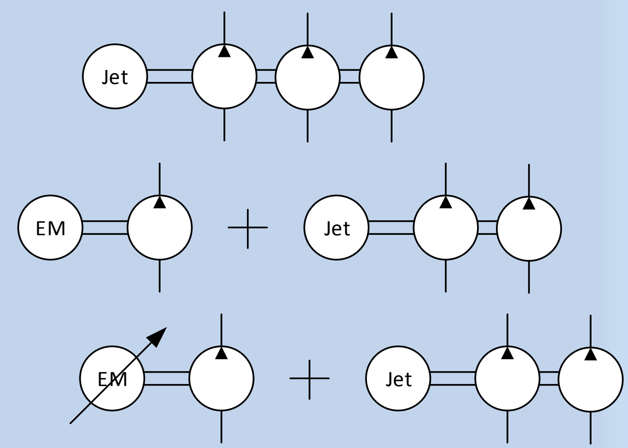
Energy management device



Digital Actuator



Digital Pump



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