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, Sweden
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;
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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.
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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
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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 $1V_{1R}$ valve of the **return module**;
- After a specific delay time, a control signal is sent to open the $1V_{1PA}$ 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.
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 were reduced 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 oscillations 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?

Cristiano C. Locatelli
cristiano@laship.com.br