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SAAB Technologies

New Perspectives on Digital Hydraulics for Aerospace Applications

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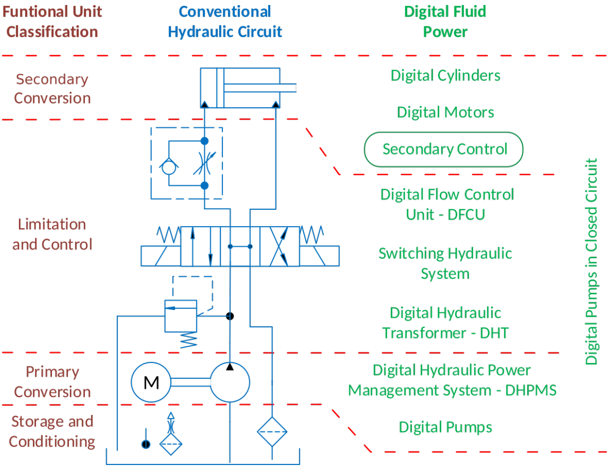
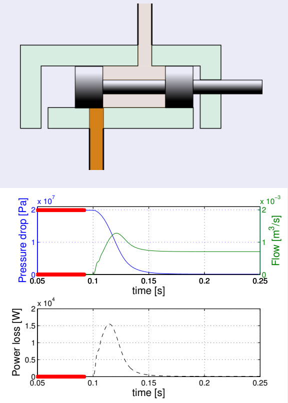
Outline

Hydraulic functional units

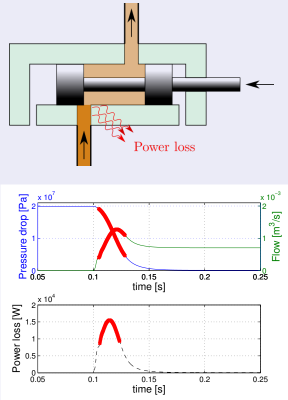


Power loss

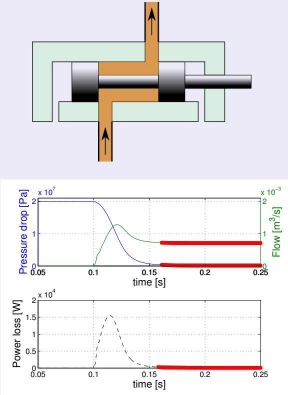
Valve closed



Valve half open



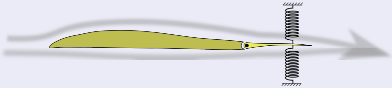
Valve open



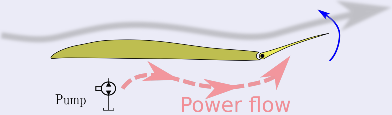
$$\text{Power} = \Delta p \times Q \qquad \text{Energy} = \int_{t_0}^{t_1} (\text{Power})\,dt$$

Energy aspects in aircraft's control surfaces

Reaction force as a spring

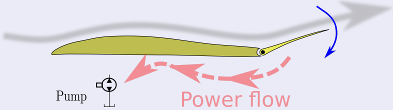


Power flow



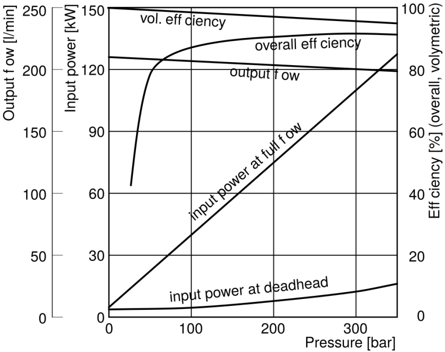
- Control surface moves away from its neutral position: energy is transfered to the control surface

- Control surface moves back to its neutral position: energy is transfered back to the system



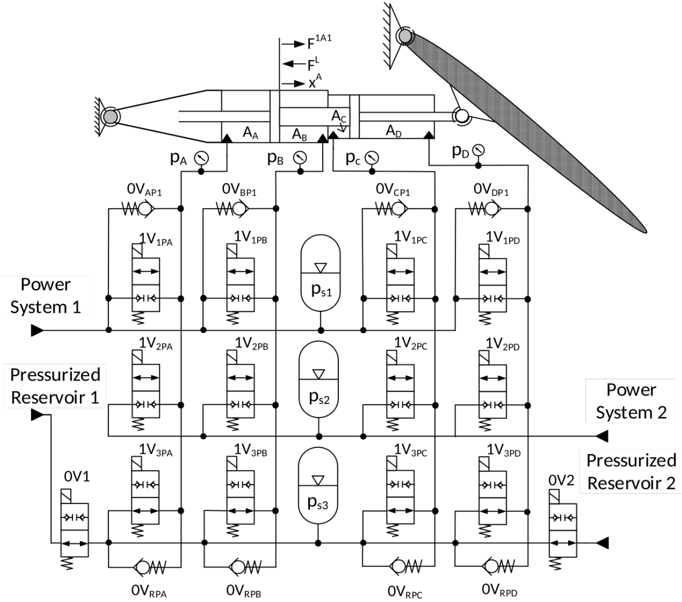
Primary convertion

- For a general military aircraft
  - 2 hydraulic circuits powered by variable displacement pumps;
  - 1 fixed displacement pump driven by Auxiliary Power Unit for safety and uses without the engine;
  - 1 fixed displacement pump driven by thermal battery used as emergency pump.
- In a steady state flight, there is low flow in the hydraulic system;
- Previous research shows that using one of the backup pumps can save up to 20% of the energy with few modifications in the hydraulic circuit.



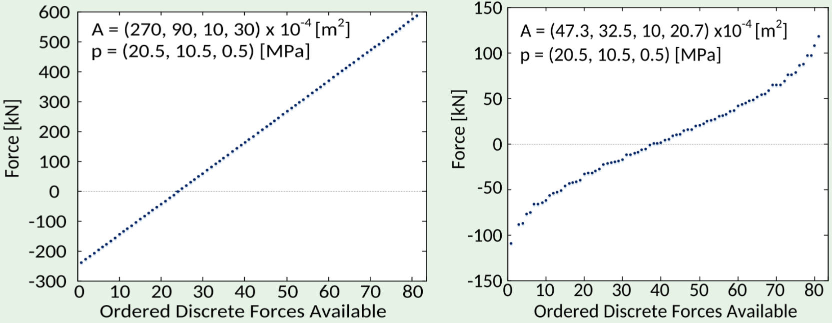
Parker Catalogue HY30-3245/UK

Secondary convertion and control



Secondary Convertion and Control

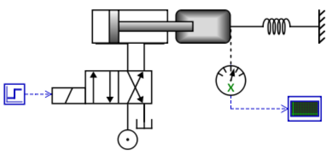
How to design pressures and cylinder areas?



Forces in digital hydraulics is a discrete set!

- N^M possible forces
  - N is the number of pressures
  - M is the number of areas

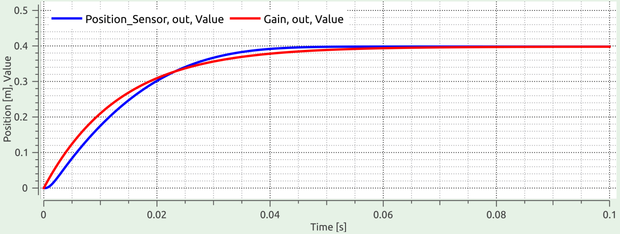
A control strategy – nonlinearity in hydraulics



$$\ddot{x} = -\frac{k}{m}x - \frac{b}{m}\dot{x} + \frac{1}{m}\left(A_A p_A - A_B p_B\right)$$

$$\dot{p}_A = \frac{\beta}{V_{A0} + A_A x}\left(C_d \cdot A \cdot sgn(p_s - p_A) \cdot \sqrt{\frac{2}{\rho}|p_s - p_A|} - A_A \dot{x}\right)$$

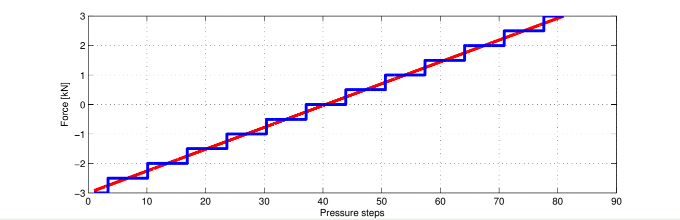
$$\dot{p}_B = \frac{\beta}{V_{B0} + A_B (L - x)}\left(C_d \cdot A \cdot sgn(p_t - p_B) \cdot \sqrt{\frac{2}{\rho}|p_t - p_B|} + A_B \dot{x}\right)$$



$$\ddot{x} = -kx - b\dot{x} + A_A p_S(t - d) - A_B p_t(t - d) \qquad \text{(for 2 chamebrs)}$$

A control strategy – quantization

Dicrete / continuous set



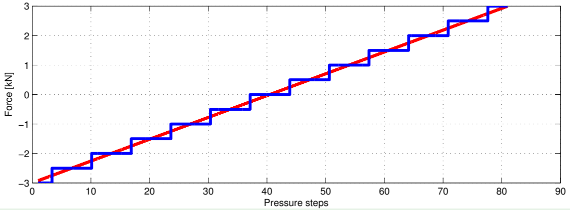
Overcome discretization error

$$\ddot{x} = -\frac{k}{m}x - \frac{b}{m}\dot{x} + \frac{1}{m}u(t-d)$$

where $u(t) = A_A p_A - A_B p_B + A_C p_C - A_D p_D$ (for 4 chambers)

A control strategy – quantization

Dicrete / continuous set



Overcome discretization error

$$\ddot{x} = -\frac{k}{m}x - \frac{b}{m}\dot{x} + \frac{1}{m}q(u(t-d))$$

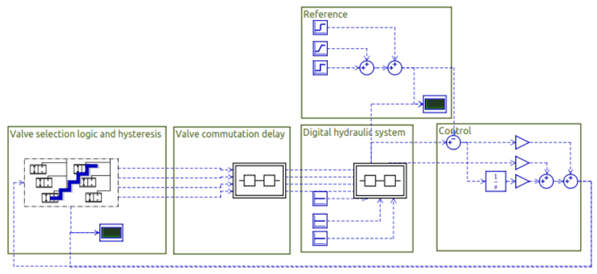
where $u(t) = A_A p_A - A_B p_B + A_C p_C - A_D p_D$ (for 4 chambers)

$q(\cdot)$ is a quantization function

Define $w(t-d)$ as the quantization error: $w(t-d) = q(u(t-d)) - u(t-d)$

Numeric example

Hopsan Model

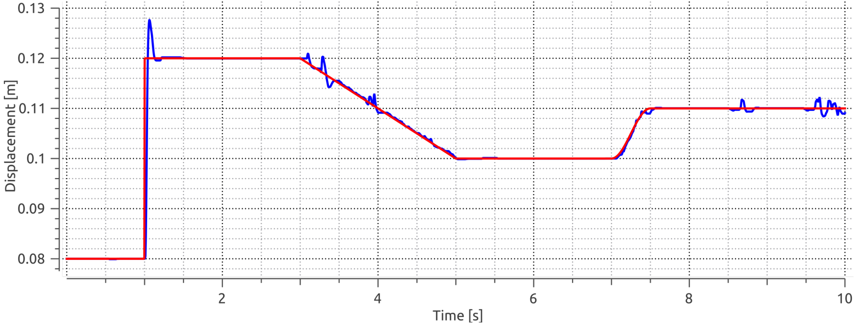


$$\dot{x}(t) = Ax(t) + Bu(t-d) + Bw(t-d)$$

where $A = \begin{bmatrix} 0 & 1 & 0 \\ \frac{-k}{m} & \frac{-b}{m} & 0 \\ 1 & 0 & 0 \end{bmatrix}$ and $B = \begin{bmatrix} 0 \\ \frac{1}{m} \\ 0 \end{bmatrix}$

Solution based on [Emilia Fridman, Michel Dambrine "Control under quantization, saturation and delay: An LMI approach"]

Simulation results – Tracking



The simulation also includes:

- Valves dynamics and cylinder modeling;
- External disturbances;
- Viscous, static and kinematic fiction.

Advantages, Future work and Conclusions

- Advantages:
  - Increase efficiency as large as 80% in control (Belan, et al., 2016);
  - Enable energy recovering from one pressure line to another;
  - Is intrinsically redundant.
- Future work:
  - Faster valves increase energy efficiency and enable better control;
  - Better theory and strategies on switched control;
  - Safety analysis for redundancy and fault monitoring (diagnostics). Then the full impact on weight and energy savings can be analysed;
- Conclusions:
  - Control and design is more complex. Lower cost processors allow also complex control, diagnostic, reconfiguration and adaptation.

Proportional valve is the rheostat of power electronics, as digital hydraulics is the nowadays power converters.

Thank you

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