ELECTRO HYDROSTATIC ACTUATORS

A NEW APPROACH IN MOTION CONTROL

2nd Workshop on Innovative Engineering for Fluid Power
Sep 2-3 2014
Agenda

• Introduction - MOOG

• Actuation Technologies

• Electro Hydrostatic Actuators

• Applications
FOCUS IN HIGH PERFORMANCE MOTION CONTROL

Established in 1951, by Bill Moog

HIGH PERFORMANCE MOTION CONTROL SOLUTIONS FOR INDUSTRIAL, MILITARY AND AEROSPACE APPLICATIONS.

Sales (2013) = US$ 2.6 Billion

11,600 employees
MOOG do Brasil Controles Ltda

Rua Prof Campos Oliveira, 338
Rua Agostinho Togneri, 457        Sto Amaro, São Paulo    Phone (11) 3572-0400
<table>
<thead>
<tr>
<th>GROUPS</th>
<th>Aircraft Group</th>
<th>Industrial Group</th>
<th>Space and Defense Group</th>
<th>Components Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>primary and secondary flight control, engine controls</td>
<td>high performance motion control for industrial applications, test (aerospace and</td>
<td>missiles and launchers trajectory control, antenas and solar panels positioning, satelites</td>
<td>Slip rings, small motors, rotating joints, fiber optics interfaces, air cooling</td>
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<tr>
<td></td>
<td></td>
<td>automotive), simulation</td>
<td>atitude control</td>
<td>solutions</td>
</tr>
</tbody>
</table>

![Airplane](image1.png)

![Wind Turbine](image2.png)

![High Performance Motion Control](image3.png)

![Schmools and Launchers](image4.png)

![Components Group](image5.png)
INDUSTRIAL GROUP - PRODUCTS

Servovalves
INDUSTRIAL GROUP - MARKETS

TURBINES
- Wind
- Gas, oil, hydro

SIMULATION

TEST
- Aerospace
- Automotive

HEAVY INDUSTRY
- Steel mills

METAL FORMING
- Presses

AFTERMARKET
- Oil & Gas
- Formula 1
- Repairs
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SERVOCONTROL = closed loop motion control

**LINEAR**
- position: $x$
- velocity: $\dot{x} = \frac{dx}{dt} = v$
- acceleration: $\ddot{x} = \frac{dv}{dt} = a$
- force: $F$
- pressure: $p$

**ROTARY**
- angular position: $\theta$
- velocity: $\dot{\theta} = \frac{d\theta}{dt} = \omega$
- acceleration: $\ddot{\theta} = \frac{d\omega}{dt} = \alpha$
- torque: $T$

Position Servocontrol

- **ERROR**
- **FEEDBACK**
- **TRANSUDER**
- **SERVO AMPLIFIER**
- **POSITION SET POINT**
- **FLOW**
- **VELOCITY**
- **POSITION**

Diagram showing the control system with inputs and outputs, and the equations for linear and rotary motion control.
ACTUATION TECHNOLOGIES

Electro-hydraulic

Electro-mechanical

Electro-hydrostatic
Elements: pump, servovalve, hydraulic cylinder.

*Power is transmitted by the fluid*  \[ P = Q \cdot p = (\text{flow} \times \text{pressure}) \]
ACTUATION TECHNOLOGIES
ELECTRO-MECHANICAL

Elements: servomotor, gearbox, ball/roller screw

Power is transmitted by the mechanics \( P = T \cdot \omega = (\text{torque} \times \text{rotation}) \)
Elements: servomotor, pump, hydraulic cylinder.

Power is transmitted by the mechanics \( P = T \cdot \omega = \) (torque \times rotation) and by the fluid \( P = Q \cdot p = \) (flow \times pressure)
# ACTUATION TECHNOLOGIES

## Comparison

<table>
<thead>
<tr>
<th>Electro-Hydraulic - EH</th>
<th>Electro-Mechanical - EMA</th>
<th>Electro-Hydrostatic - EHA</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ High robustness and reliability</td>
<td>+ High energy efficiency</td>
<td>+ Good energy efficiency</td>
</tr>
<tr>
<td>+ Ideal for high &amp; static forces</td>
<td>+ Powered by wire (no HPU)</td>
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<tr>
<td>+ Fail-safe options</td>
<td>+ Easy installation and commissioning</td>
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</tr>
<tr>
<td>+ Easy redundancy (2+ actuators)</td>
<td>+ Environmental cleanliness</td>
<td>+ High robustness and reliability</td>
</tr>
<tr>
<td>+ No backlash</td>
<td>+ Well suited for rotary actuation</td>
<td>+ Fail-safe options</td>
</tr>
<tr>
<td>+ Easy maintenance</td>
<td>+ High stiffness</td>
<td>+ Easy redundancy (2+ actuators)</td>
</tr>
<tr>
<td>+ High frequency operation</td>
<td></td>
<td>+ No backlash</td>
</tr>
<tr>
<td>+ Compact size</td>
<td></td>
<td>+ Good for high &amp; static forces</td>
</tr>
<tr>
<td>+ Light weight</td>
<td></td>
<td>+ Unlimited hydraulic gearbox ratio</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Low energy efficiency</td>
<td>- Heavy weight</td>
<td>- Weight</td>
</tr>
<tr>
<td>- Requires HPU* &amp; piping</td>
<td>- No fail safe (gearbox can block)</td>
<td>- Higher cost</td>
</tr>
<tr>
<td>- Environment contamination</td>
<td>- No redundancy (single actuator)</td>
<td>- Complexity</td>
</tr>
<tr>
<td></td>
<td>- High power consumption to hold static load</td>
<td>- Electrical noise</td>
</tr>
<tr>
<td></td>
<td>- Backlash</td>
<td>- Limited stiffness</td>
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<tr>
<td></td>
<td>- High maintenance effort ($)</td>
<td>- Power consumption to hold static load</td>
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<td>- Electrical noise</td>
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*HPU: hydraulic power unit = motor + pump + filtering + cooling
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EHA - AN OLD CONCEPT

Hydrostatic transmissions have been used in a wide range of mobile applications

Same principles can be applied to get a “Basic EHA”
+ No need for a “separated” HPU
+ Self contained hydraulic system
- Low frequency response
- Requires auxiliary devices (cooling, filtration, anti-cavitation)
EHA - DEVELOPMENTS

1) Replacing the variable pump by a fixed pump + servo motor
   • Gear Pump: lower cost, loss of performance
   • Piston Pumps: higher cost, better efficiency

2) Adding filtering, small accumulator (to keep system pressurized) and anti-cavitation check valves.
EHA – OPERATION

Balanced Cylinder

- Fixed pump
- Servomotor
- Anti-cavitation valves
- Small accumulator
3) Dealing with unbalanced cylinders
   Requires:
   • large accumulator: to hold the differential oil volume
   • pilot operated anti-cavitation check valves: to assure the pressurization of the pump port to avoid cavitation
EHA – OPERATION

Unbalanced Cylinder

extend

fixed pump

servomotor

anti-cavitation valves
(one is pilot operated)

large accumulator

retract
EHA – Dealing with unbalanced cylinders

- 3 ports pump, for unbalanced flow control
EHA – CONTROL ARCHITECTURE

Position Transducer

Position Feedback

Hydraulic Cylinder

Bidirectional pump

Servomotor

Position Command
EHA – CONTROL ARCHITECTURE

MACHINE <-> EHA

Machine Cabinet
- PLC

Axis Cabinet
- Motion Control
- Frequency Converter

Actuator
- Power Conversion:
  - Electrical V-I → Mechanical T-ω → Hydraulic p-Q → Mechanical F-v
EHA – CONTROL ARCHITECTURE

DYNAMIC BEHAVIOR

Large, low speed, high torque pump

Small, high speed, low torque pump
EHA – SAFETY based on spring

Normal Operation

Fail Safe Movement

extend
EHA – SAFETY based on accumulator

Normal Operation - extend

Normal Operation - retract
EHA – SAFETY based on accumulator

Fail Safe Movement - extend

 Accumulator Recharge
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APPLICATIONS

EHA applications

• Injection molding machines
• Metal Forming & Presses
• Flight Control
• Wind turbines pitch control
APPLICATION
INJECTION MOLDING AND DIE CASTING MACHINES
Clamp Unit & Ejector
APPLICATION
METAL FORMING & PRESSES

CUSHION CONTROL - velocity and pressure control
APPLICATION

LOCKHEED MARTIN F-35 PRIMARY & SECONDARY FLIGHT CONTROLS
APPLICATION - FLIGH CONTROL

Features
• Manageable failure modes
• Flexible packaging
• Multiple electrical channels possible
• High power consumption to hold load

• Overload relief
• Multiple failure modes:
  ✓ Normal servocontrolled operation
  ✓ Bypass (to allow other actuators to operate control surface)
  ✓ Damped
  ✓ Blocked
  ✓ Damped - Blocked
APPLICATION – FLIGHT CONTROL - REDUNDANCY

Bypass

Active

Bypass

Blocked

(or dampered)
APPLICATION – FLIGHT CONTROL - REDUNDANCY

Active 1

Blocked

(or dampered)

Blocked

Active 2
APLICATION - BLADE PITCH CONTROL
Wind Turbine

PITCH CONTROL SYSTEM: adjusts the pitch turbine blade angle.

• 3 blades follow the same command (synchronized)
• The turbine main controller sets blade pitch angle
• The pitch control system is assembled inside the blades and rotates with the turbine.
1. STOP the turbine in case of emergencies and failures

2. MAXIMIZE energy conversion in a large wind speed range

\[
\text{Power} \approx \text{pitch angle} \cdot (\text{wind speed})^3
\]

CONFIABILITY is the main feature of a pitch control system
APLICATION - BLADE PITCH CONTROL

Wind Turbine

Blade
Hub

worker
Blade

Wind farm

Blade
Hub

workers

worker
Hub
APLICATION - BLADE PITCH CONTROL

Wind Turbine
APLICATION - BLADE PITCH CONTROL

Wind Turbine
APPLICATION - BLADE PITCH CONTROL

Wind Turbine
That’s all folks!

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HYDROSTATIC TRANSMISSION
SERVOPUMP

Swashplate position mechanical feedback
Normal Operation
EHA – SAFETY BALANCED CYLINDER

Fail-Safe Movement
**Electro-Hydrostatic Actuation**

- Power on demand, Energy efficient, Energy recovery
- Powered by wire
  - Self-contained
  - No hydraulic piping
- Additional features
  - e.g. fail safe
- Low noise
- High force capability
Electro-Hydrostatic Actuation

**Balanced EHA**

1. Hydraulic cylinder
2. Radial piston pump
3. Motor
4. Check valve
5. Low pressure reservoir

**Unbalanced EHA**

1. Hydraulic cylinder
2. Radial piston pump
3. Motor
4. Check valve
5. Low pressure reservoir

High pressure
Medium pressure
Low pressure