DIGITAL SERVOVALVES

The smart approach to electrohydraulic motion control

WIEFP 2016

OCTOBER 25-26 · FLORIANÓPOLIS - SC · BRAZIL

3rd Workshop on Innovative Engineering for Fluid Power

AGENDA

– Introduction - MOOG

– Electrohydraulic motion control

– Modern Automation

– Digital Servovalve

– Applications

Abstract

The integration of powerfull microprocessor based electronics in the servovalves is allowing new and flexible motion control architectures. Smart "automation nodes" coupled with high speed communication are revolucionizing the concept of motion control automation. In this presentation we are going to explore the history and reasons behind the digital valve development, the technology's state-of-the-art and application examples.

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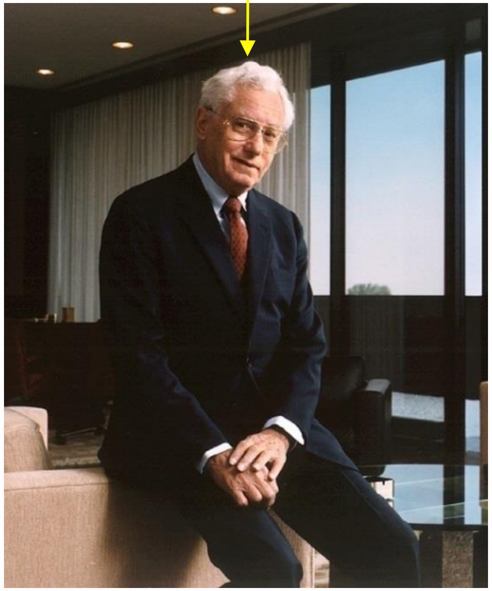
- Electrohydraulic motion control
- Modern Automation
- Digital Servovalve
- Applications

COMPANY PROFILE

- Established in 1951, by Bill Moog
- Focus in high performance motion control solutions for industrial, military and aerospace applications.
- Sales (FY16) = US$ 2,6 Billions
- 10.700 employees
- Headquarter: Buffalo, NY



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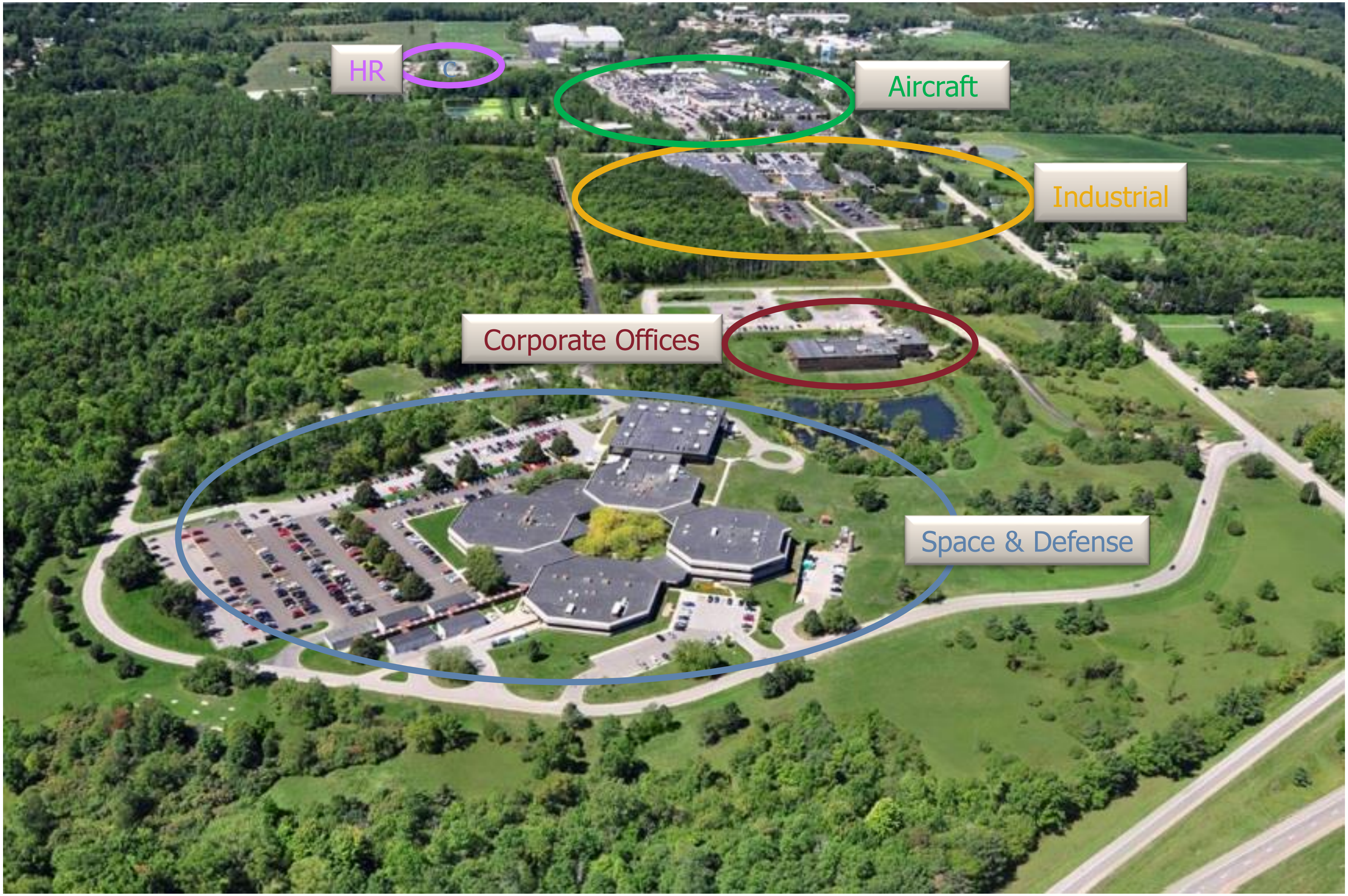
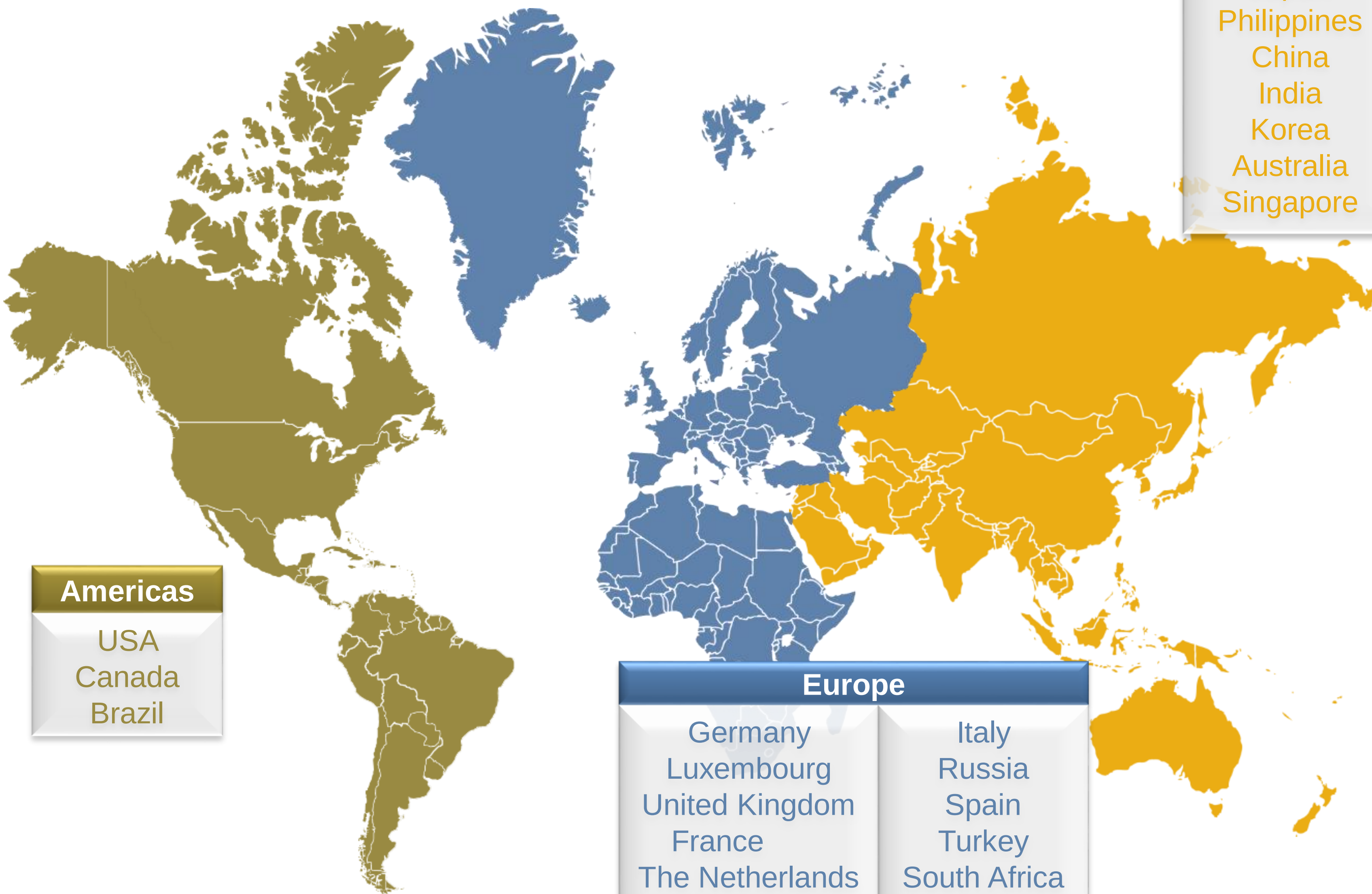
MOOG HEADQUARTERS (Buffalo-NY)



GLOBAL PRESENCE



Asia Pacific

Japan
Philippines
China
India
Korea
Australia
Singapore

Americas

USA
Canada
Brazil

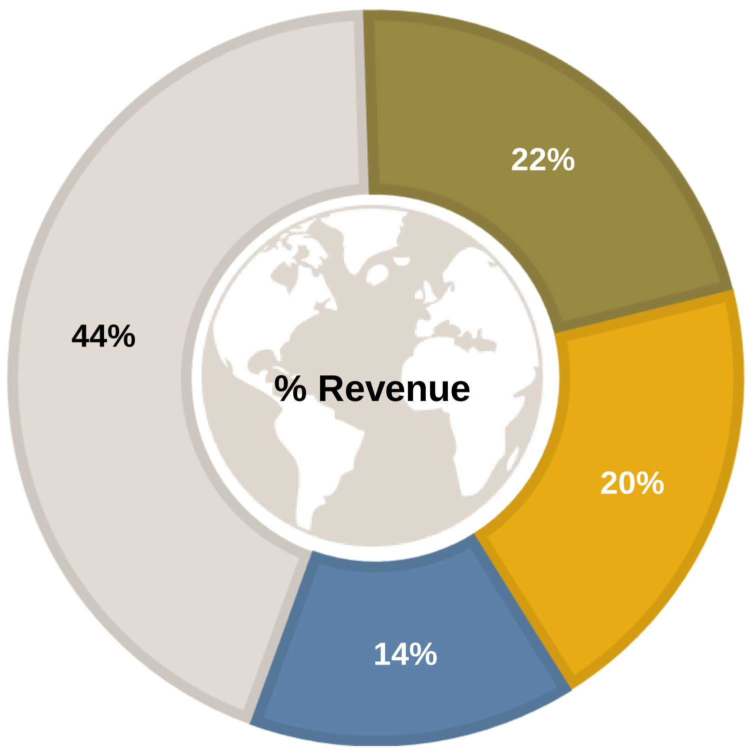
Europe

Germany	Italy
Luxembourg	Russia
United Kingdom	Spain
France	Turkey
The Netherlands	South Africa
Ireland	

4 GROUPS

MOOG INC.
US$ 2.6 BILLIONS FY16

AIRCRAFT GROUP	INDUSTRIAL GROUP	COMPONENTS GROUP	SPACE AND DEFENSE GROUP
US$ 1,2 B	US$ 591 M	US$ 545 M	US$ 395 M



4 GROUPS

Aircraft Group

primary and secondary flight controls, engine controls





Industrial Group

high performance motion control for industrial applications, test and simulation




Components Group

Slip rings, small motors & actuators, fiber optics interfaces, air cooling solutions, infusion pumps

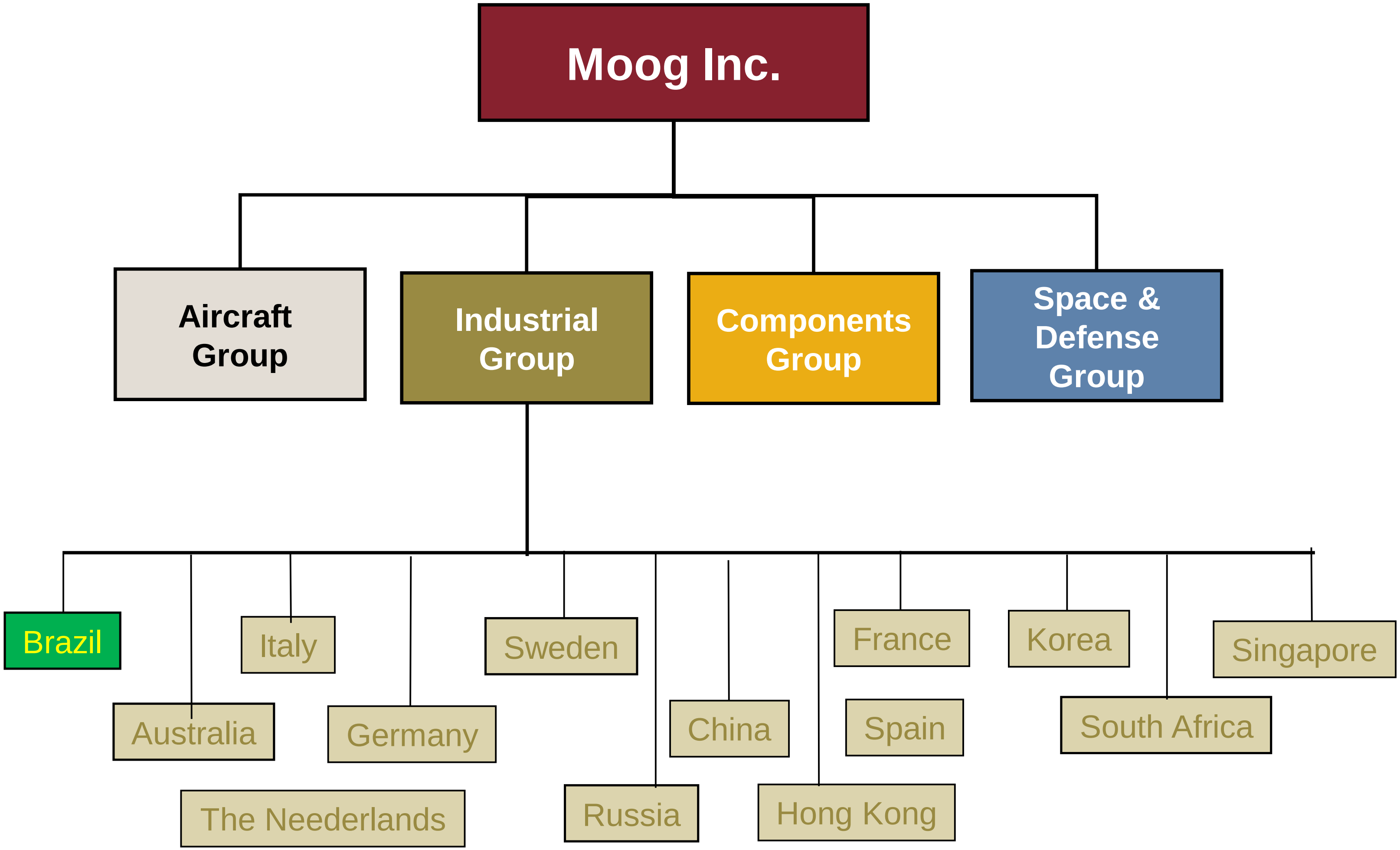


Space and Defense Group

missiles/ launchers trajectory control, antenas and solar panels positioning, satelites atitude control, infusion pumps



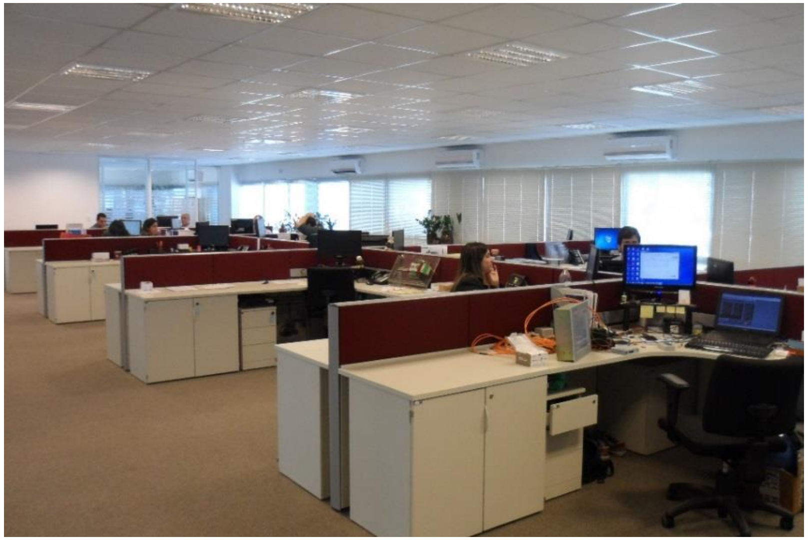
INDUSTRIAL GROUP



MOOG do Brasil Controles Ltda

Plant 1: Rua Prof Campos Oliveira, 338

Plant 2: Rua Agostinho Togneri, 457



São Paulo SP phone +55 (11) 3572-0400 www.moog.com.br

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INDUSTRIAL GROUP - PRODUCTS

INDUSTRIAL GROUP - MARKETS

ENERGY

SIMULATION

TEST

HEAVY INDUSTRY

METAL FORMING

OIL & GAS

PLASTICS

SERVICES

AGENDA

– Introduction to MOOG

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– Modern Automation

– Digital Servovalve

– Applications

SERVOCONTROL

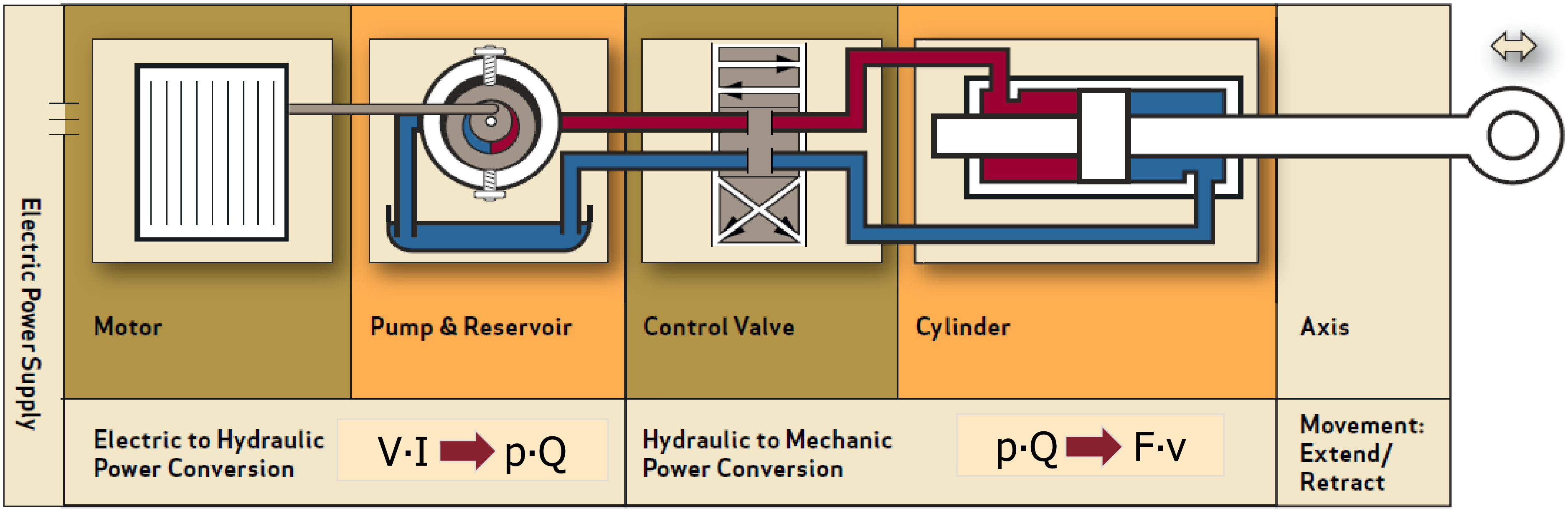
- Closed loop motion control
- Control of: position, velocity, acceleration, force, pressure

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

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

- Tecnologies: ELECTROHYDRAULIC, electromechanical, electrohydrostatic

ELECTRO-HYDRAULIC MOTION CONTROL

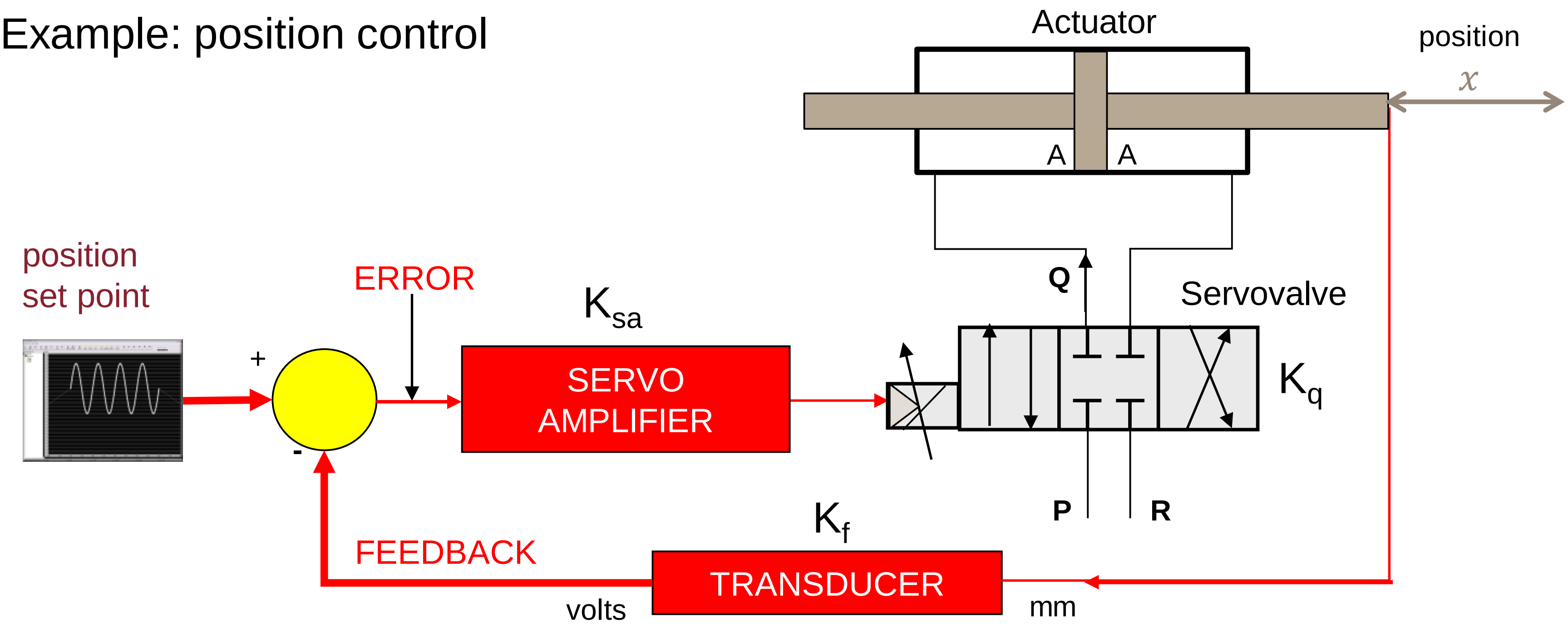


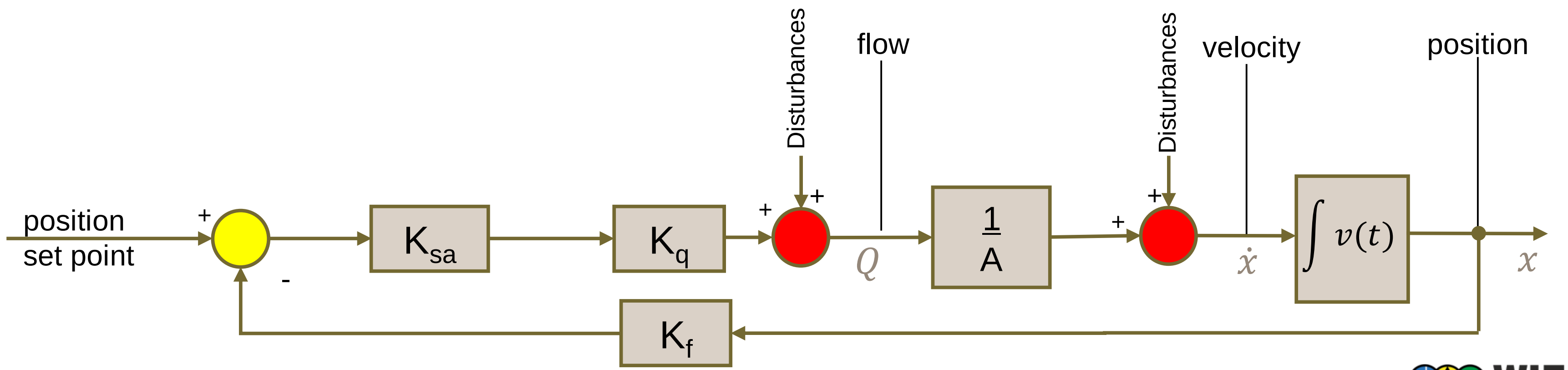
Elements: pump, valve, hydraulic cylinder.

Power is transmited by the fluid $P = Q \cdot p = (flow\ x\ pressure)$

ELECTRO-HYDRAULIC MOTION CONTROL

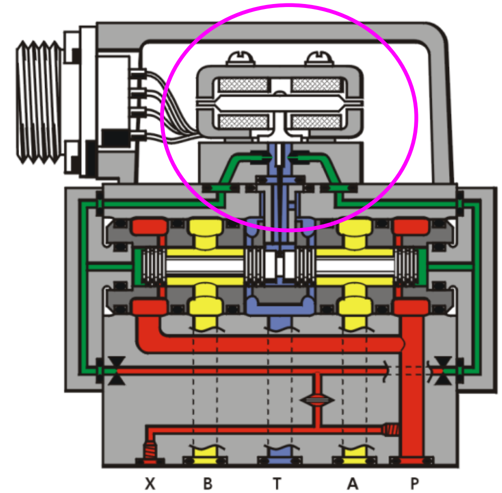
Example: position control

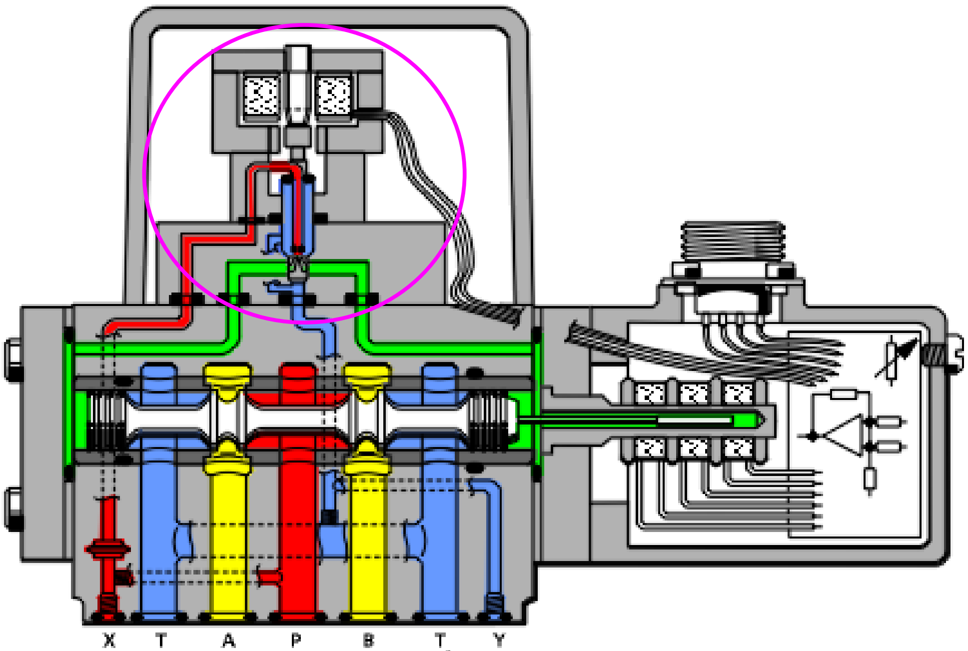




ELECTRO-HYDRAULIC MOTION CONTROL
SERVOVALVES

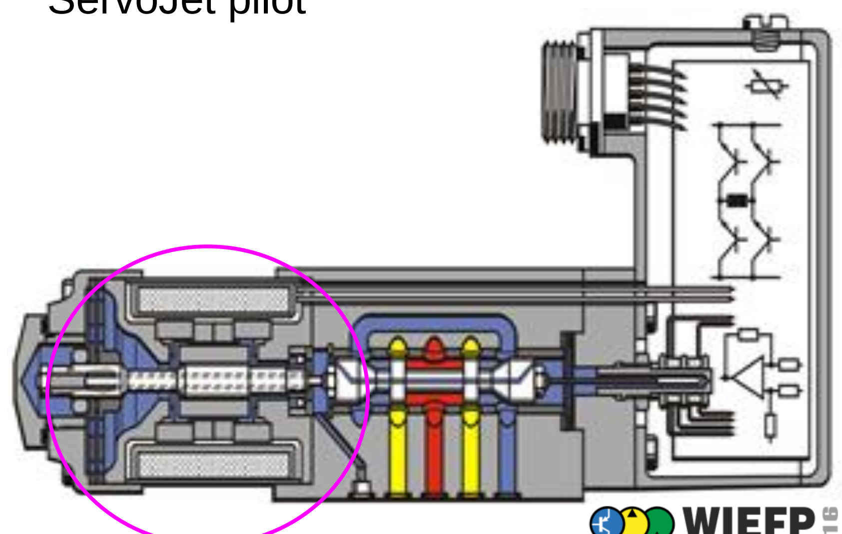
MFB = Mechanical Feedback
nozzle–flapper pilot





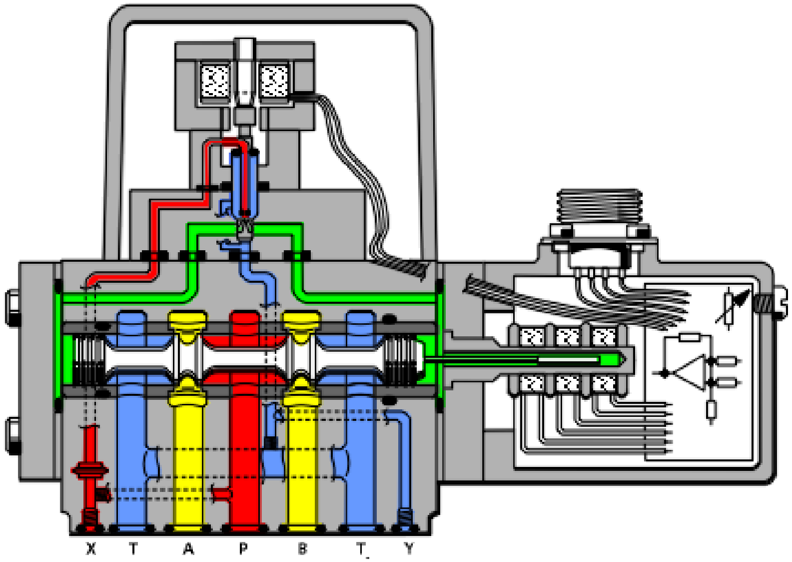
EFB = Electrical Feedback
ServoJet pilot

EFB = Electrical Feedback
DDV pilot



ELECTRO-HYDRAULIC MOTION CONTROL

Analog Servovalve → Digital Servovalve



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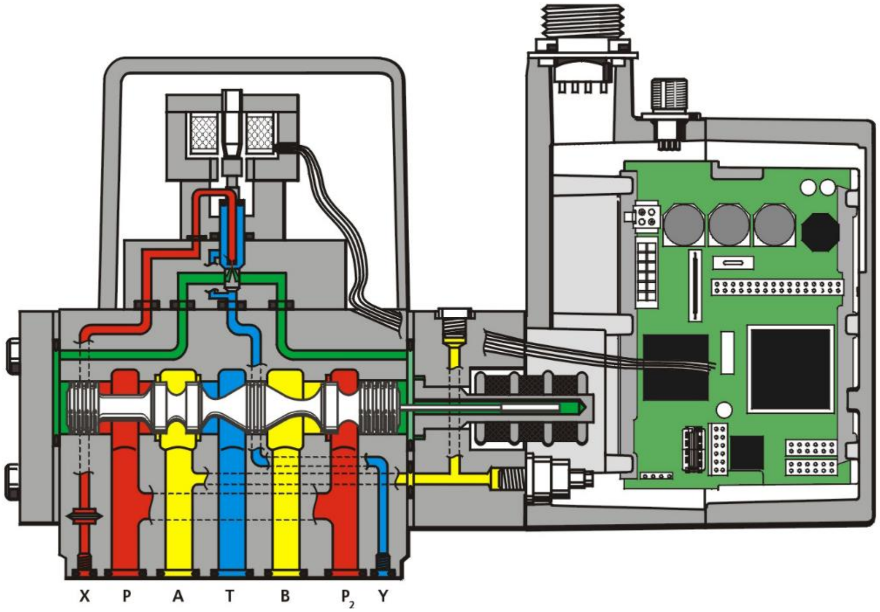

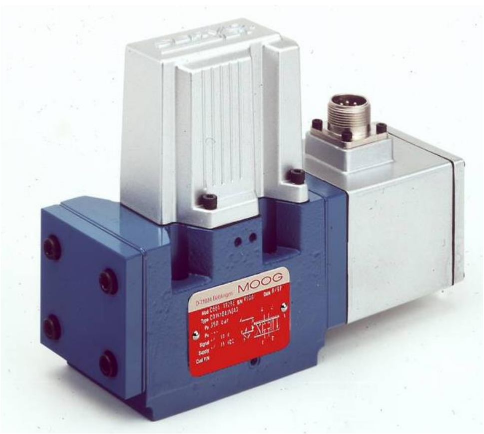

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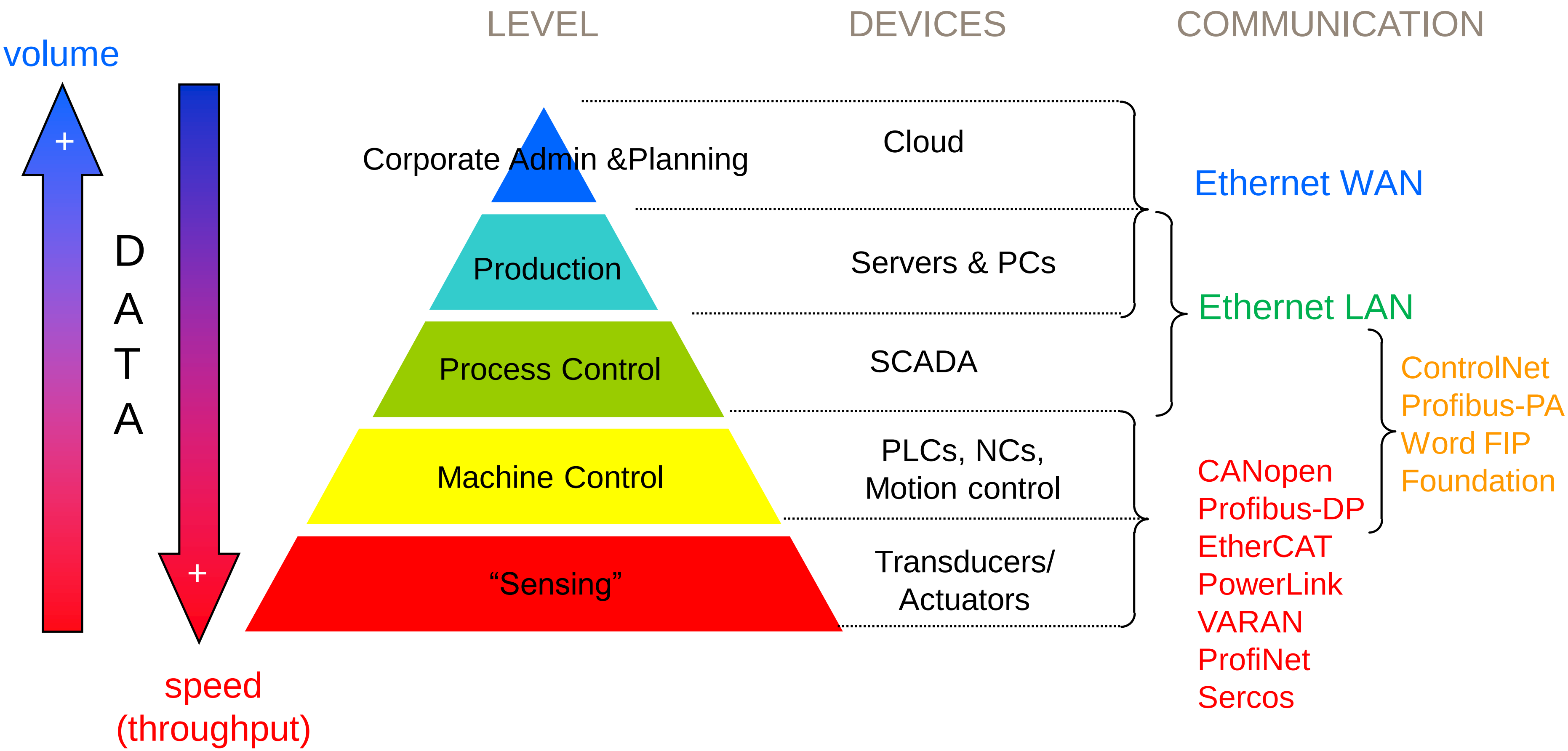
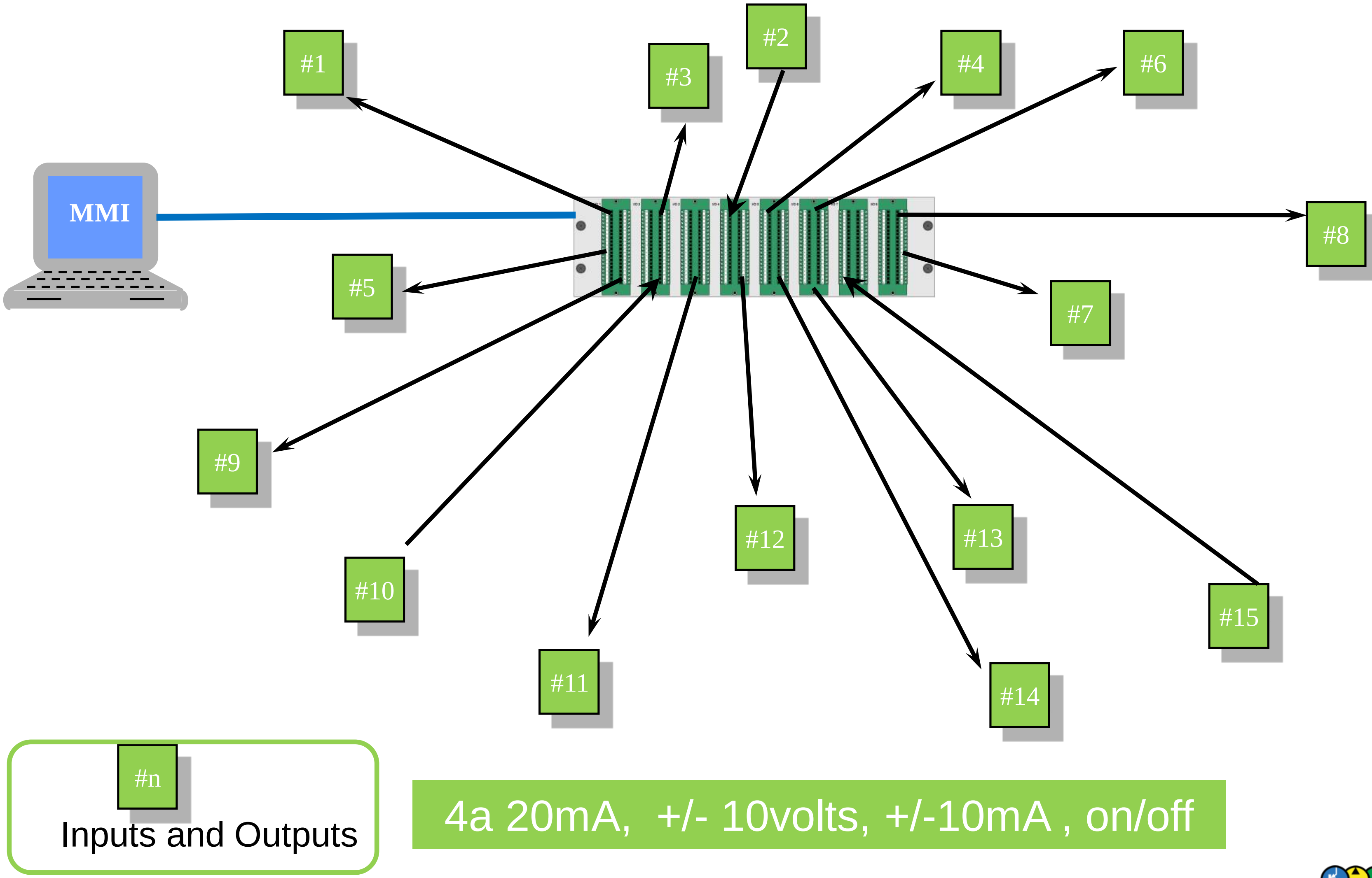
AUTOMATION TECHNOLOGY



SCADA = Supervisory Control and Data Acquisition

TRADITIONAL AUTOMATION ARCHITECTURE
CENTRALIZED CONTROL



4a 20mA, +/- 10volts, +/-10mA , on/off

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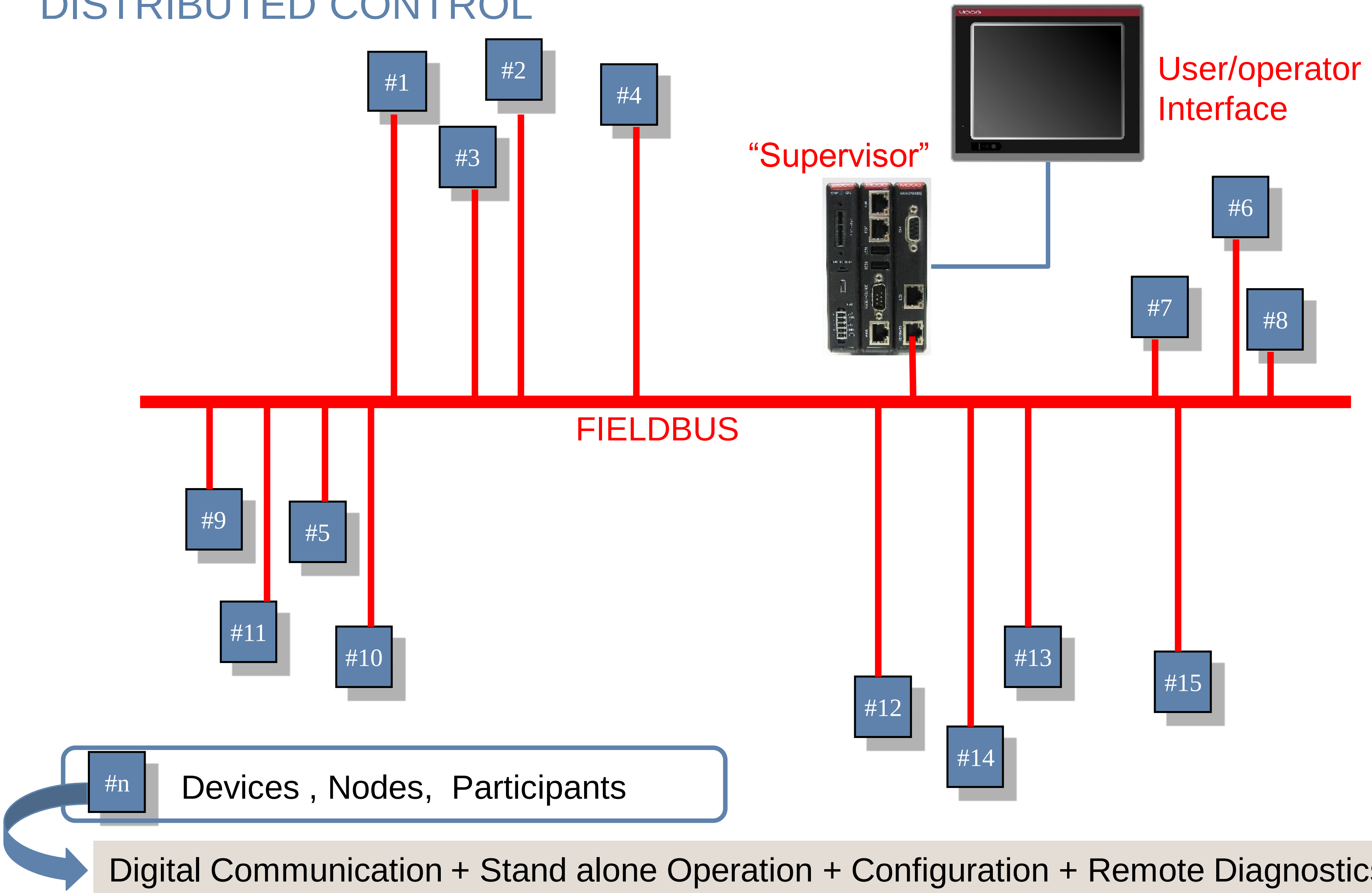
MODERN (FACTORY 4.0) AUTOMATION ARCHITECTURE
DISTRIBUTED CONTROL



Digital Communication + Stand alone Operation + Configuration + Remote Diagnostics

FIELDBUS - Definition by IEC 61158-2

Digital data communications for measurement and control for use in industrial control systems

IEC 61158 standard consists of the following parts:

Part 1: Overview and guidance for the IEC 61158 series

Part 2: Physical Layer specification and service definition

Part 3: Data Link Service definition

Part 4: Data Link Protocol specification

Part 5: Application Layer Service definition

Part 6: Application Layer Protocol specification

OSI 7 layers model

7 – Application Layer

6 – Presentation Layer

5 – Session Layer

4 – Transport Layer

3 – Network Layer

2 – Data Link Layer

1 – Physical Layer

OPEN PROTOCOL = when used layers are clearly specified, documented and made available to interested users = interoperability & compatibility

Only layers 1, 2 and 7 are specified for FIELDBUSSES!

- IEC (International Electrotechnical Commission) is a worldwide organization for standardization that promotes international co-operation on all questions concerning standardization in the electrical and electronic fields.
- OSI (Open Systems Interconnection) defined by ISO Standards

FIELDBUS - make your choice! ;>)

BSAP - Bristol Babcock Inc

DF-1

CC-Link

CIP -Common Industrial Protocol - ODVA

CAN -Controller Area Network - Bosch

CAN open

ControlNet - Allen-Bradley

DeviceNet - Allen-Bradley

Interbus - Phoenix Contact

HART Protocol (run in 4-20mA lines)

Modbus RTU - Schneider

Modbus NET

Modbus TCP

Modbus Plus

Modbus PEMEX

EGD - GE Fanuc

Fieldbus FOUNDATION

FINS - Omron

GE SRTP - GE Fanuc PLCs

Host Link - Omron

Mechatrolink - Yaskawa

MelsecNet/10 - Mitsubishi Electric

Optomux - Opto 22

PieP - Open Fieldbus Protocol

Profibus - Siemens

Profibus-DP

Profibus-PA

SERCOS

Sinec H1 - Siemens

SynqNet - Danaher

* Supported by MOOG

FIELDBUS - Ethernet-based, **real time** communication

EtherCAT - Beckhoff Automation

EtherNet/IP - ODVA

Ethernet Powerlink - B&R

PROFINET - Siemens

SafetyNET p – Pilz GmbH

SERCOS III - Sercos International

TTEthernet -TTTech Computertechnik AG

VARAN - VNO (Varan-bus Nutzerorganisation)

RAPIEnet - Korea

CANopen	1 Mbit/sec
Profibus DP	12 Mbit/sec
EtherCAT, PowerLink, Varan	100 Mbit/sec

* Supported by MOOG

FIELDBUS + / -

PLUS:

- Direct communication between the PLC (Fieldbus-Master) and actuators/transducers
  → lower cost wiring and smaller electrical cabinet
  → reduced number of discrete I/Os
- Digital command and feedback signals → no noise, no loss
- Remote monitoring, parametrization, diagnostics, troubleshooting
- Direct communication between slave devices is possible in some fieldbusses

MINUS:

- Real time communication capability is limited depending on the fieldbus speed and the number of connected devices.
- Devices are more expensive (must have built-in fieldbus interface)
- Implementation requires skilled workforce

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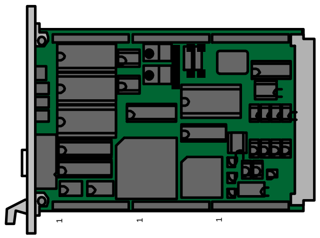
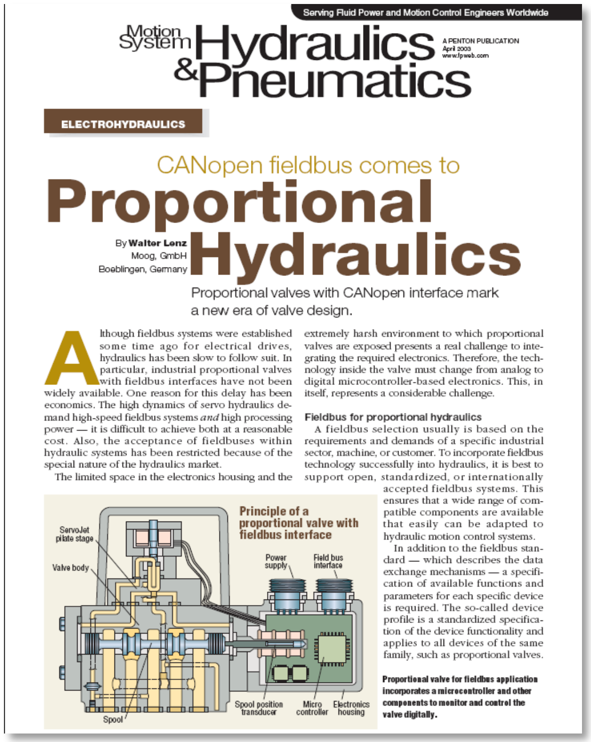
HISTORY



- **1992:** checking the possibility of controlling a servovalve with digital electronics
- **1995:** industrial controller (eurocard format) installed in a servovalve with analogue spool control, simple CAN interface.
- **1998:** embedded hardware/software, basic CANopen and VDMA standard functionalities, mixed analogue/digital spool position control.
- **2000:** DCV (Digital Control Valve): 2 boards design electronics, full CANopen, full VDMA, full digital valve control , MoVaCo (Configuration Software Tool)



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Motion System Hydraulics & Pneumatics

A PENTON PUBLICATION
April 2003
www.fpweb.com

ELECTROHYDRAULICS

CANopen fieldbus comes to
Proportional Hydraulics

By **Walter Lenz**
Moog, GmbH
Boeblingen, Germany

Proportional valves with CANopen interface mark a new era of valve design.

Although fieldbus systems were established some time ago for electrical drives, hydraulics has been slow to follow suit. In particular, industrial proportional valves with fieldbus interfaces have not been widely available. One reason for this delay has been economics. The high dynamics of servo hydraulics demand high-speed fieldbus systems *and* high processing power — it is difficult to achieve both at a reasonable cost. Also, the acceptance of fieldbuses within hydraulic systems has been restricted because of the special nature of the hydraulics market.

The limited space in the electronics housing and the extremely harsh environment to which proportional valves are exposed presents a real challenge to integrating the required electronics. Therefore, the technology inside the valve must change from analog to digital microcontroller-based electronics. This, in itself, represents a considerable challenge.

Fieldbus for proportional hydraulics

A fieldbus selection usually is based on the requirements and demands of a specific industrial sector, machine, or customer. To incorporate fieldbus technology successfully into hydraulics, it is best to support open, standardized, or internationally accepted fieldbus systems. This ensures that a wide range of compatible components are available that easily can be adapted to hydraulic motion control systems.

In addition to the fieldbus standard — which describes the data exchange mechanisms — a specification of available functions and parameters for each specific device is required. The so-called device profile is a standardized specification of the device functionality and applies to all devices of the same family, such as proportional valves.

Principle of a proportional valve with fieldbus interface

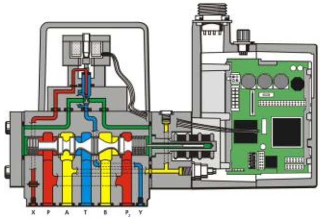
ServoJet pilate stage
Valve body
Power supply
Field bus interface
Spool position transducer
Micro controller
Electronics housing
Spool

Proportional valve for fieldbus application incorporates a microcontroller and other components to monitor and control the valve digitally.

CANopen

VDMA
Verband Deutscher Maschinen- und Anlagenbau
Mechanical Engineering Industry Association

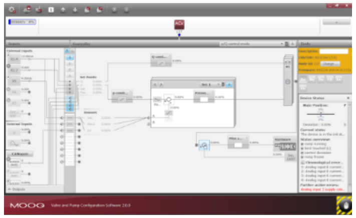
HISTORY



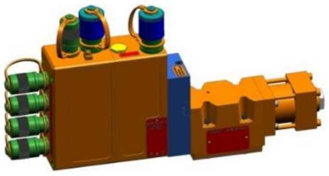
- **2003:** digital pQ valve (pressure + flow control)
- **2005:** modular design (3 boards), Profibus, aditional analog and digital inputs, digital RKP pumps
- **2007: ACV (**Axis Control Valve): closed loop with external transducers

- **2009**: EtherCAT
- **2011**: improved electronics, powerfull microprocessors

- **2012:** new configuration software tool (MoVaPuCo), VARAN



- **2014**: explosion proof versions, new models



- **2016**: PowerLink

A LARGE FAMILY OF DIGITAL VALVES

Models

Models	RATED FLOW L/MIN AT 10 BAR (150 PSI) ΔP	STEP RESPONSE (0 to 100% STROKE) MS	PILOT OPERATED VALVE	DIRECT DRIVE VALVE	INTEGRATED PRESSURE SENSOR	SIZE (ISO 4401)
D675	1000 – 1500	10 – 43	●			10
D945	1000 – 1500	30 – 43	●		●	10
D674	550 – 550	14 – 44	●			08
D944	550 – 550	17 – 44	●		●	08
D673	350 – 350	13 – 33	●			08
D943	350 – 350	15 – 33	●		●	08
D672 SERVO	60 – 90	7	●			07
D672 PROPORTIONAL	150 – 250	10 – 44	●			07
D942	150 – 250	11 – 44	●		●	05
D671 SERVO	8 – 68	9 – 19	●			05
D671 PROPORTIONAL	30 – 80	11 – 28	●			05
D941	8 – 80	11 – 28	●		●	05
D639	24 – 40	14		●	●	05
D637	24 – 40	14		●		05
D638	2 – 16	8		●	●	03
D636	2 – 16	8		●		03

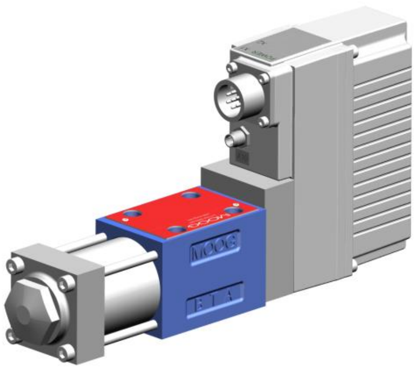
RATED FLOW L/MIN AT 10 BAR (150 PSI) ΔP: 1 2 5 10 20 30 100 200 500 1k 2k 3k

STEP RESPONSE (0 to 100% STROKE) MS: 0 5 10 20 30 40 50

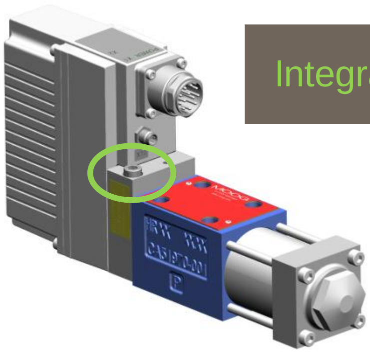
DCV - DIGITAL CONTROL VALVE

Functionality & Interfaces

DCV-Q : Flow Control
Analog Command

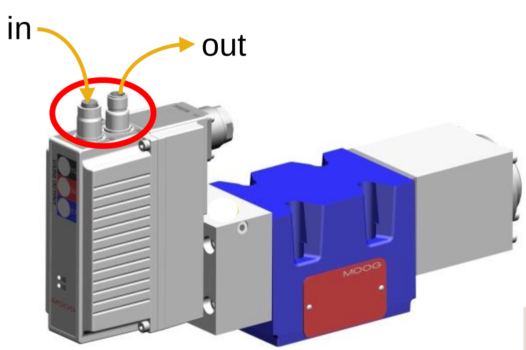


DCV-pQ : Flow & Pressure Control
Analog Command

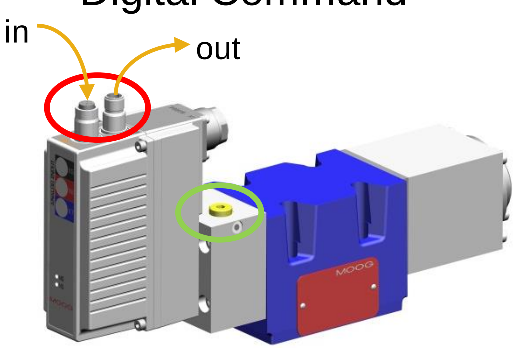


Integrated Pressure Transducer

DCV-Q : Flow Control
Digital Command



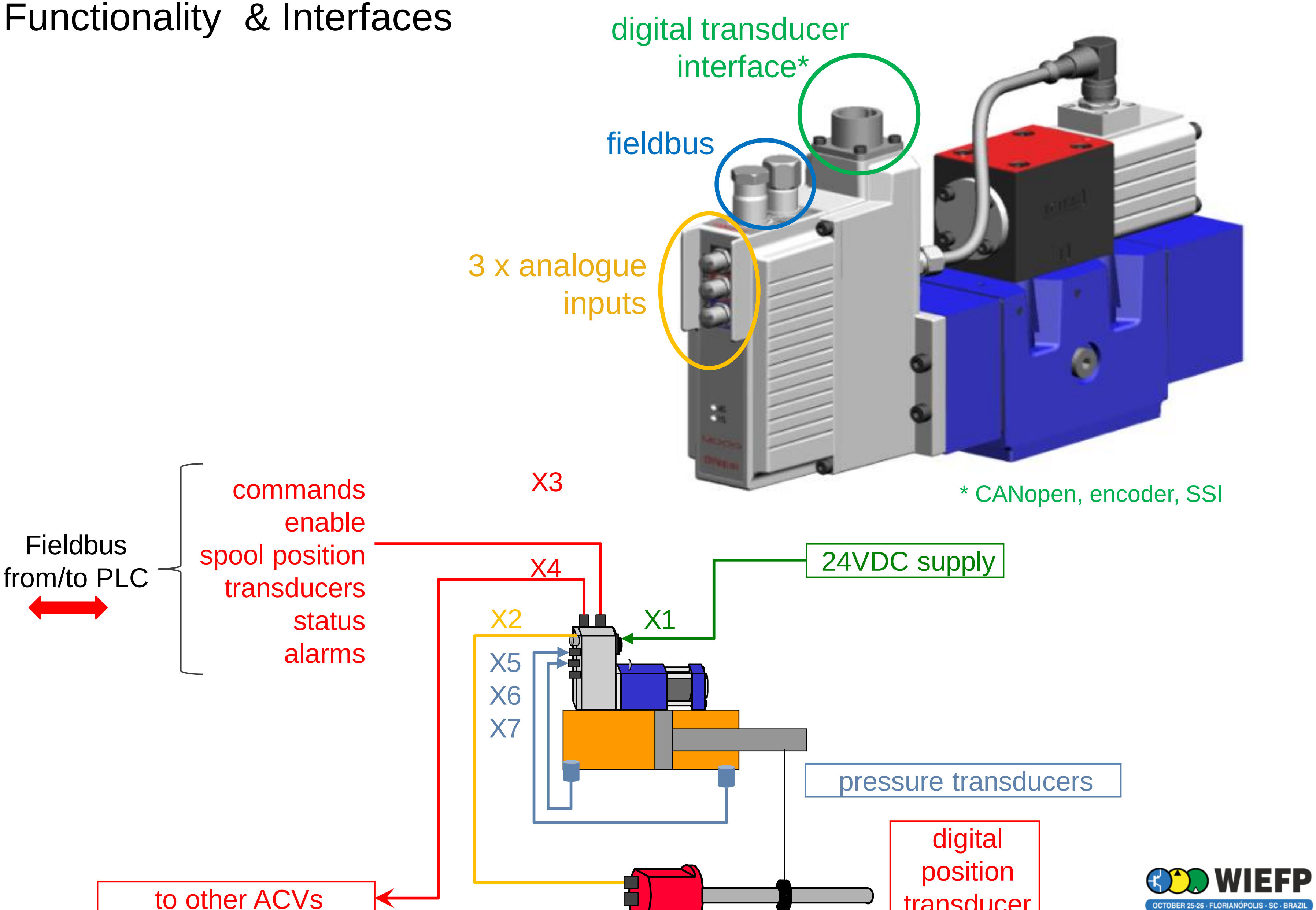
DCV-pQ : Flow & Pressure Control
Digital Command



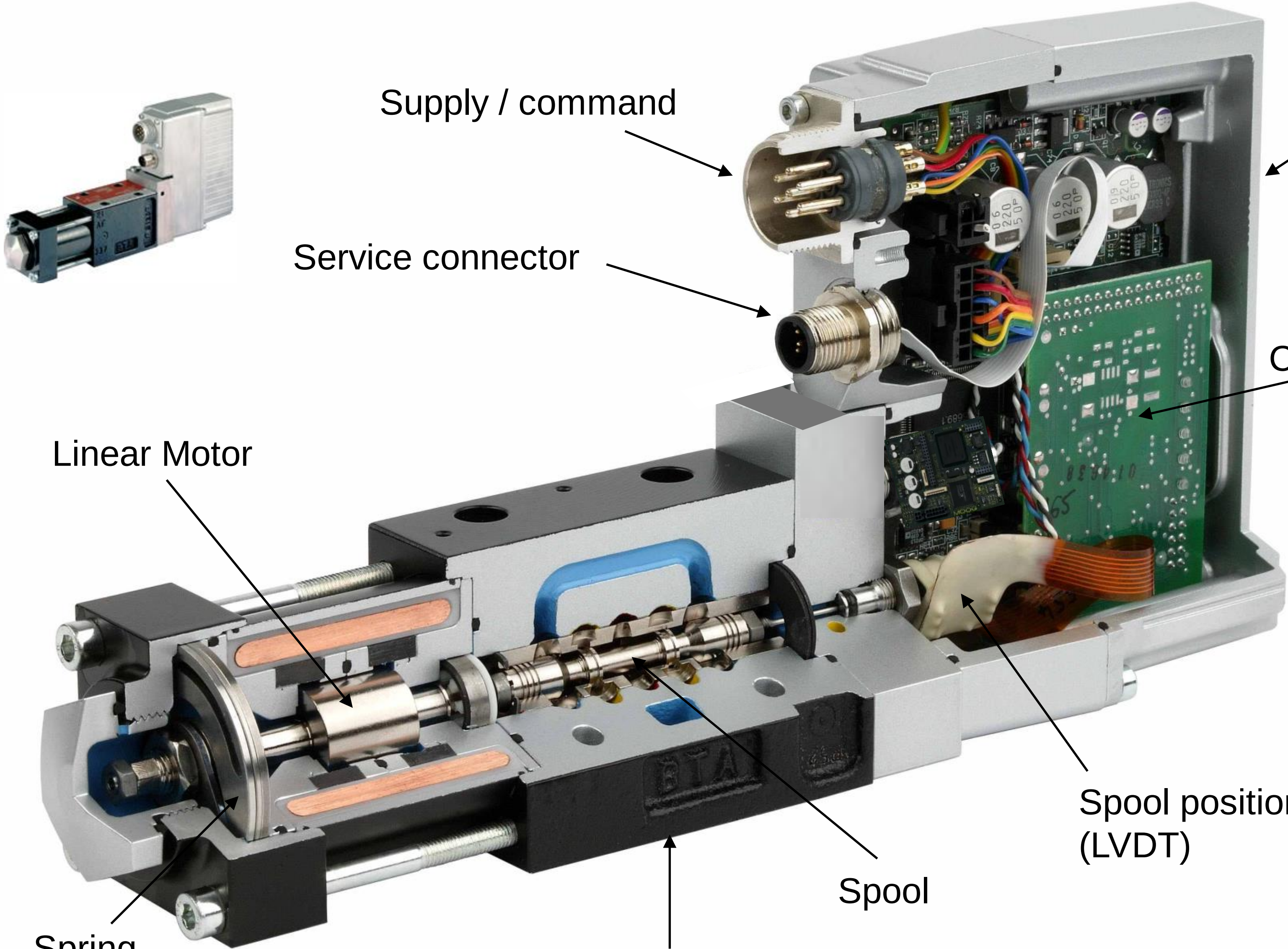
FIELDBUS Interface

ACV - AXIS CONTROL VALVE

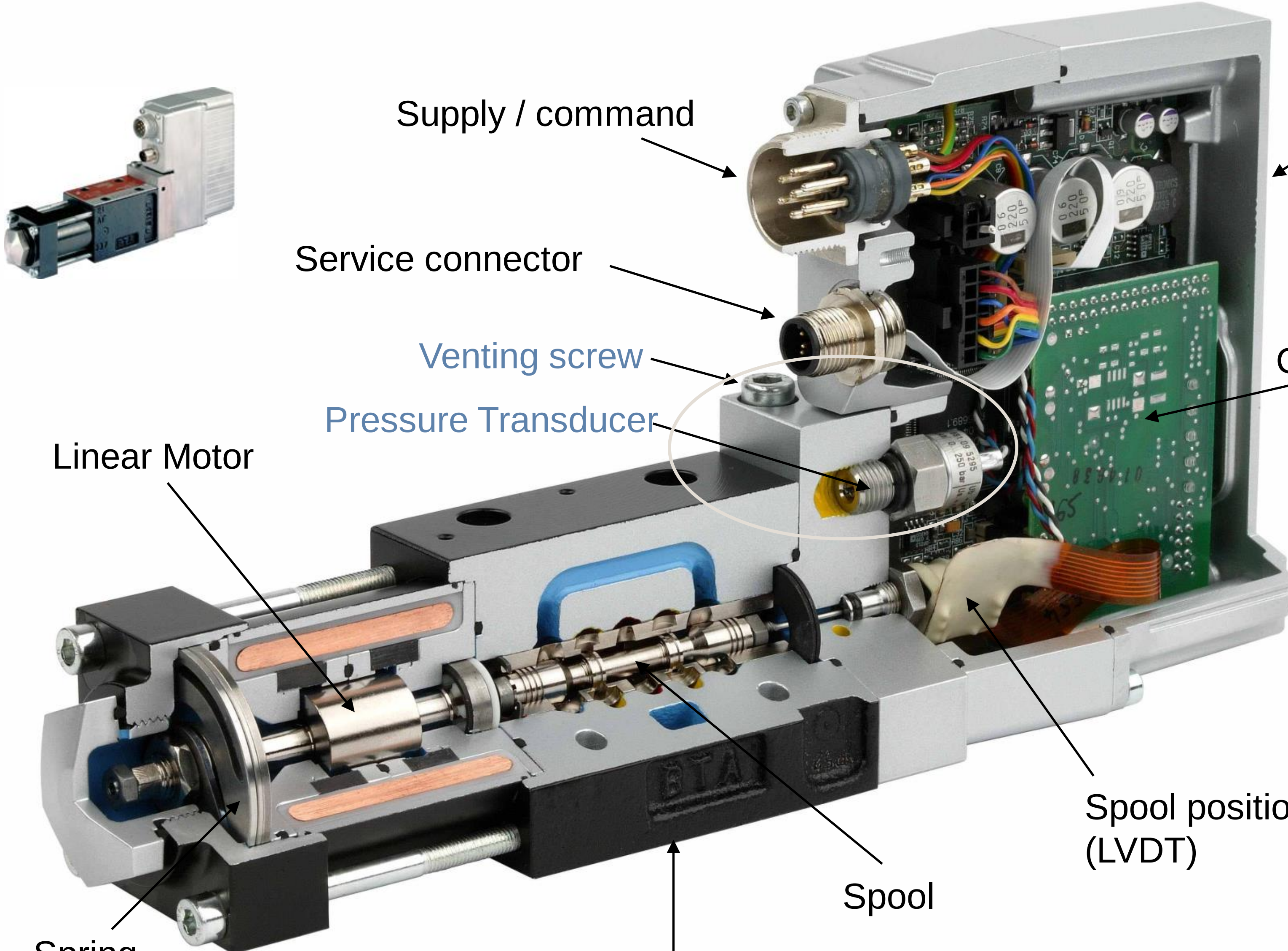
Functionality & Interfaces



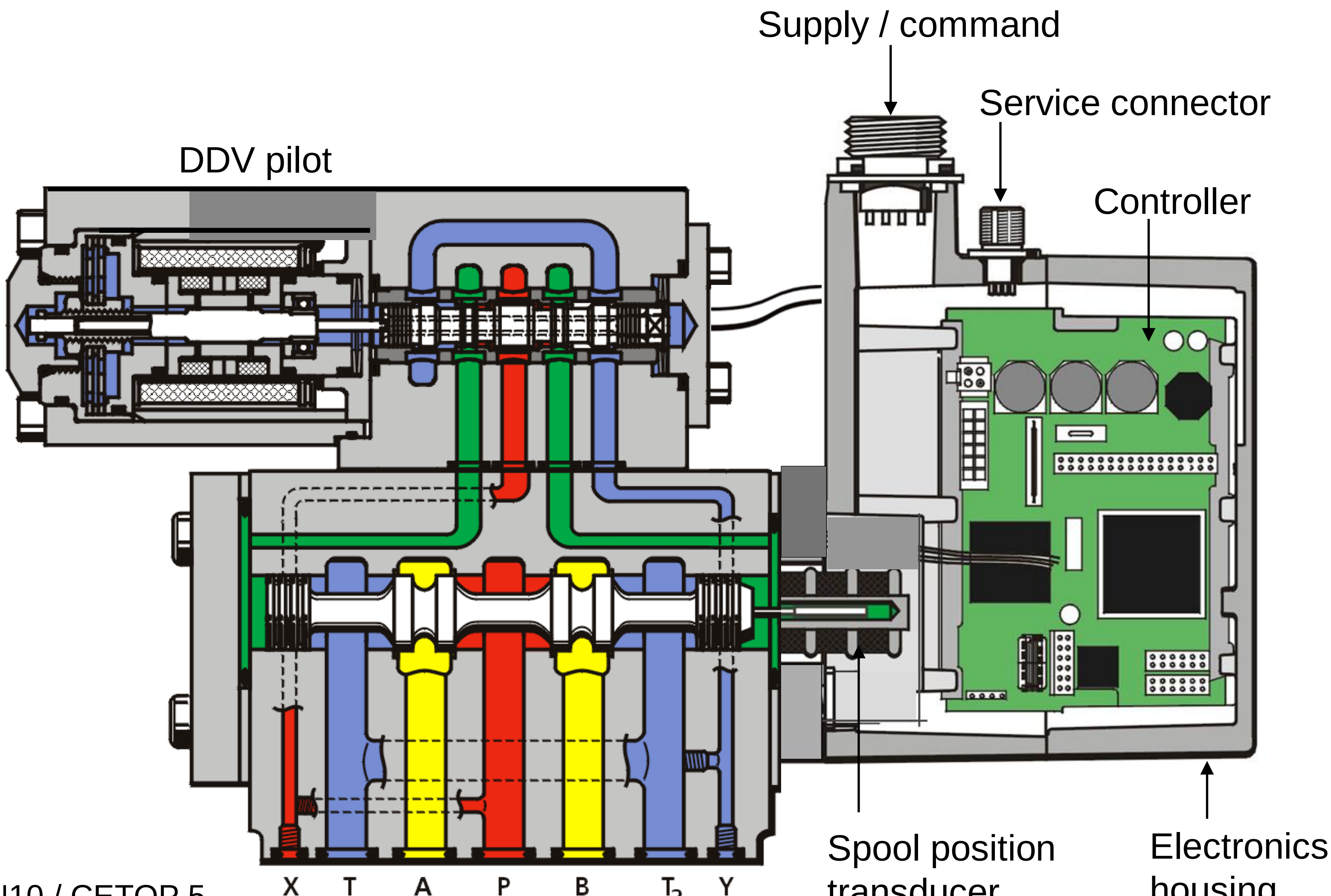
DCV – Q DDV Direct Drive Valve D636 D637 TN6 / CETOP 3 TN10 / CETOP 7



DCV - pQ DDV Direct Drive Valve D638 D639 TN6 / CETOP 3 TN10 / CETOP 7

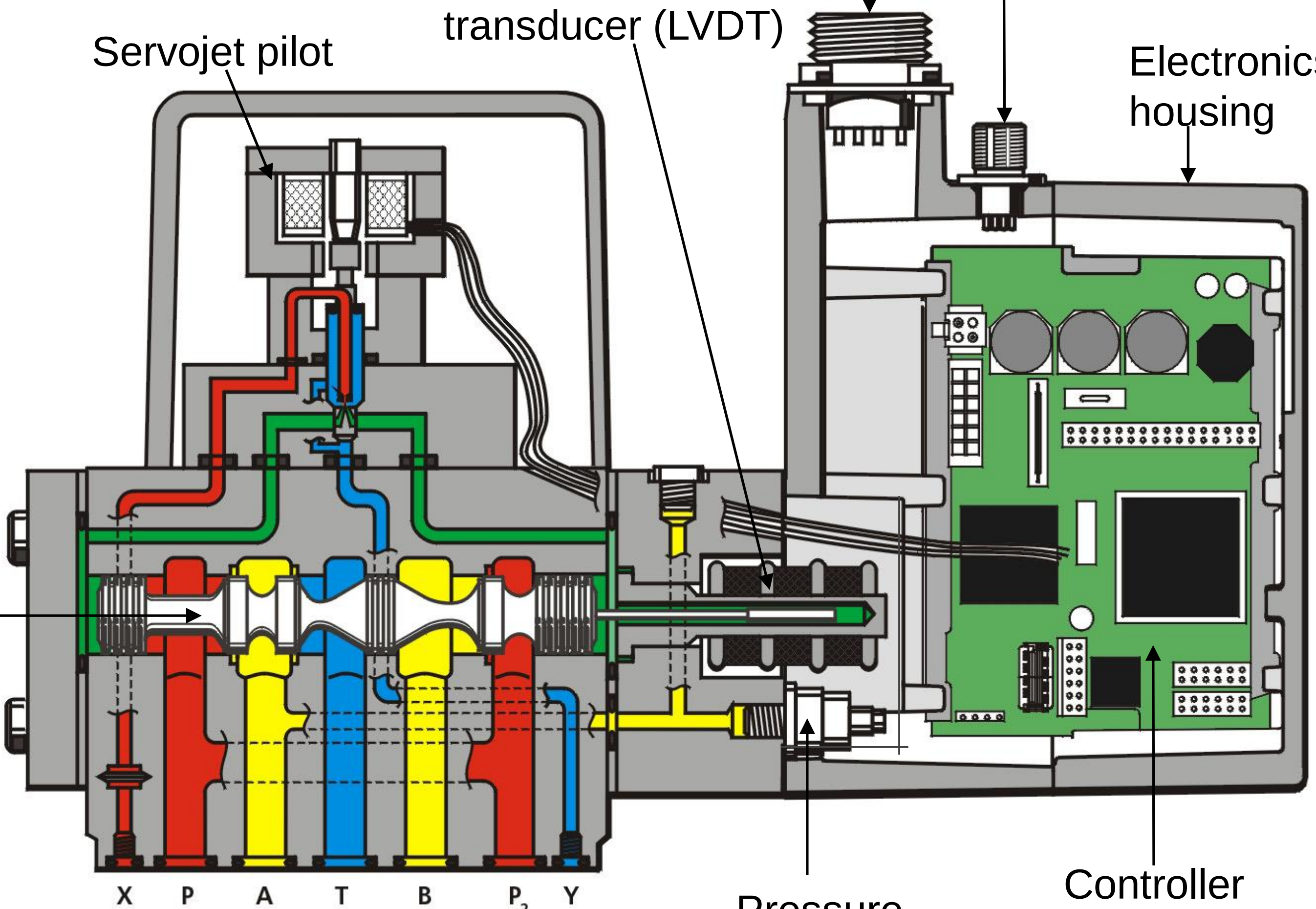


DCV - Q   DDV   D671   TN10/ CETOP 5



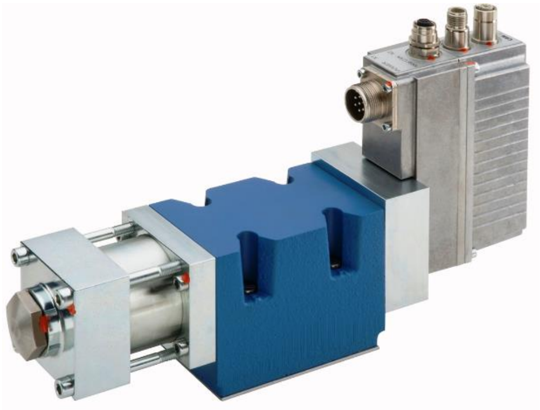
D671 TN10 / CETOP 5
D672 TN16 / CETOP 7
D673 TN25 / CETOP 8
D674 TN25 / CETOP 8
D675 TN32 / CETOP10

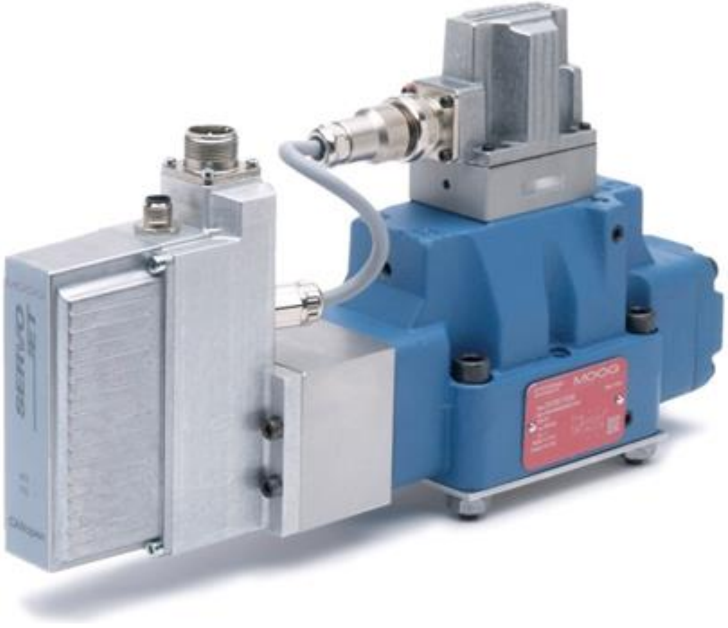
DCV - pQ SERVO JET D941 TN10 / CETOP 5

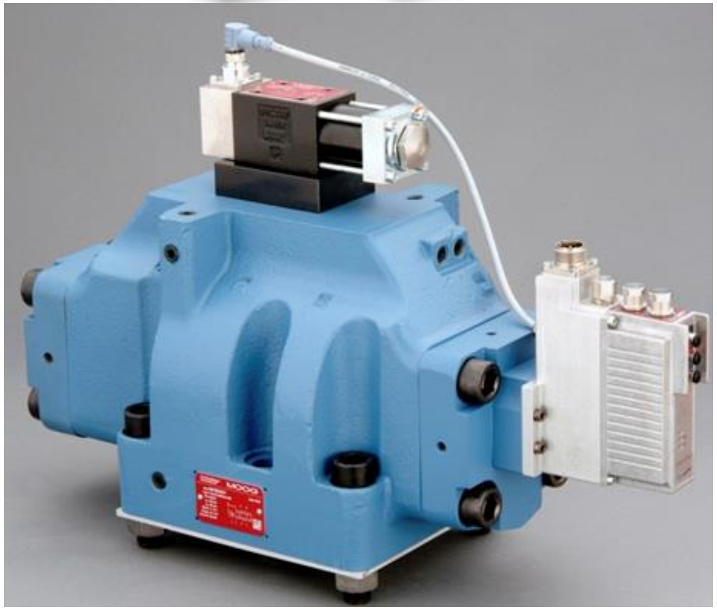


D941 TN10 / CETOP 5
D942 TN16 / CETOP 7
D943 TN25 / CETOP 8
D944 TN25 / CETOP 8

DIGITAL SERVOVALVES - models

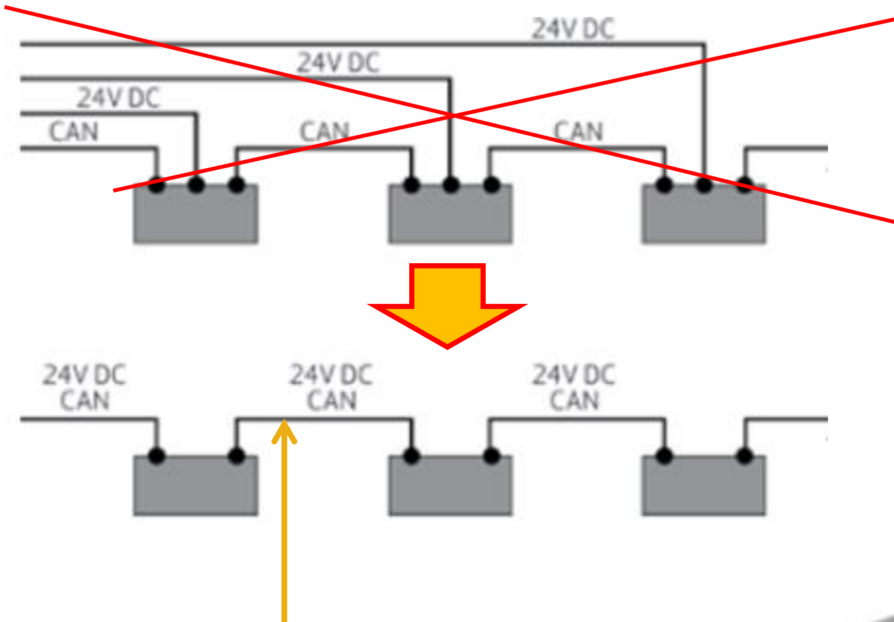




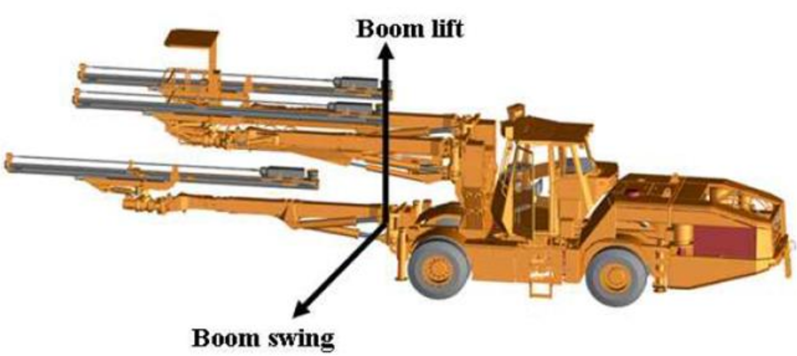


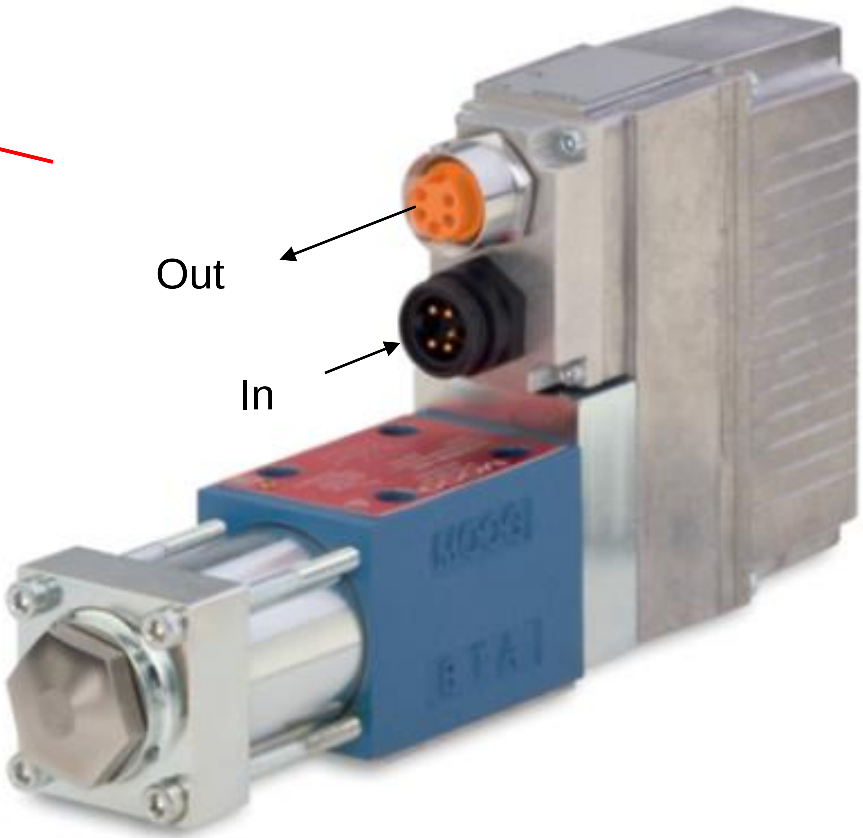
DIGITAL SERVOVALVES – Customized Versions

Power on fieldbus



Supply & Fieldbus in one cable





DIGITAL SERVOVALVES – Customized Versions

LOAD COMPENSATION

Constant flow despite variable loads

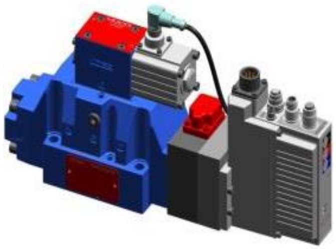
Measurement of supply pressure and both load with integrated pressure transducer module

Higher dynamics and better stability than hydro-mechanical pressure drop compensators

Additional functionality through pressure and flow measurement

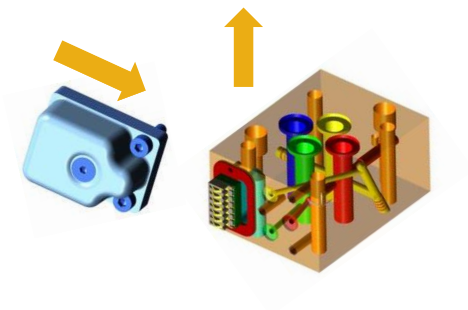
NG 10

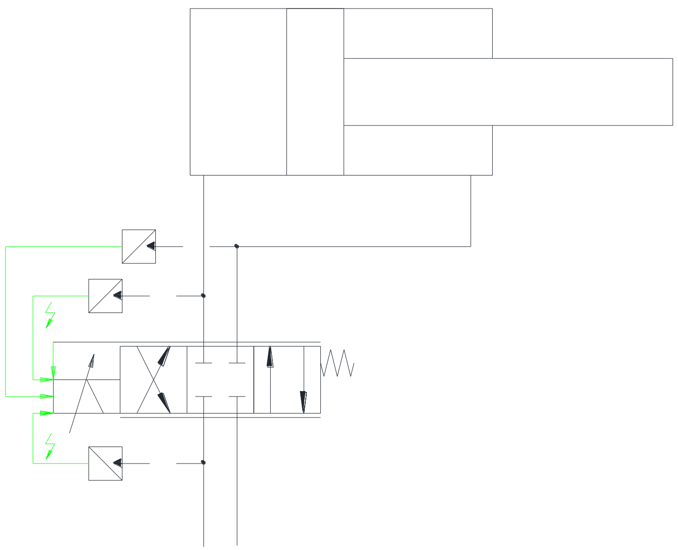
NG 16
NG 25



NG 32

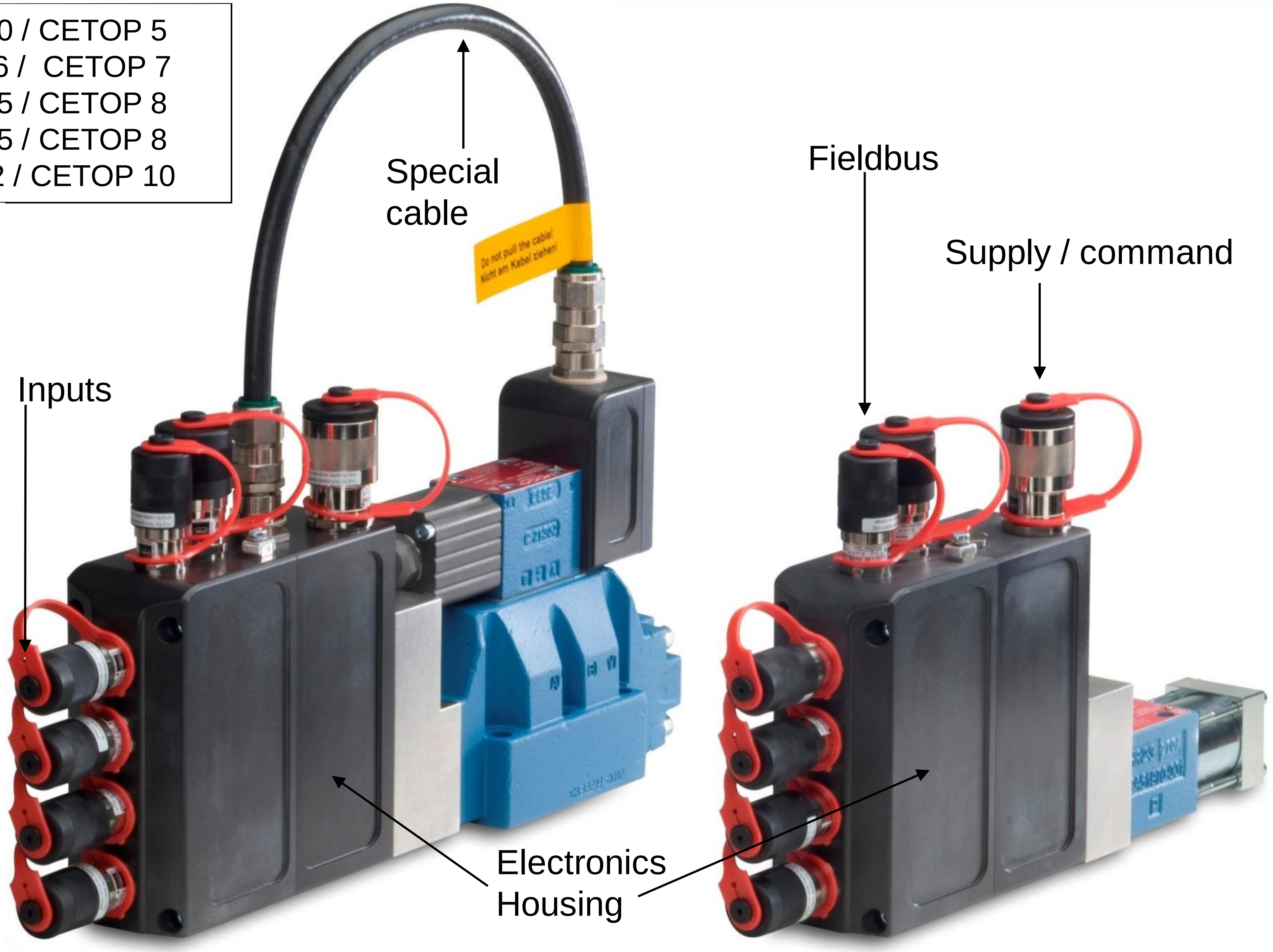
NG 06





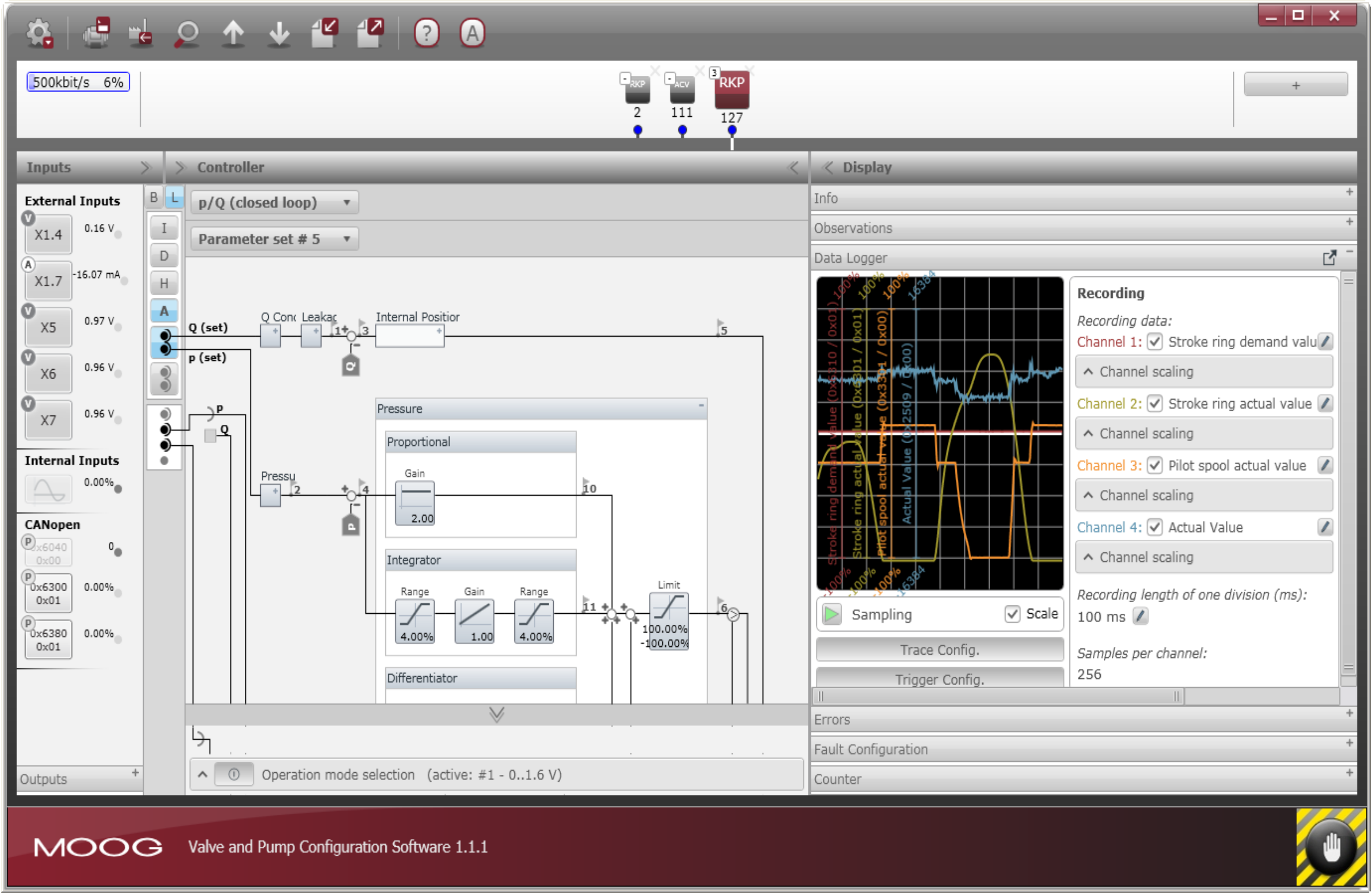
DIGITAL SERVOVALVES – EXPLOSION PROOF Versions

TN10 / CETOP 5
TN16 / CETOP 7
TN25 / CETOP 8
TN25 / CETOP 8
TN32 / CETOP 10



Connectors can be plugged under load

MoVaPuCo - Moog Valve and Pump Configuration Software



User-friendly WINDOWS interface/toll for parameterization, setup, monitoring and troubleshooting

USB- CANopen connection

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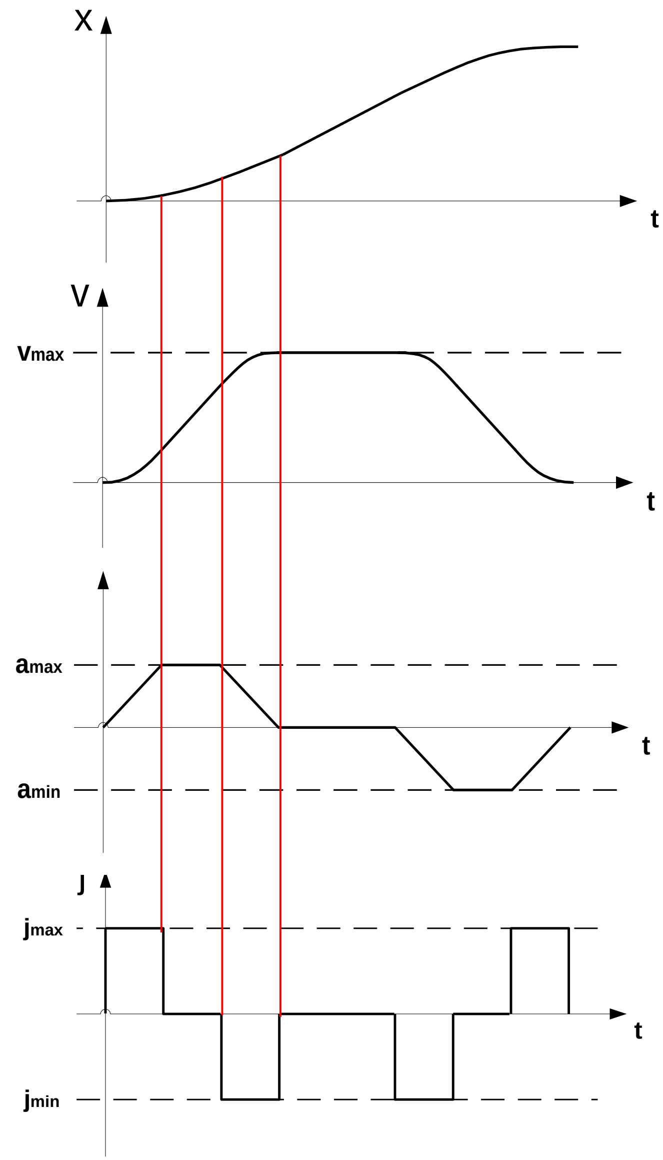
DIGITAL SERVOVALVES – Special Functionality

Trajectory Generator

- Decentralized control topology
- Reduces PLC´s CPU load
- Reduces PLC speed requirements
- Replaces real-time communication
- Decreases fieldbus communication traffic
- Can increase systems performance



Command values :

- target position
- max. velocity
- max. acceleration
- max. jerk

DIGITAL SERVOVALVES – Special Functionality
Event Handler

- “event” = user defined expressions based in “C” programming syntax
- Used to calculate values and take actions based in internal and external parameters.
- One “event” can enable/disable another “event”.
- Multiple actions can be executed in one “event”.
- Calculations are processed every milisecond by the EVENT HANDLER.

Symbol	Description
/	divide
*	multiply
-	subtract / negate
+	add
>>	shift right
<<	shift left
<, <=	smaller, smaller or equal
>, >=	greater, greater or equal
==	equal
!=	not equal
&	bit AND
|	bit OR
&&	logical AND
||	logical OR
?:	if (?) than (:) else
=	assign
;	separate within expression

DIGITAL SERVOVALVES – Special Functionality

Event Handler - Examples

prsval>100?ctlmod=4

IF the actual pressure (*prsval)* *IS BIGGER THAN* *100 bar*,

THEN change to pressure control mode (ctlmod=4)

posval<25?ctlmod=9;evtena[4]=1;evtena[5]=0;

IF the actual position (posval) IS SMALLER THAN 25 mm,

THEN change to position control mode (ctlmod=9)

AND enable event 4 (set to 1)

AND disable event 5 (set to 0)

DIGITAL VALVE DOES NOT REPLACE THE PLC!

PLC

PROCESS SUPERVISION/ COORDINATION

Logic sequencies execution: test conditions and take actions

Fully programmable by the user

Large number of I/Os

Electrical panel operation (controlled environment)

Digital Servovalve

CLOSED LOOP CONTROL

Internal status check

Limited programming through the “Event Handler”

Parametrization done by the user

Limited number of I/Os

Field operation (aggressive environment)

AGENDA

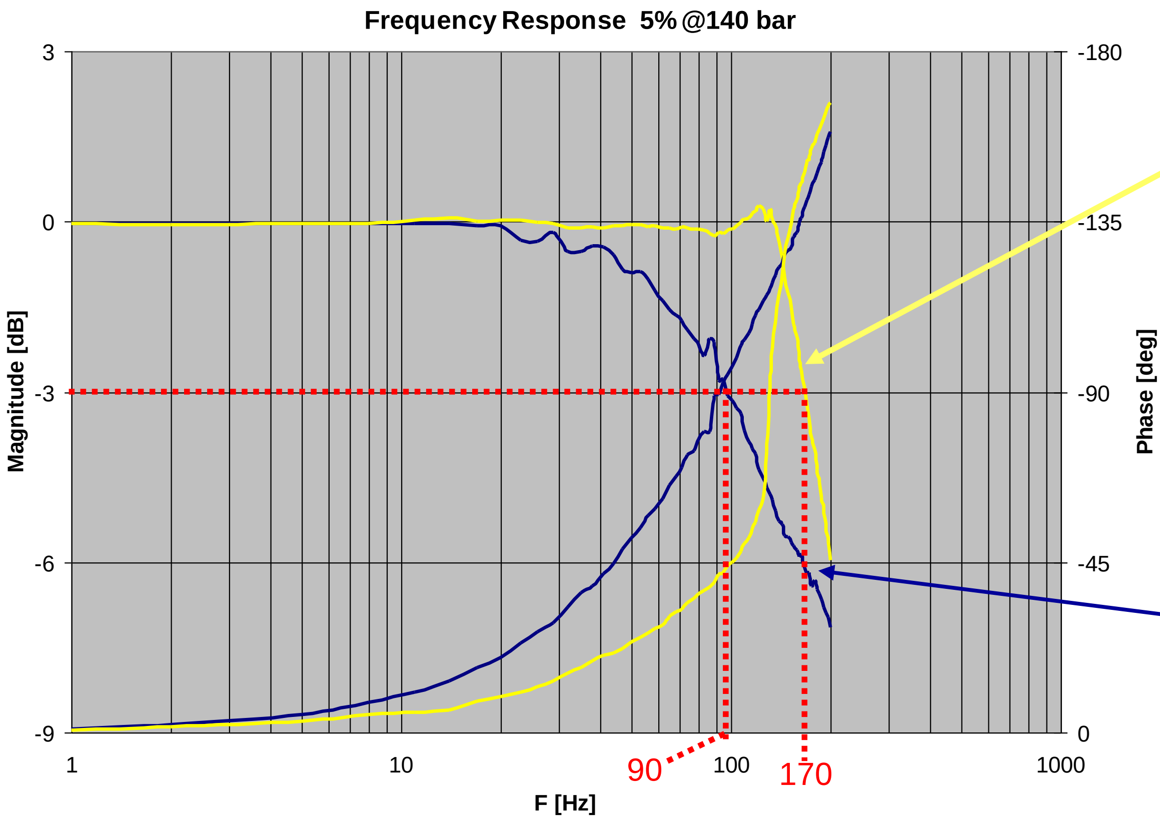
- Introduction to MOOG
- Electrohydraulic motion control
- Modern Automation
- Digital Servovalve
- Applications

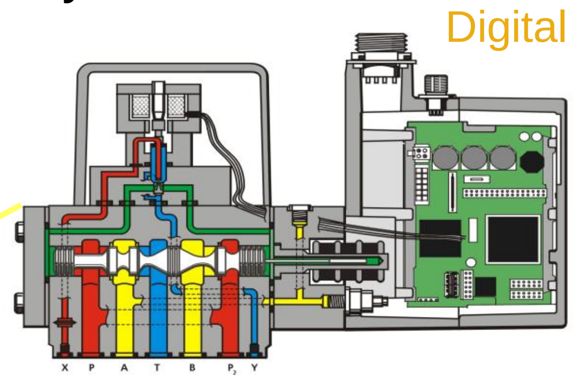
DIGITAL SERVOVALVES – Intrinsic Advantages

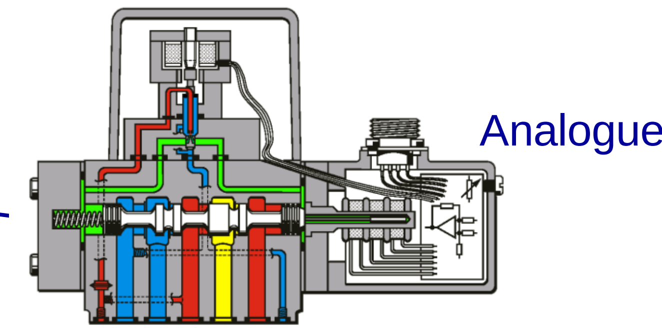
High precision spool position control:

- increased resolution
- no drift
- improved frequency response

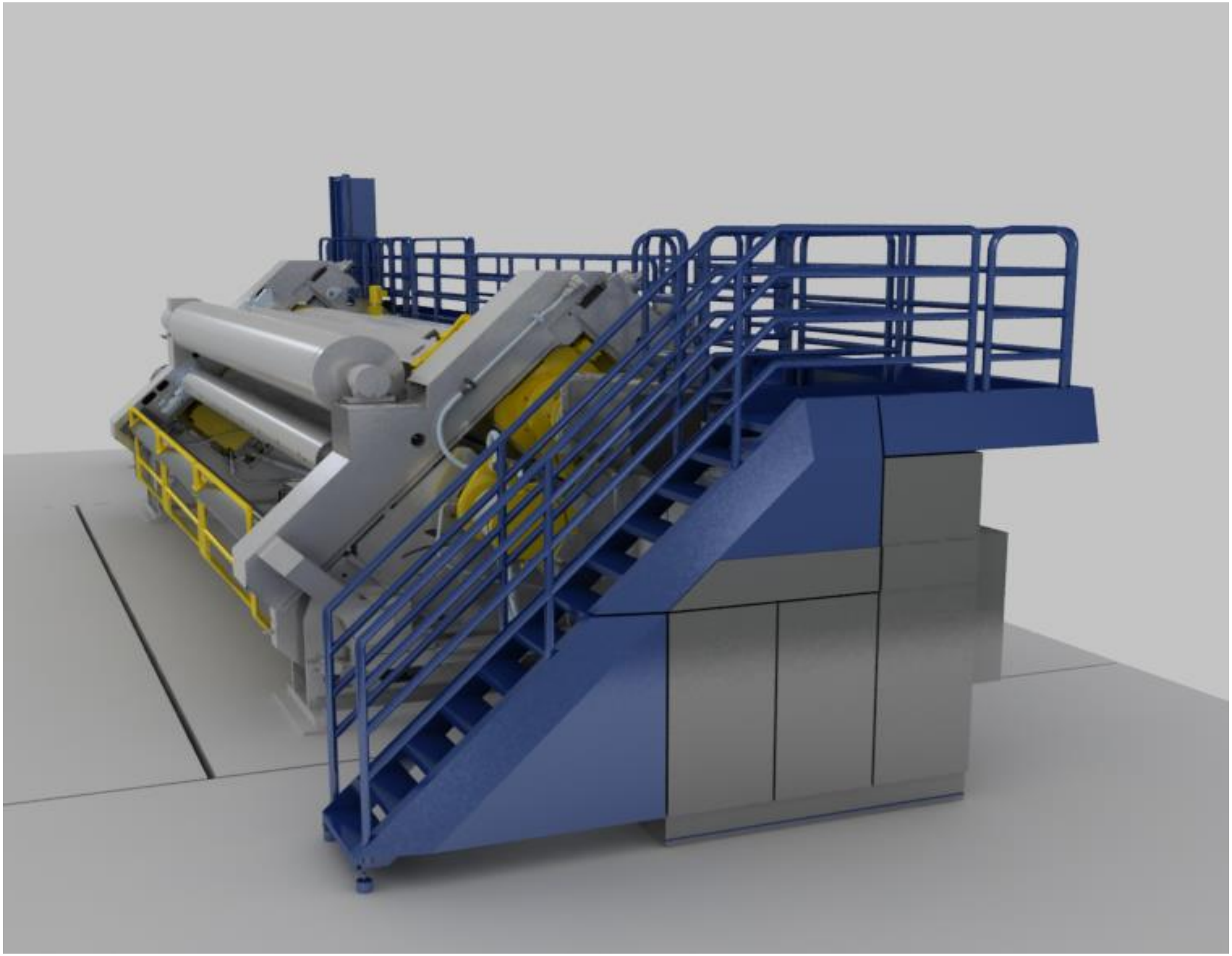
Allows high control loop gain = errors ⬇ repetibility ⬆







NIP CONTROL – Paper Calander

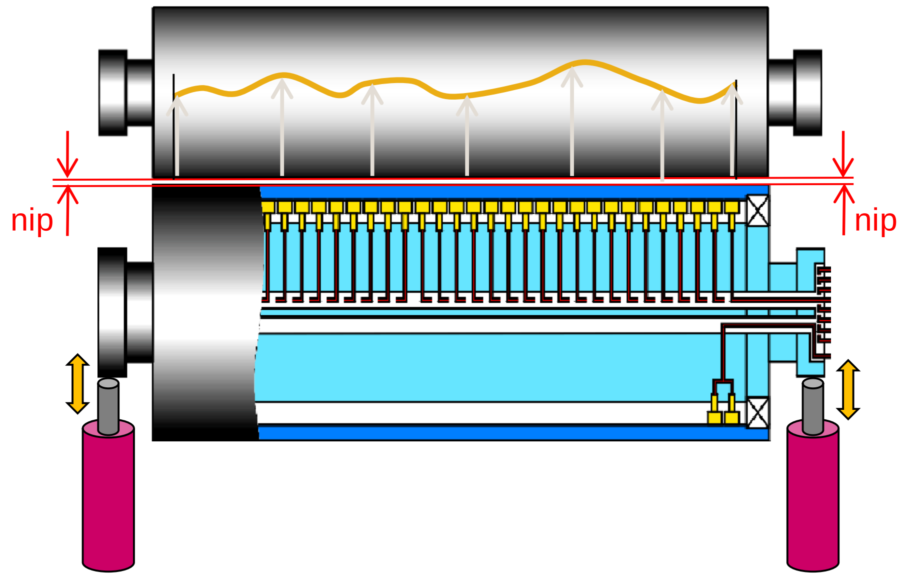


NIP CONTROL – Paper Calander

Transducer:
- Pressure transducer integrated in the valve

Functionality:
- Precise pressure control implemented by each digital servovalve
- Remote monitoring and diagnostics

Pressure Profile



Advantages:
- Distributed control: PLC just send pressure commands and reads real pressures (no closed loops execution)
- Compact and robust unity, IP65, integrating transducer and loop closure.
- Fieldbus communication simplifies wiring and reduces analogue I/O requirements (30 to 150 points pressure profile, depending on calander size)

DEEP DRAWING PRESS – CUSHION CONTROL

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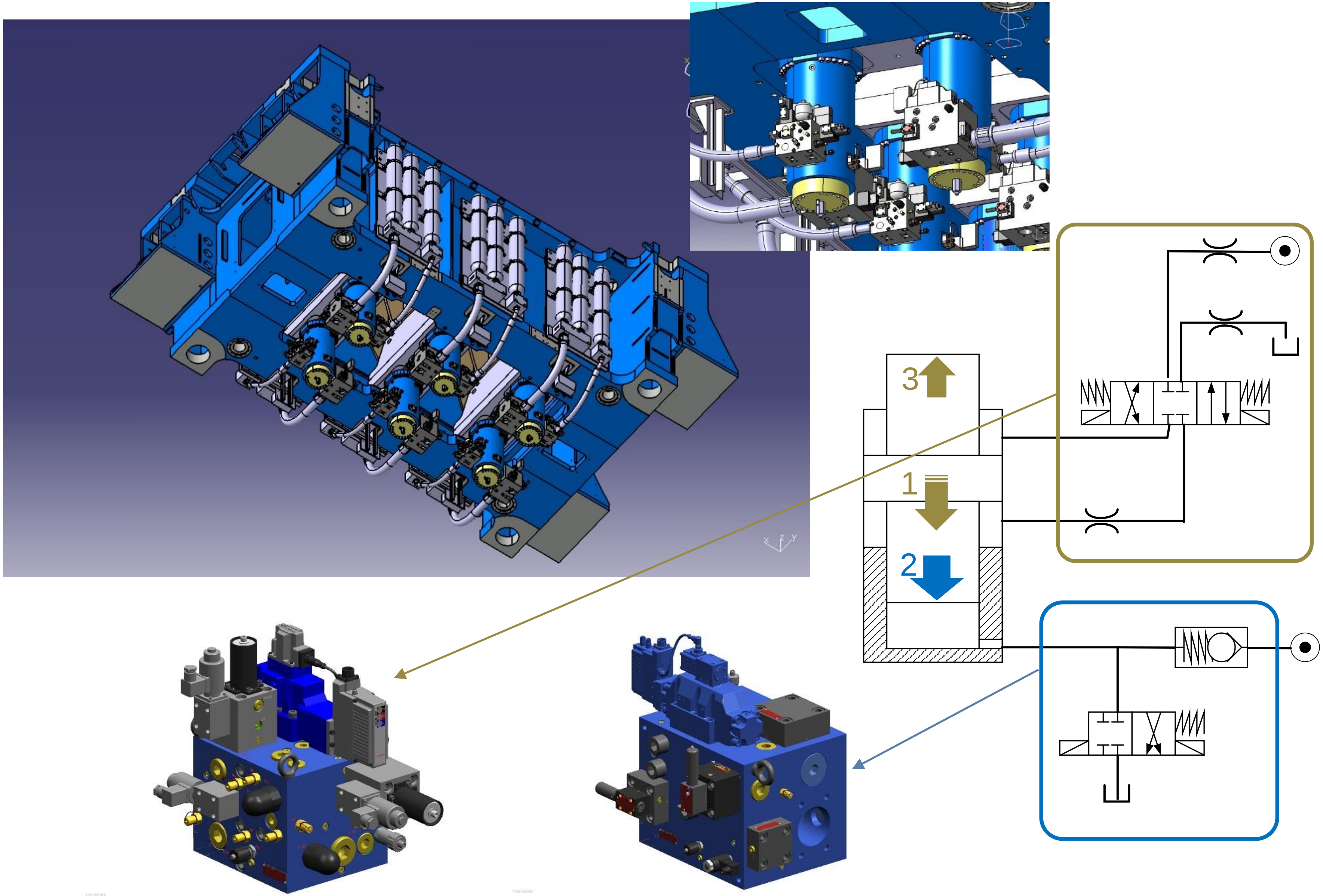
DEEP DRAWING PRESS – CUSHION CONTROL



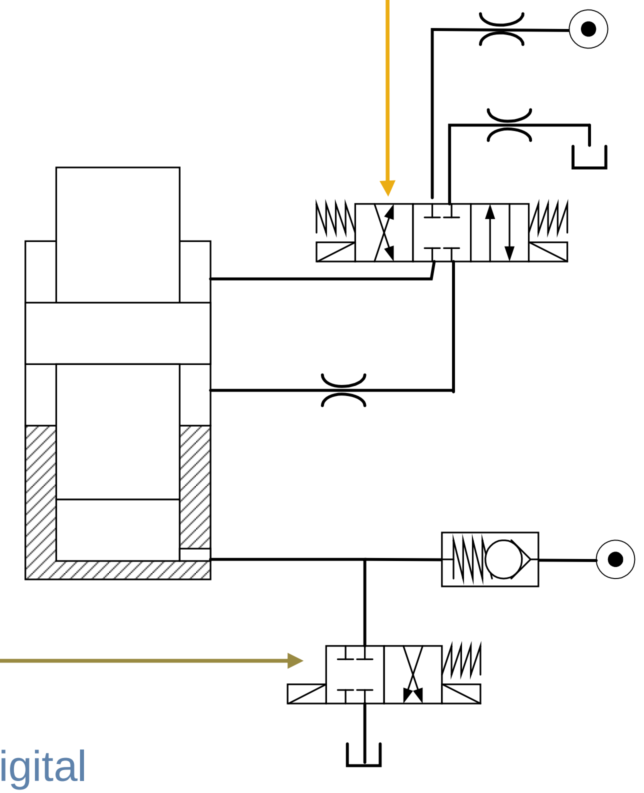
Stroke control manifold - D674

Cushion control manifold - D672

MEDEEP DRAWING PRESS – CUSHION CONTROL

Position control

Pressure (cushion) control



Transducers:

- position: encoder
- Pressure: pressure transducer

Functionality:

- Fieldbus commands/monitoring
- High precision flow control (spool) that allows high performance position and pressure controls

Advantages:

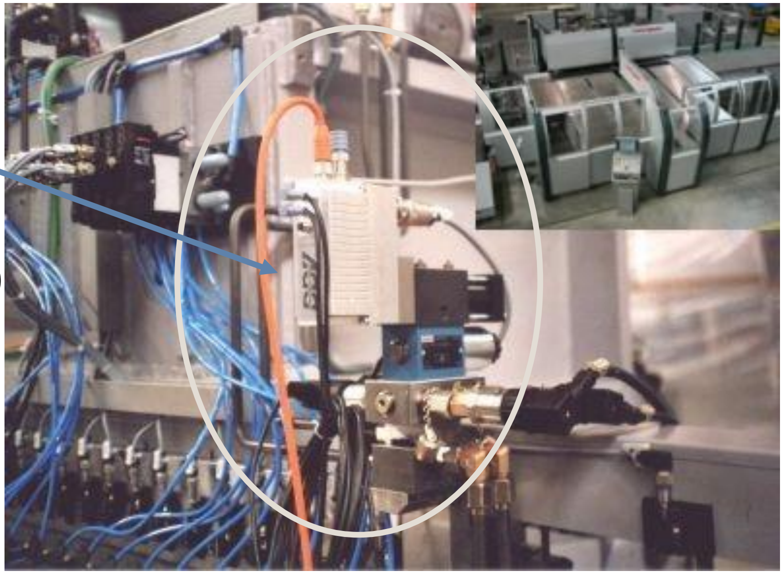
- Fieldbus connection: reduced wiring, less I/O modules, digital command (no noise), remote monitoring (detailed alarms / condition), remote troubleshooting
- Better dynamics, no drift, repeatibility

Numbers of strokes / min :	17
Max force :	1.200 KN
Min force	250KN
Moveable mass cushion	25.000 kg

METAL FORMING - Multi Stage Bending Press

METAL FORMING - Multi Stage Bending Press

Position & force control using ACV



Transducers:
- position: encoder
- force: 2 x pressure (force is calculated indirectly)

Functionality:
- Trajectory generator
- High precision position control
- Position control to pressure control bumpless transfer
- Pressure (force) limiting

Advantages:
- Distributed control: PLC coordinates the process, does not close hard real time loops
- Modularity: axis can be added easily, allowing different machine configurations

WIND TURBINE - PITCH CONTROL

WIND TURBINE - PITCH CONTROL

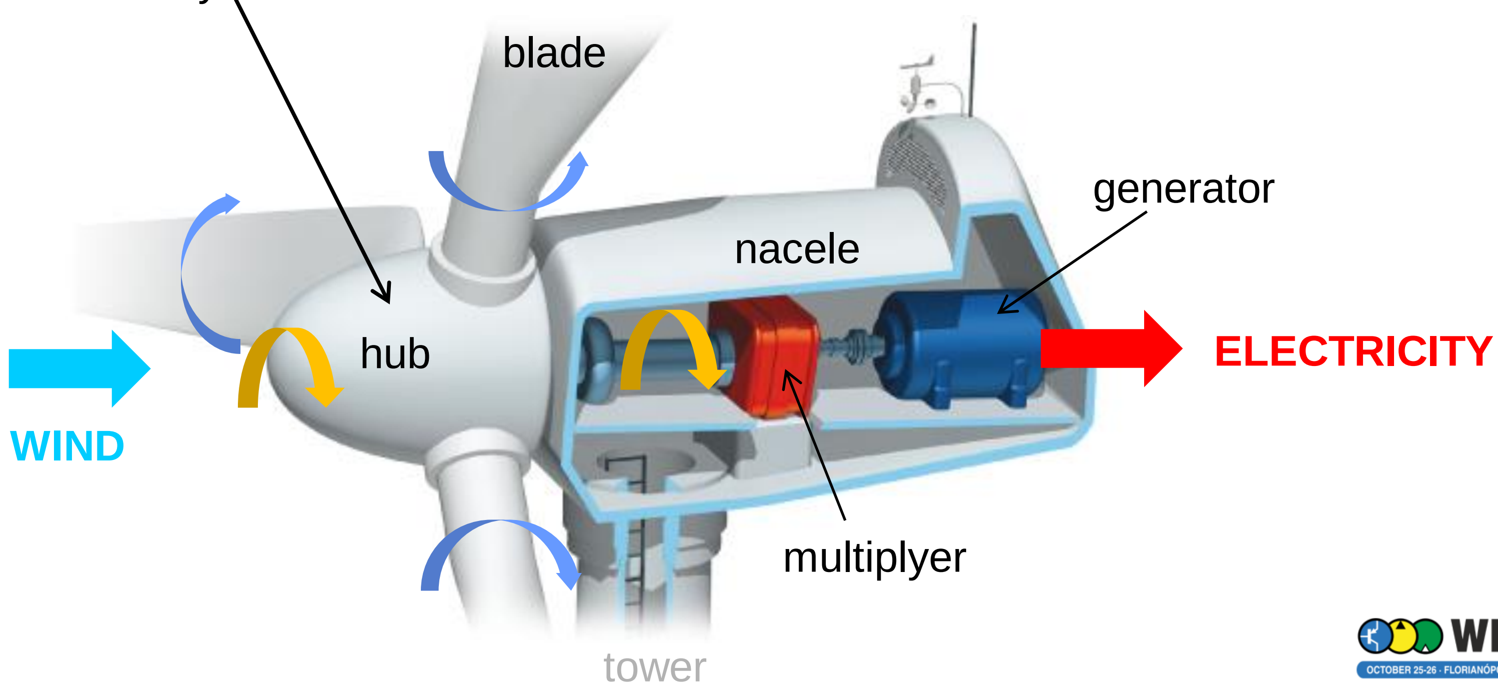
The PITCH CONTROL adjusts the turbine blades angle to:

1. *STOP the turbine in case of* emergencies/failures
2. MAXIMIZE energy conversion in a large wind speed range

Power ≈ pitch angle · (wind speed)^3

Functionality

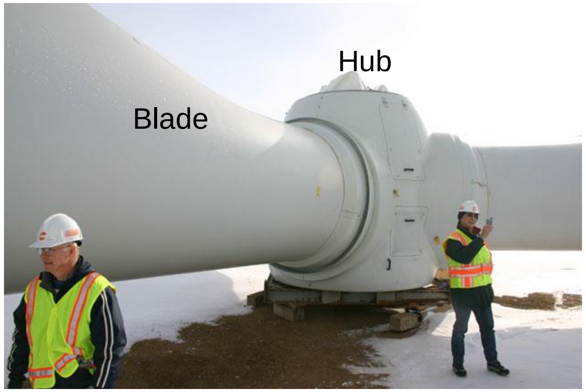
- 3 blades follows the same position command (syncronized movement)
- the pitch control system is assembled in the hub and rotates with the turbine

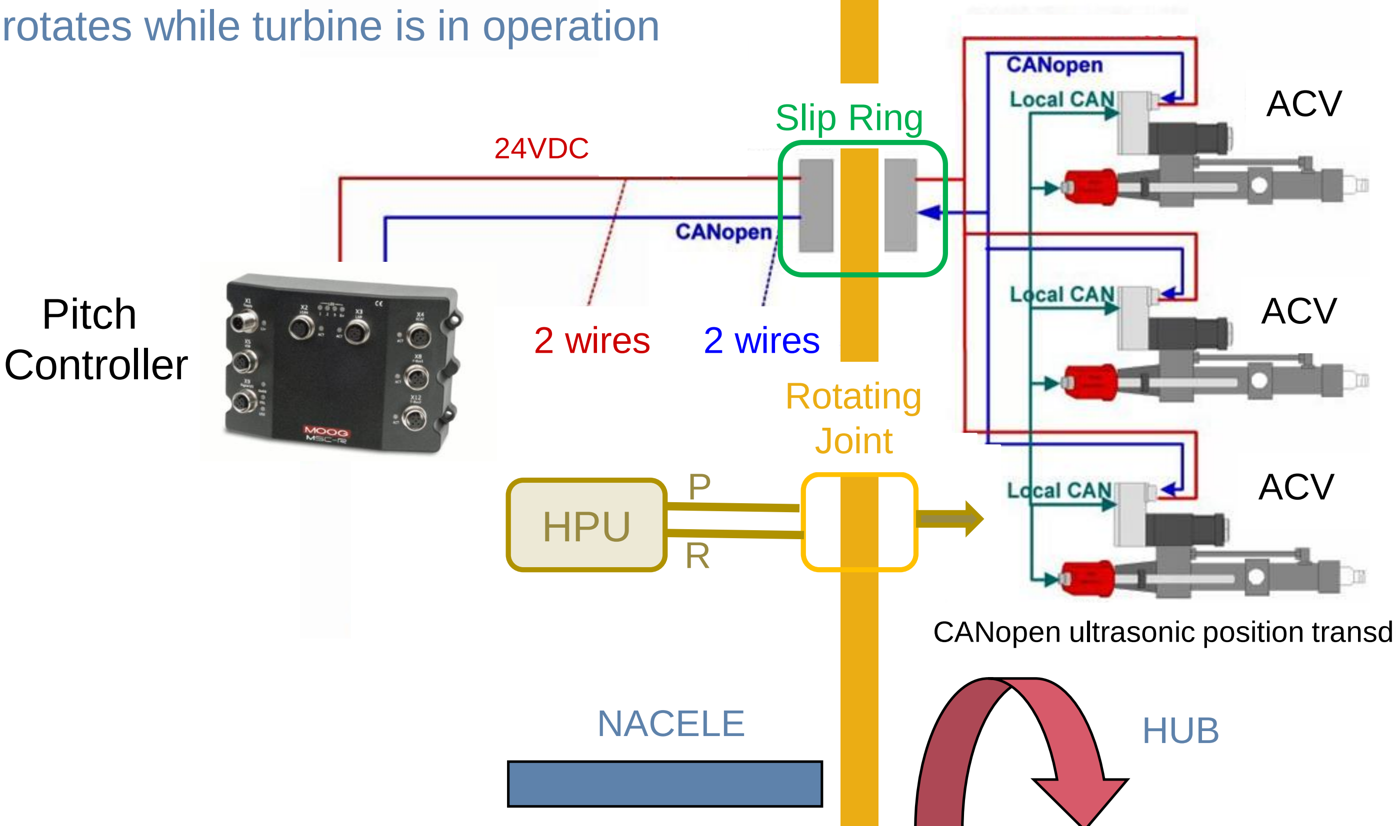


WIND TURBINE - PITCH CONTROL

Advantages

- Safer, individual position closed loop is implemented by each Axis Control Valve.
- Reliable data transmission through the slip ring (fieldbus communication = few wires)
- Remote system monitoring: very important because access to the hub is difficult and the hub rotates while turbine is in operation





THANK YOU!

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