Hydraulic Proportional and Closed Loop System Design

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Rexroth
Bosch Group

Contents

Proportional Components

- Operate under electronic control
  - Pressure Relief
  - Pressure Reducing
  - Throttling
  - Flow Control
  - Directional Control
  - Pump Control
    - Flow
    - Pressure
    - HP Limiting















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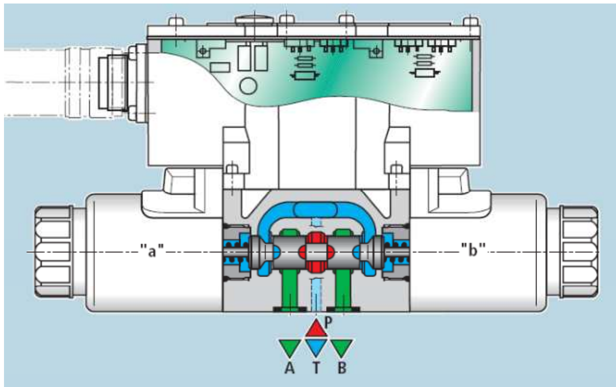
4 Main Control Principles

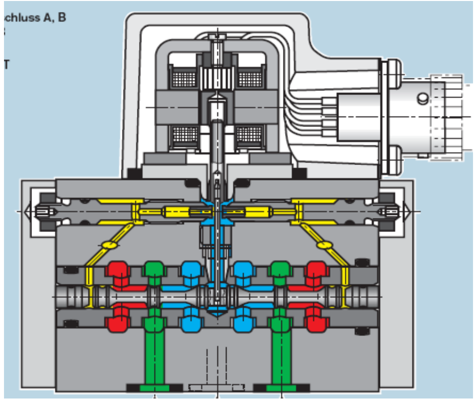
- Force Controlled



Servo Solenoid

Position Controlled Solenoid

Servo Valves



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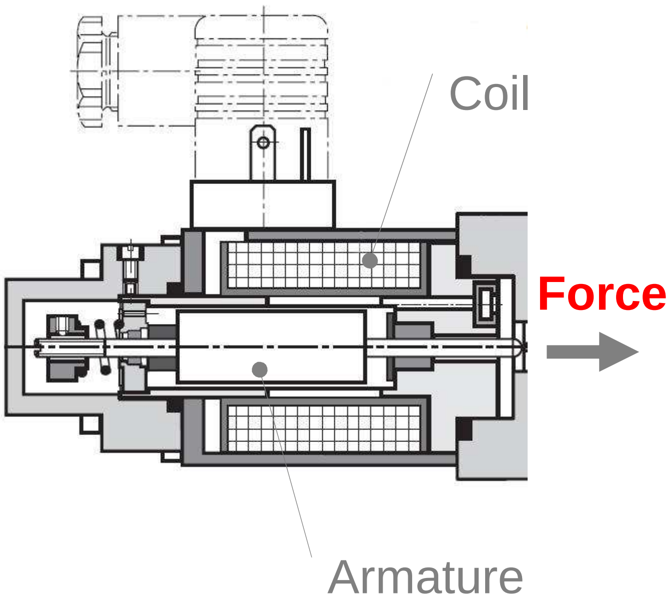
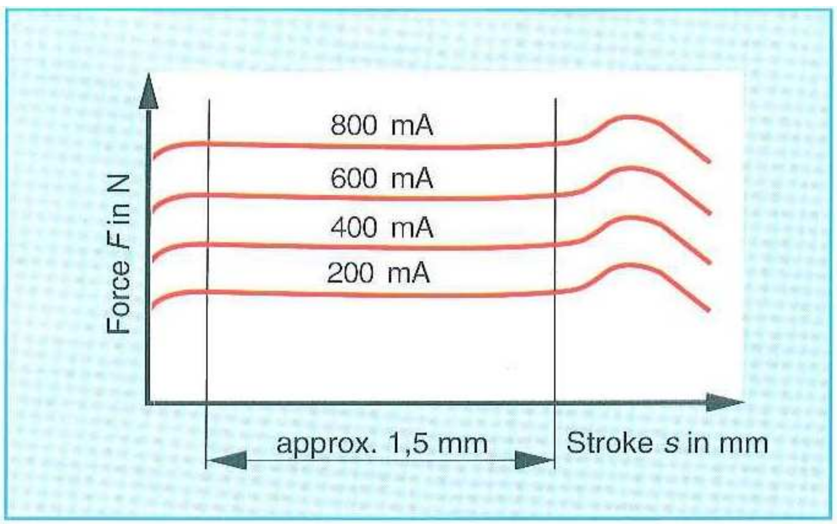
Proportional Force Solenoid

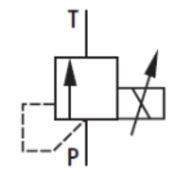
- Solenoid current is proportional to armature force, unlike on/off solenoid
- This proportional force is linear within a working stroke (approx 1.5 mm)
- Given a constant current, solenoid force remains constant within the working stroke

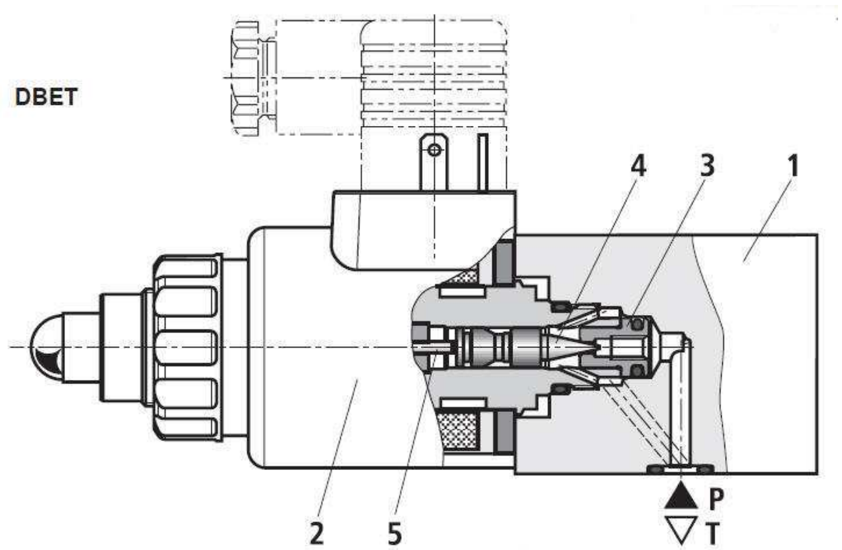


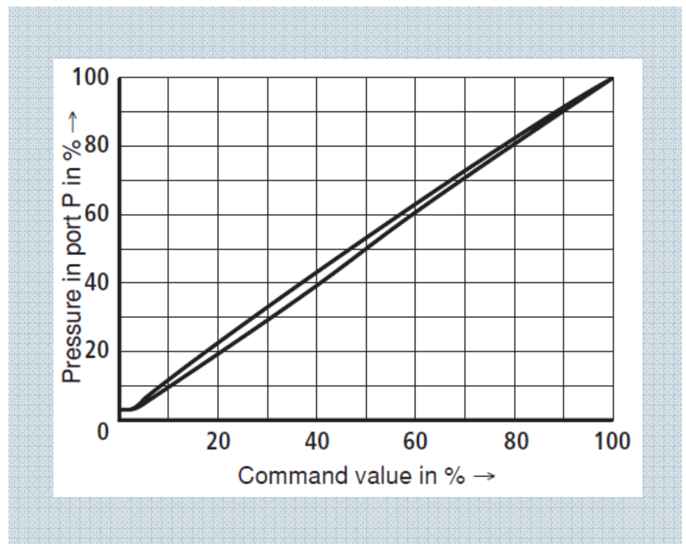


Proportional Solenoid on a Pressure Relief

- Solenoid force opposed by pressure P x A (area seat 3)
- Input to amplifier changes solenoid current (output Force)
  - 20% input => 20% pressure
  - 80% input => 80% pressure

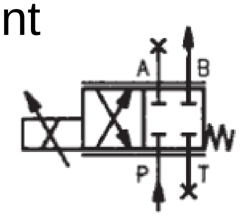


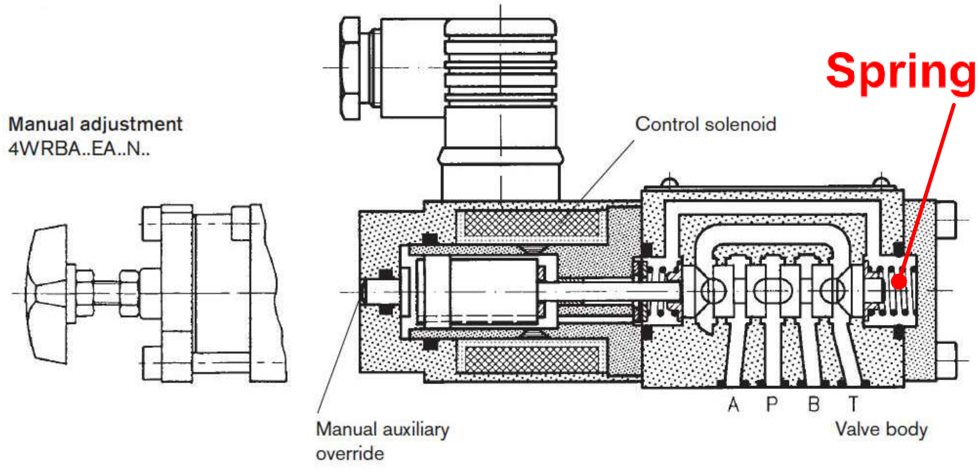


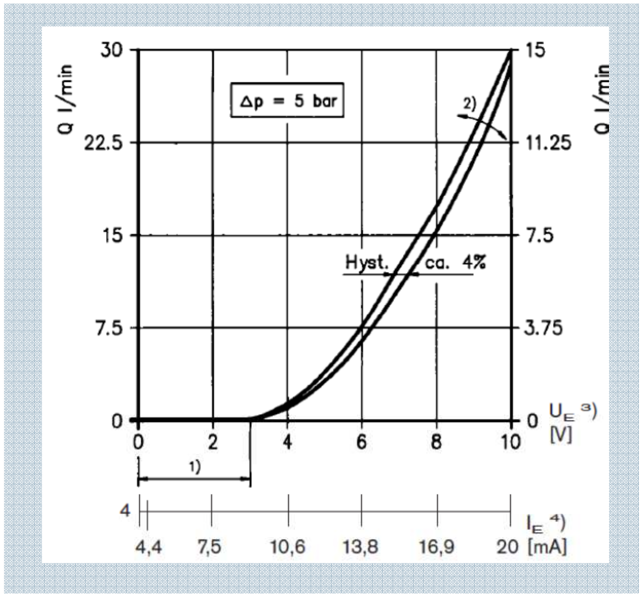


Proportional Solenoid on a Throttle Valve

- Solenoid force opposed by spring force = rate x displacement
- Spool position is constant, when forces are balanced
- Input (coil current) is directly proportional to output force
  - 40% input => 5% flow (due to spool overlap, deadband)
  - 80% input => 50% flow



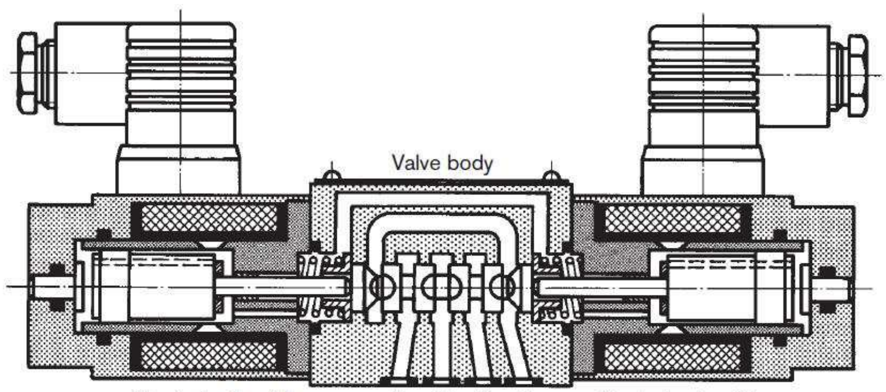




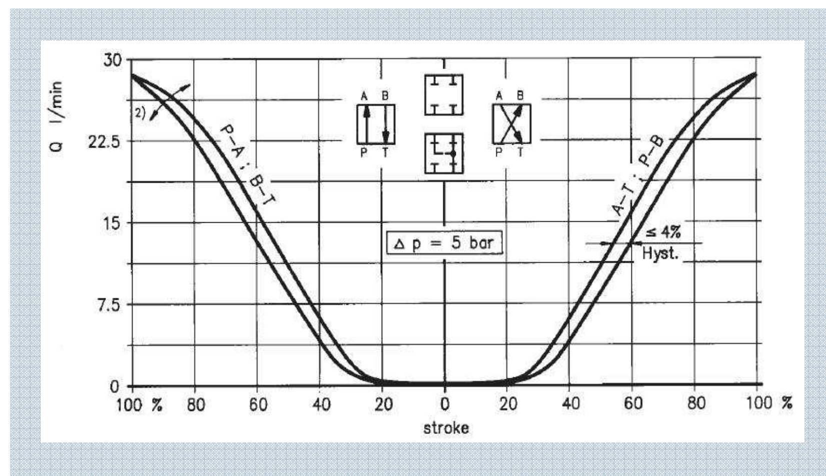
Proportional Solenoids on a Directional Valve

- Solenoid force vs. spring force positions spool
- Select one solenoid to control direction and flow
  - 40% input Sol-a => 15% flow P-to-B
  - 80% input Sol-b => 80% flow P-to-A
- Hysteresis <6 %

a  b

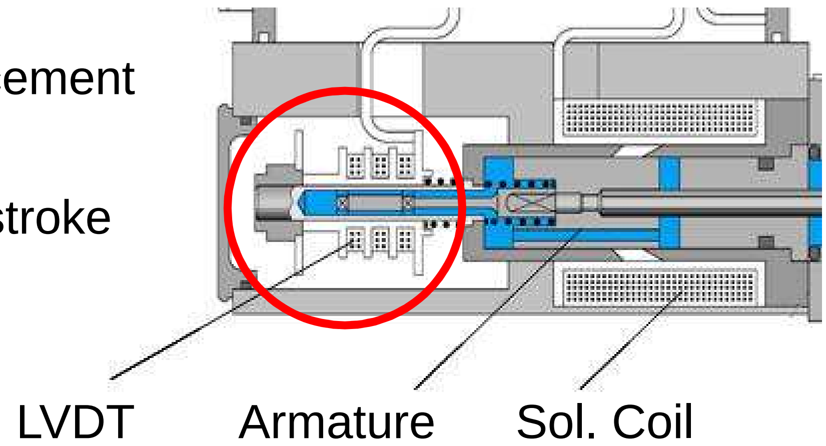


a b



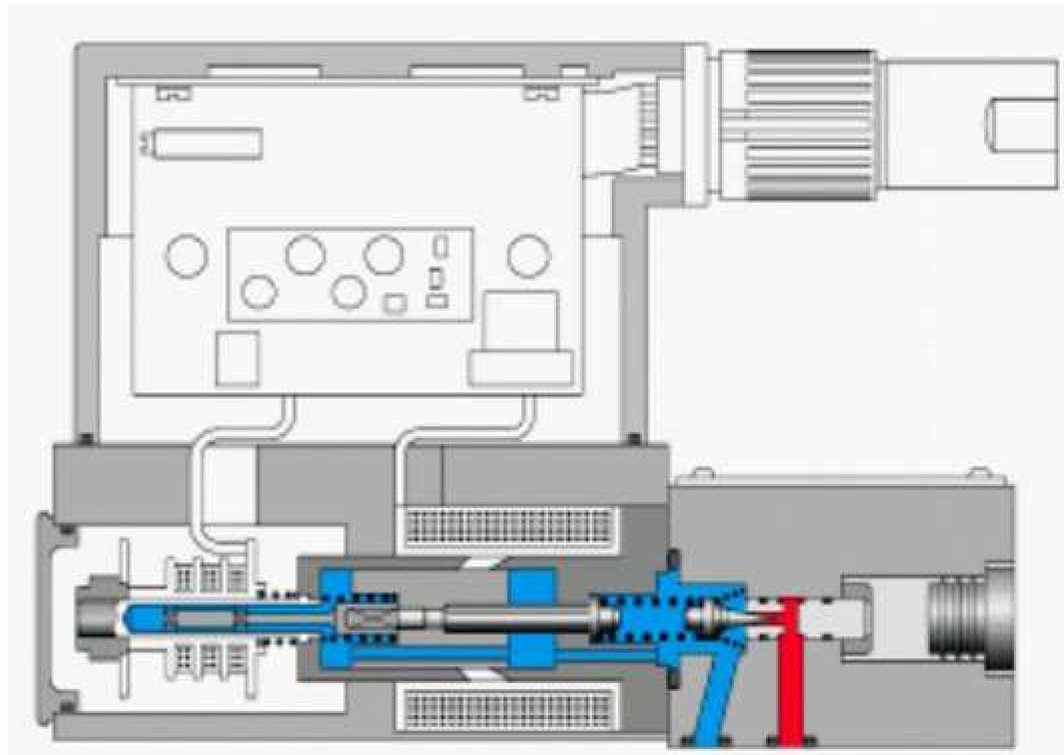
Stroke Controlled Solenoid

- Improve accuracy and performance with position feedback on solenoid
- LVDT – Linear Variable Displacement Transformer
  - Position transducer – short stroke
  - High resolution
  - Non-contacting
  - Robust



Stroke Controlled Pressure Relief

- Adding LVDT position feedback greatly improves resolution
- 0.2% Hysteresis



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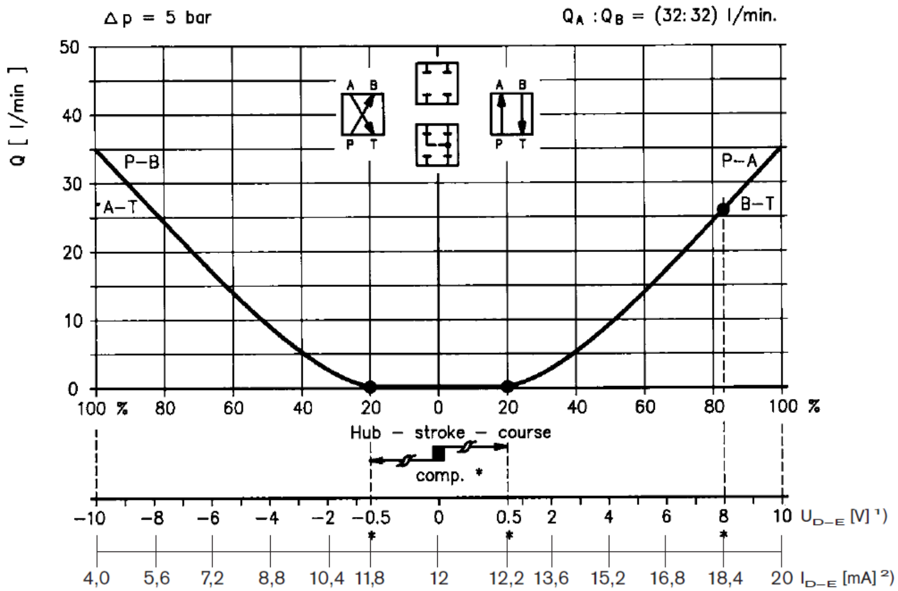
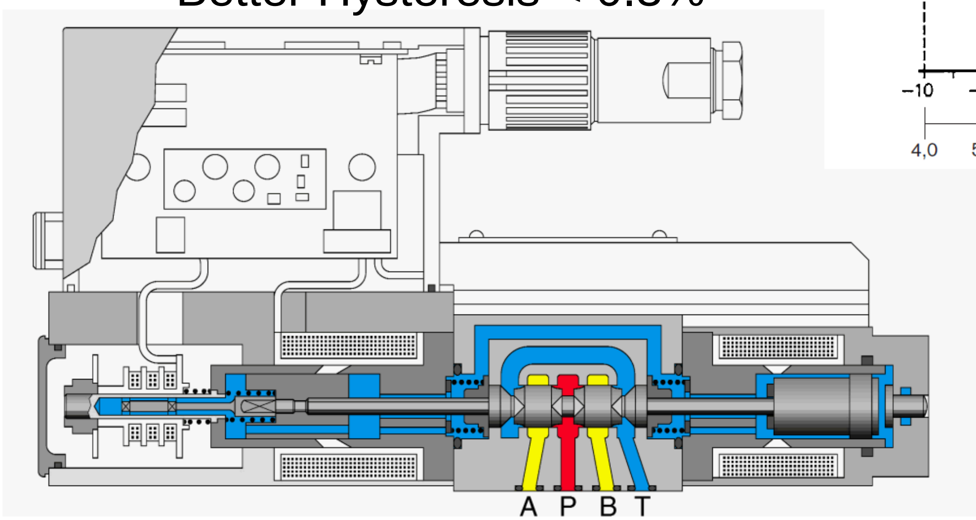
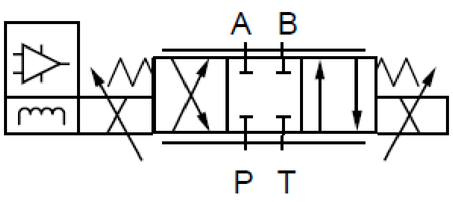
Stroke Controlled Directional Valve

- LVDT position feedback improves performance
  - Increased flow capacity
  - Higher Power Limit
  - Better Response Sensitivity
  - Better Hysteresis < 0.3%







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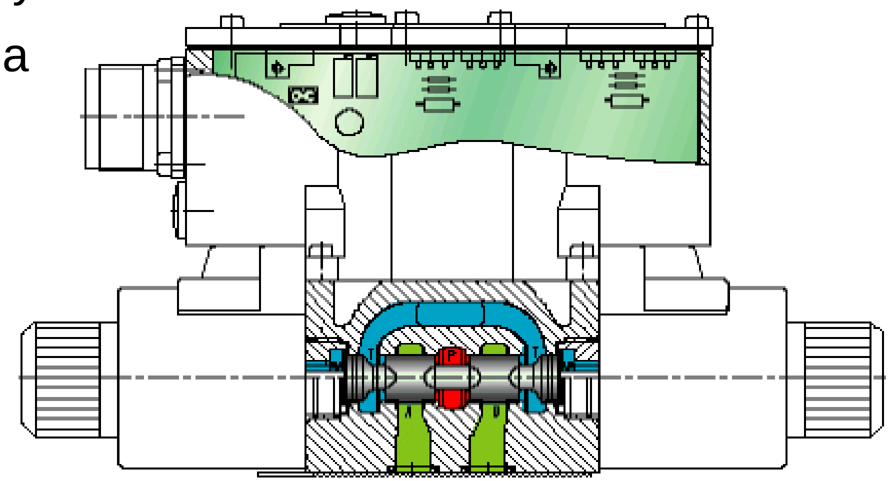
Construction of Proportional Valves

- Proportional spools slide in cast body
  - No sleeve, in main stage (unlike a servo valve)
  - Robust construction similar to on/off directional valves
  - High flow capacity
  - Low cost
- Throttle area normally formed by notches cut into spool
- Notch size and geometry determine flow capacity for a given housing



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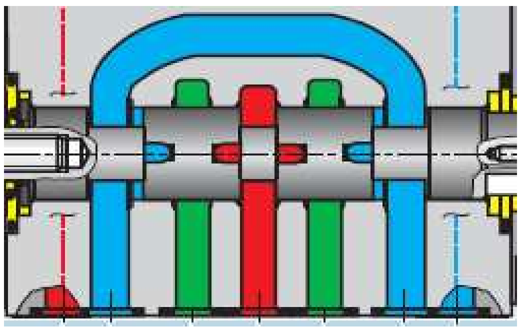
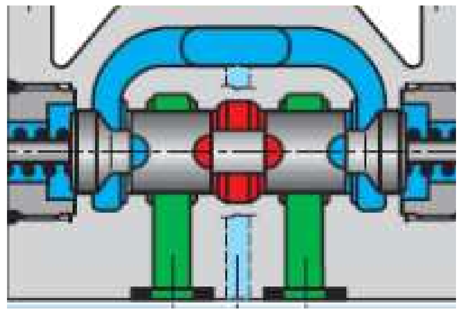
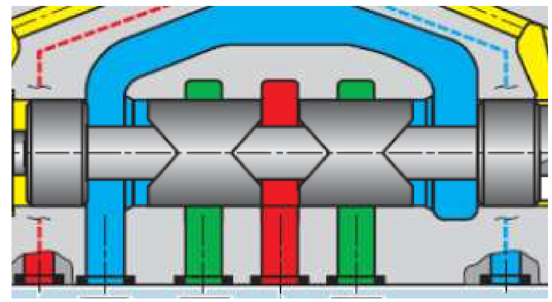
Proportionals

Notch shape determines flow characteristic



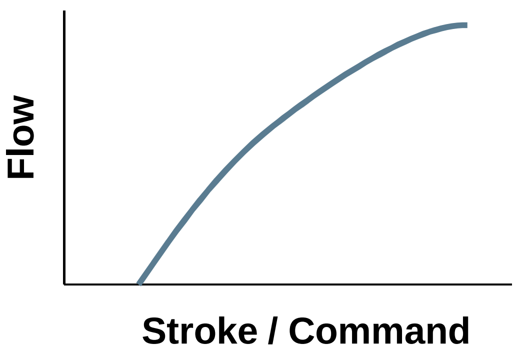


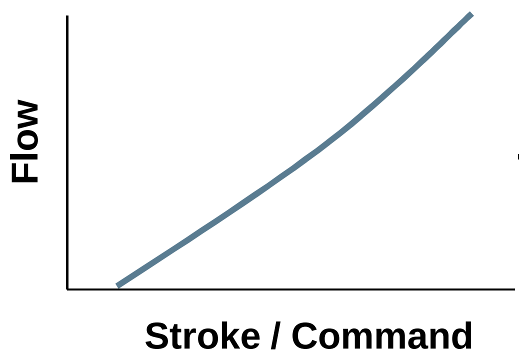


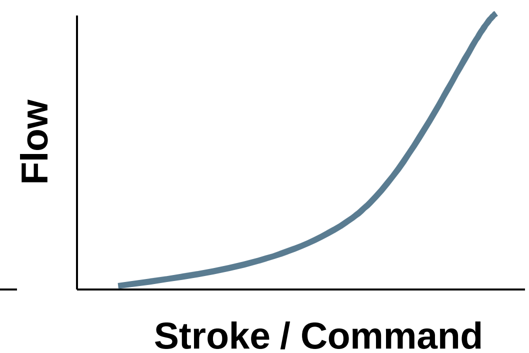
- “Square” Cut

“D” Cut

“V” Cut







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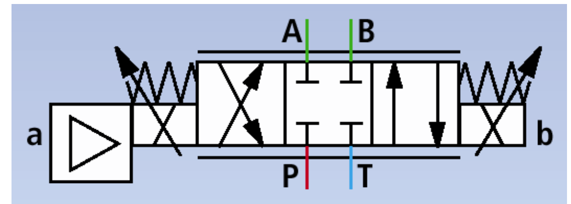
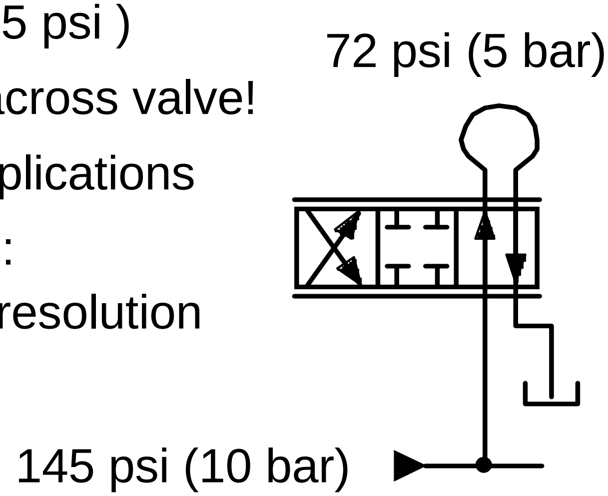
Nominal Flow Rating of Proportionals

- “Nominal Flow” for proportional spools is rated at Δp = 10 bar (145 psi) total, 5 bar per land
- Example 4WRA “Nominal Flow” is 7 to 60 LPM rated @ Δp =10 bar (145 psi)
- Only 145 psi pressure drop across valve!
  - This is a not typical for applications
  - Avoid to common mistake:
    Supersizing spool = poor resolution





Flow Rating of Proportional Valves

- Required Flow is normally given, Q_{req}
- Nominal valve drop Δp = 10 bar (145 psi)
- You must estimate pressure drops,
  $p_{system} - p_{load} = p_{valve}$
- To find a spool, solve for "Nominal flow"
  - Estimate required valve pressure drop
  - Q is proportional to square root of corresponding Δp

$$Q_{nominal} = Q_{req} \bullet \sqrt{\frac{\Delta P_{nominal\ rating}}{\Delta P_{real\ valve\ drop}}}$$

  - Then, go to valve data sheet and select the closest spool to this value

$$Q_n = c\,A\sqrt{\Delta P_n}$$

$$Q_{req} = c\,A\sqrt{\Delta P_{real}}$$

c = orifice flow co-efficient
A = Area of orifice
(same values for both equations)

Using Flow Diagrams

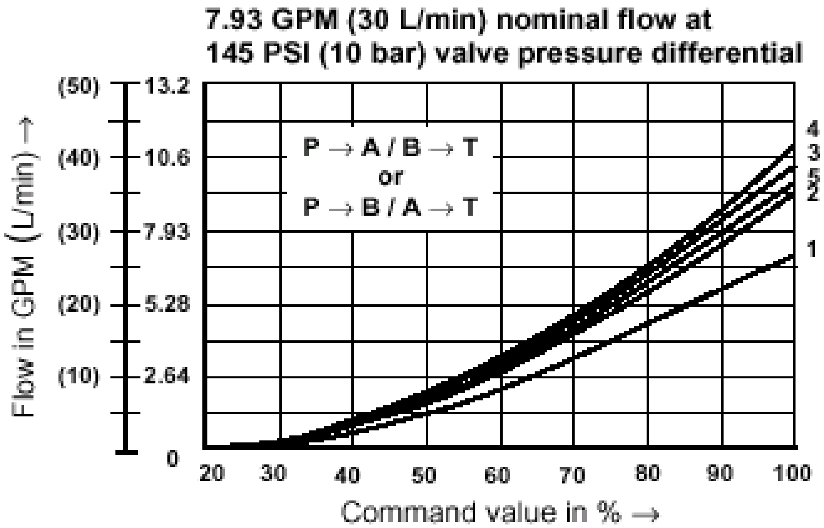
- Estimate Δp required across valve in both flow paths,

  System pressure – Load pressure

- Each housing size may have several spool flow options

  Find a spool curve that fits the target nominal flow around 90% Command, with a reasonable Δp, close the your estimated valve Δp

30



1 Δp = 145 PSI (10 bar) constant
2 Δp = 290 PSI (20 bar) constant
3 Δp = 435 PSI (30 bar) constant
4 Δp = 725 PSI (50 bar) constant
5 Δp = 1,450 PSI (100 bar) constant

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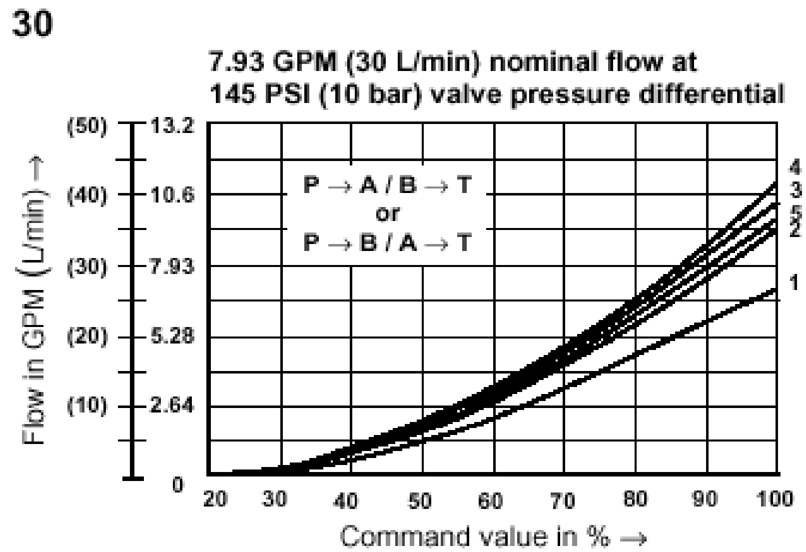
Can Valve Pressure Drop Be Too High?

- Yes, valve Δp over 50% system pressure is high
- Avoid over-flowing valve! curve 5
- High flow forces try to center spool on direct operated proportional valves

  High Δp in a proportional valve creates a high rotational force
- Anti-Rotation design prevents spinning spools, but limit time at extreme conditions to avoid problems
- Sleeve and Spool valves do not have rotational forces



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5 Δp = 1,450 PSI (100 bar) constant

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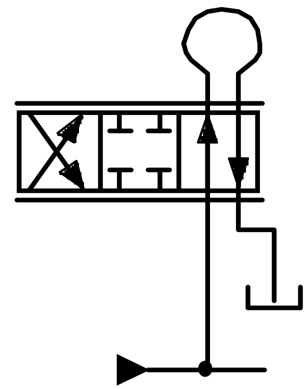
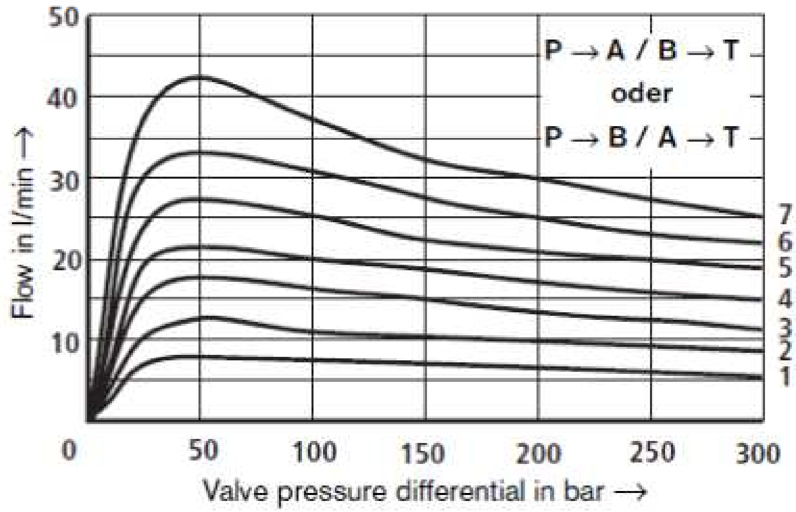
Power Limits

- All direct operated proportional valves have Power Limits ($Q_{valve} \cdot \Delta p_{valve}$)
- Bernoulli forces try to center spool at high Δp_v
- Power Limit decreases if flows are unequal



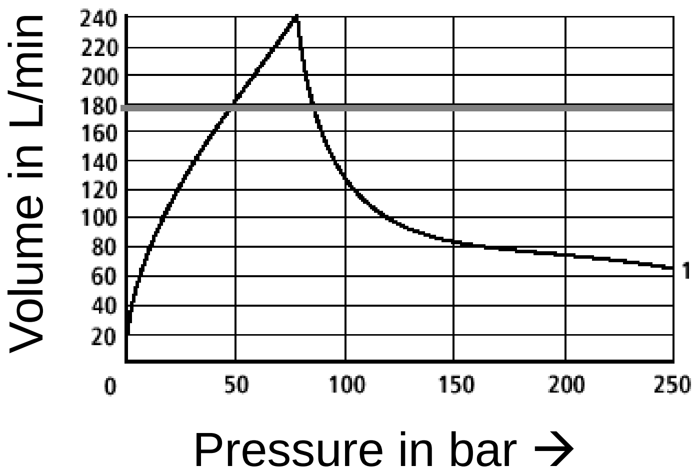
Performance limit, nominal flow 30 l/min

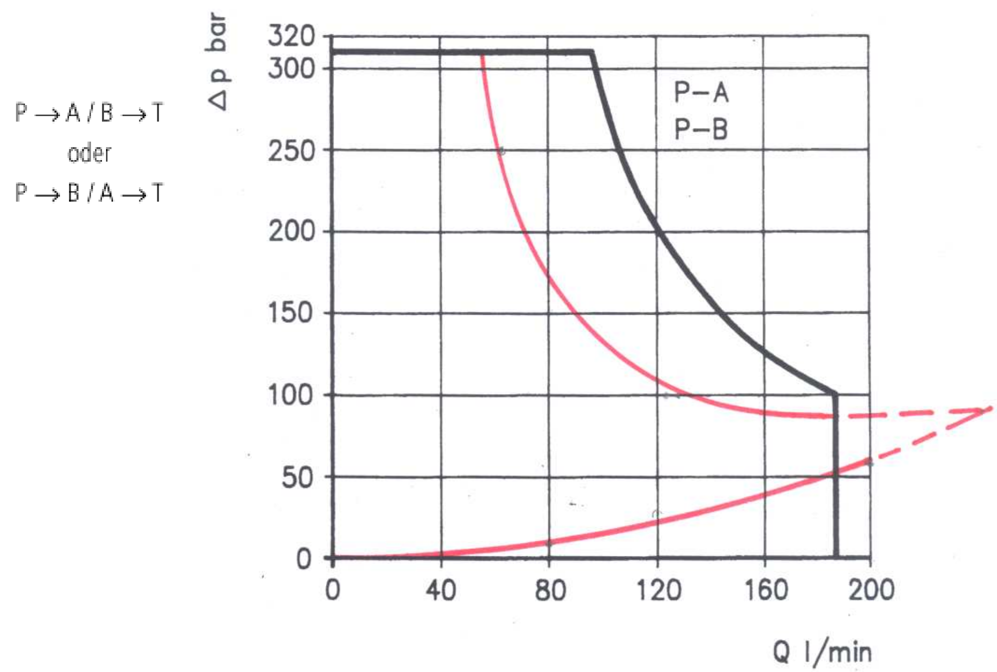


1 Com. value = 40 %
2 Com. value = 50 %
3 Com. value = 60 %
4 Com. value = 70 %
5 Com. value = 80 %
6 Com. value = 90 %
7 Com. value = 100 %

Power Limits

- Power limit diagrams may be plotted in different ways, but they represent the same thing
- Sometimes performance limits are only listed in a table





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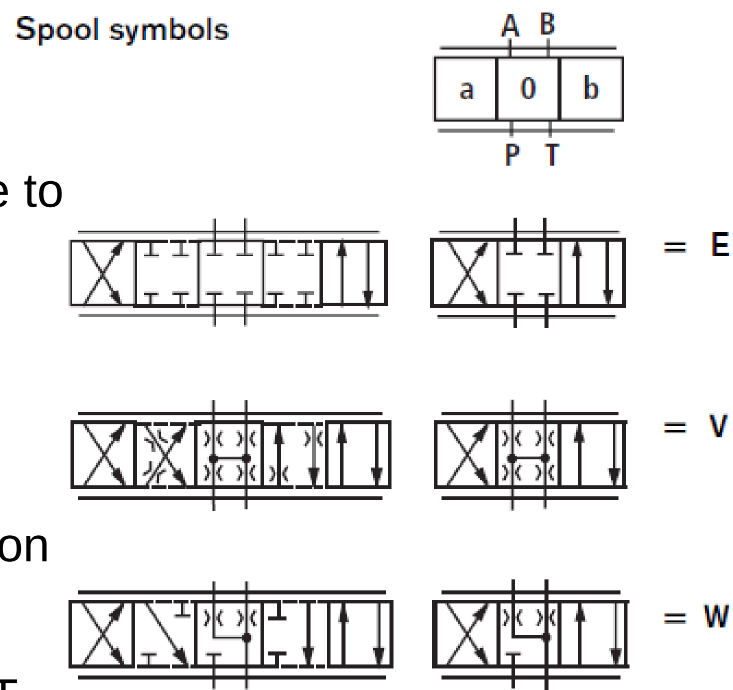
Common Proportional Spools

- E-spool: All ports blocked
  - Overlap 10% to 20% on each side
  - Differential cylinder may creep, due to leakage in cylinder and spool
  - Closed loop positioning requires a more advanced controller
- V-spool: No deadband
  - 1% underlap allows housing variation
  - *Only* for closed loop control
- W-spool: 2% to 3% open A to T, B to T
  - Primarily for differential cylinders
  - *Only* for open loop applications



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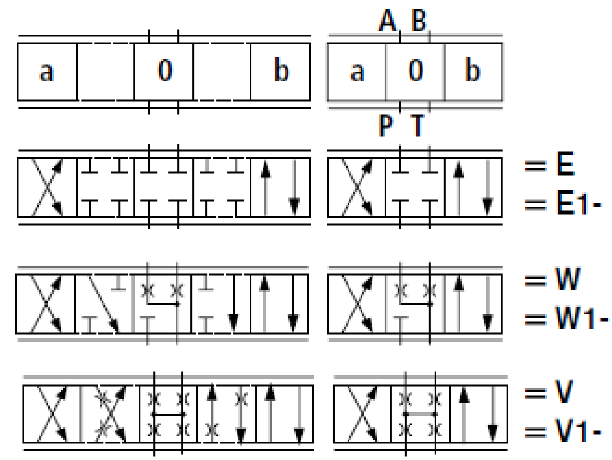
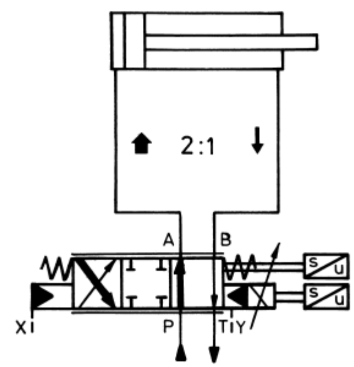
Asymmetrical Spools

- Asymmetric spools like E1-, W1-, V1-
  - 2:1 flow area (4 notches vs. 2 notches)
  - For differential area cylinders
- Balances Δp across each flow path, due to unequal flows to/from cylinder
  - Can prevent cylinder cavitation
  - May improve cycle time
    - Better deceleration
    - Shorter reversal time
  - This is more important with larger flow valves





With spool symbol E1-, W1-, V1-:

P → A :	q_{Vmax}	B → T:	$q_V/2$
P → B:	$q_V/2$	A → T:	q_{Vmax}

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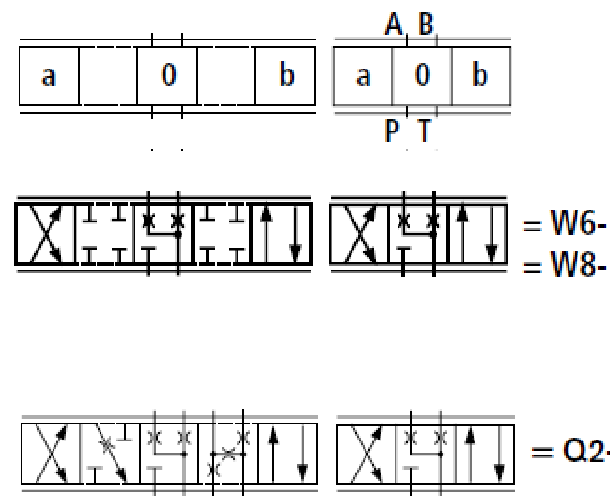
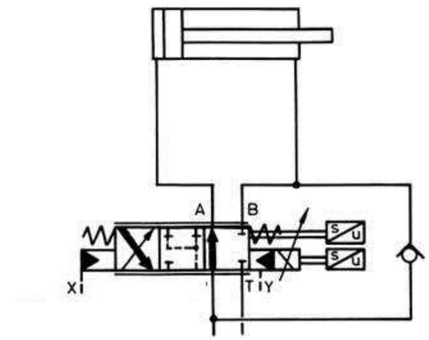
Additional Spool Types

- W6-spool: improved W-spool
  - crossover all ports are closed (to stop)
  - then decompress at center, open 2% A to T and B to T
- W8-spool: improved W1-spool, like W6 but 2:1 flow area
- Q2-spool: for injection molding cylinders



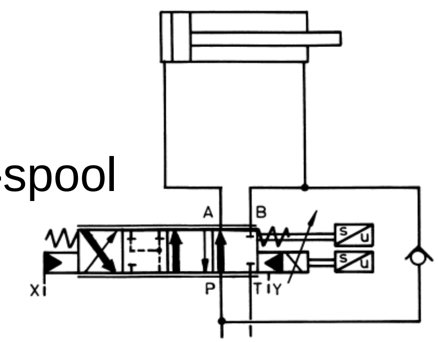
Regen Spools with external bypass

- W3-spool: hydraulic regeneration extends cylinder quickly. Rod side is blocked by B port. High pressure on rod end pushes flow over external check valve
  - Fast traverse. but rod pressure is high!
  - Tonnage reduced!
    Extending force = rod area x pressure bore
- W9-spool: improved W3 (decel like W8)
- W4-spool: 4-position, regen spool
  - Full tonnage below 33% (P-to-A and P-to-B, like W1)
  - Regen above 33% (P-to-A and B blocked, like W3)



W3-spool
W9-spool

W4-spool



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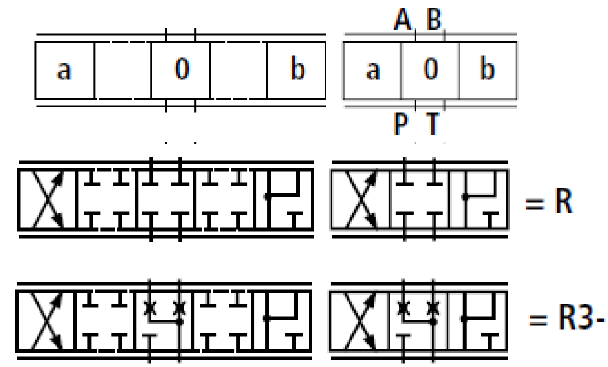
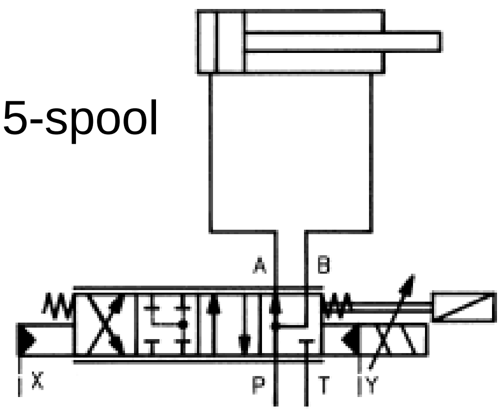
Spools with Internal Regen

- R-spool: Internal hydraulic regeneration
  - Combines B to P in spool!
  - Blocked center, so cylinder could creep
- R3-spool: Internal regen
  - connects B-to-P path inside housing
  - Center P blocked, A and B to T
- R5-spool: Internal regen with 4-position press-regen spool
  - P-to-A full tonnage below 33%
  - Regen above 33% (like R3)
- Internal regen flow can not exceed limits of main valve (lower flow than external regen)

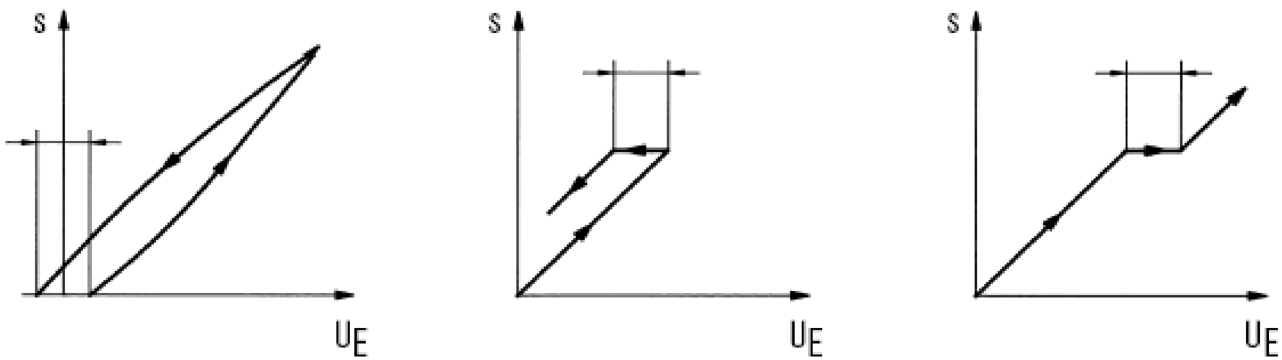


R5-spool



Performance Terms

Hysteresis ≤ 5% **Reversal Error ≤ 1%** **Response Sensitivity ≤ 0.5%**



- Hysteresis is max. position error which depends on direction history
- Reversal Error is the smallest signal that moves spool in the opposite direction
- Response Sensitivity is the smallest signal to move spool in the same direction, after stopping (resolution of valve)

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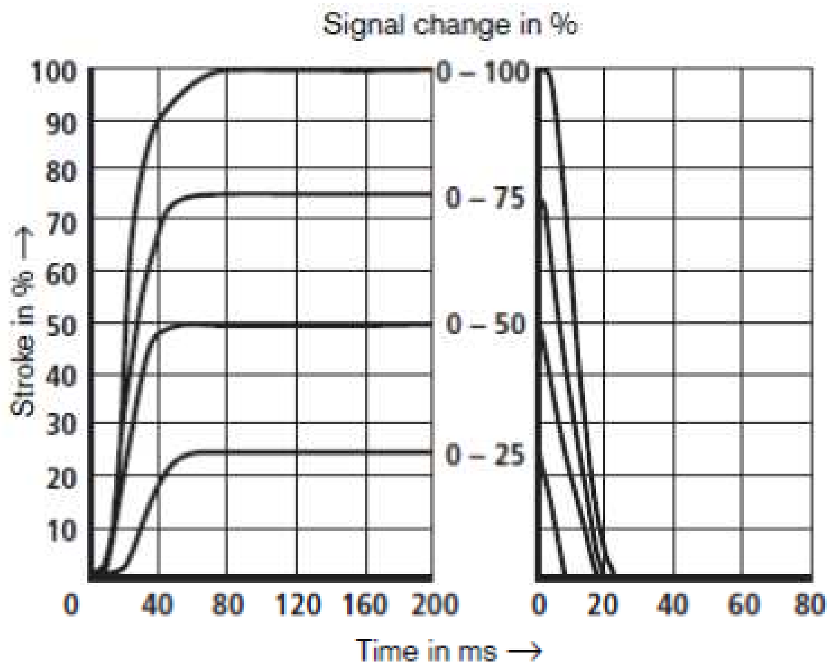
Performance Terms

- **Repeatability** - Ability to achieve the same spool position (or pressure) given the same valve, under the same conditions, with the same command input
  - Force controlled valves: 2% to 3%
  - Stroke controlled: 0.1% to 0.5%
  - Typically half the Hysteresis

- Question… if you need to achieve 100 psi pressure repeatability on a system operating at 5000 psi, should you use a proportional relief valve with a repeatability of 3%?
  - No… maximum repeatability is 0.03 x 5000 psi = 150 psi

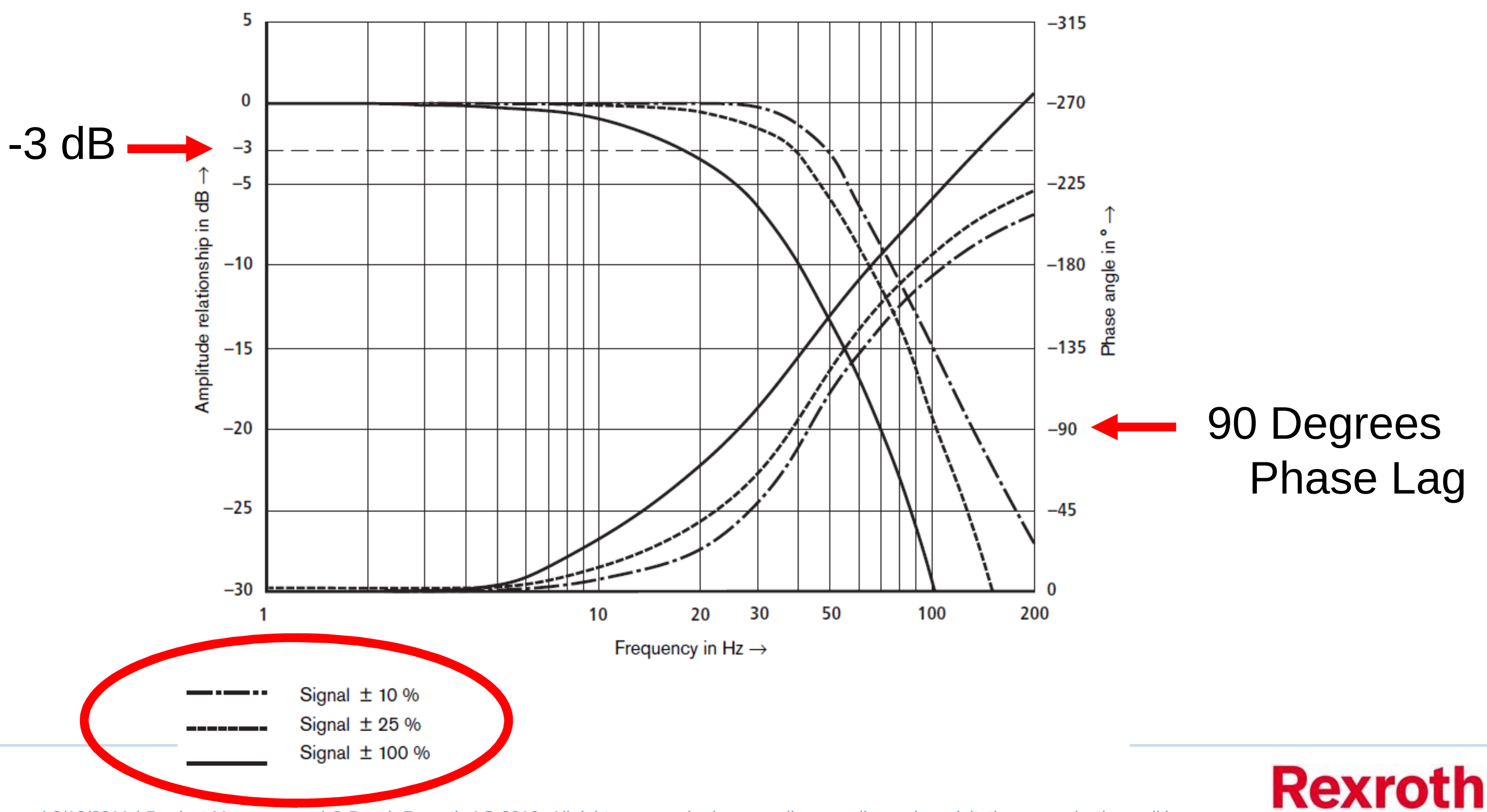
Step Response

- Time for spool transition given a stepped input
- Standard test conditions (fluid temp, pressure) may not match your application
- If only given a time, you must know measurement criteria
  - 0 to 100%
  - 10 to 90%,
  - 20% to 80%



Bode Diagrams

- Valve frequency response @ -3dB amplitude
- Phase Lag @ -90 degrees



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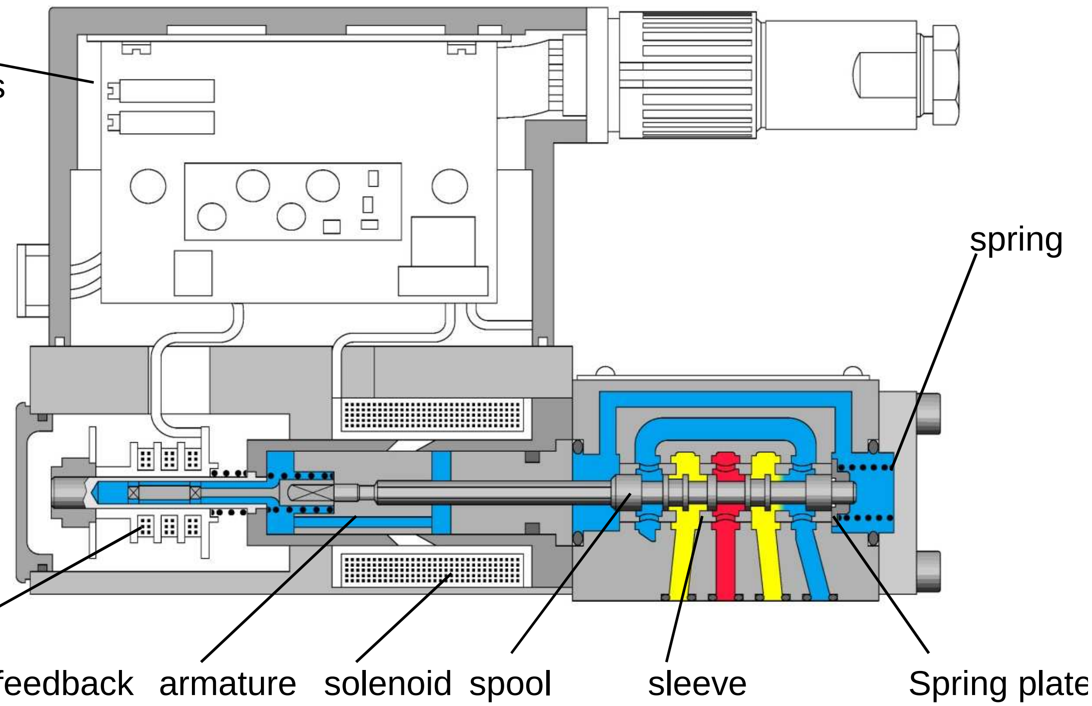
Tester for Integrated Electronic Valves

- VT-VETSY-1-1X/1-2-1-1-0/USA
  - R978050422
- Includes 24vdc power supply with US power cord, 2 cables for 7-pin, servo adapter, VET tester

Servo Solenoid Basics

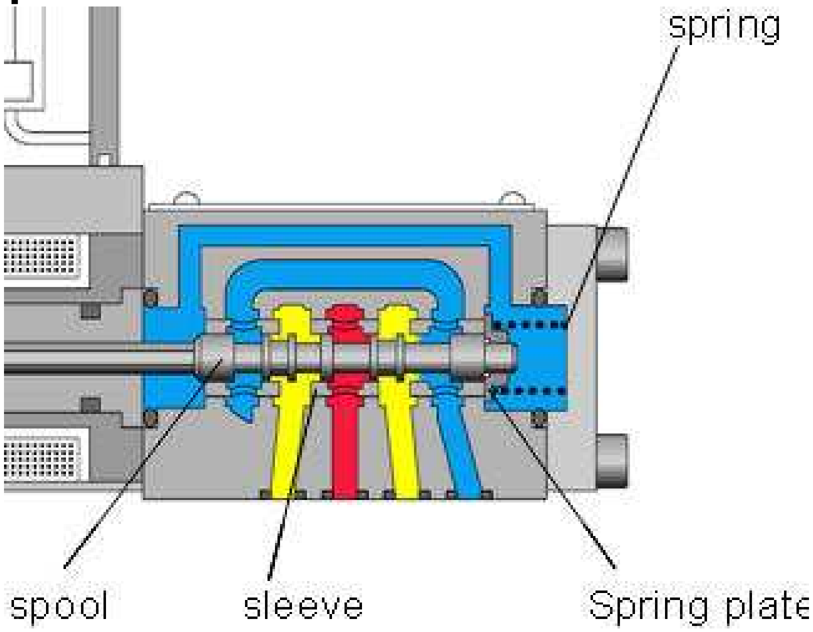
Servo Solenoid – Direct Operated

- Very Fast Stroke Solenoid
  - Directly Positions Spool
  - No Flapper/Nozzle
  - No Jet-pipes
  - No Pilot Leakage



Servo Solenoid – Direct Operated

- Spool and Sleeve Assembly
  - Zero Overlap
  - Accurate
  - Symmetrical
  - Linear
- Normal filtration
- Main sleeve means Nominal Flow @ Δp 70 bar or 1000 psi !
  - 2 to 100 Lpm (size 6 & 10) like a Servo Valve @ 70 bar Δp



4WRPEH - Direct Operated

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Nominal Flow Conversion

- Easily convert between
  - Sleeve/Spool rated Nominal Flow @1000 psi Δp
  - Proportional rated Nominal Flow @ 145 psi Δp

$$\sqrt{\frac{70}{10}} = \sqrt{7}$$

- Servo to Proportional nominal rating, divide by square root 7
- Proportional to Servo nominal rating, multiply by square root 7

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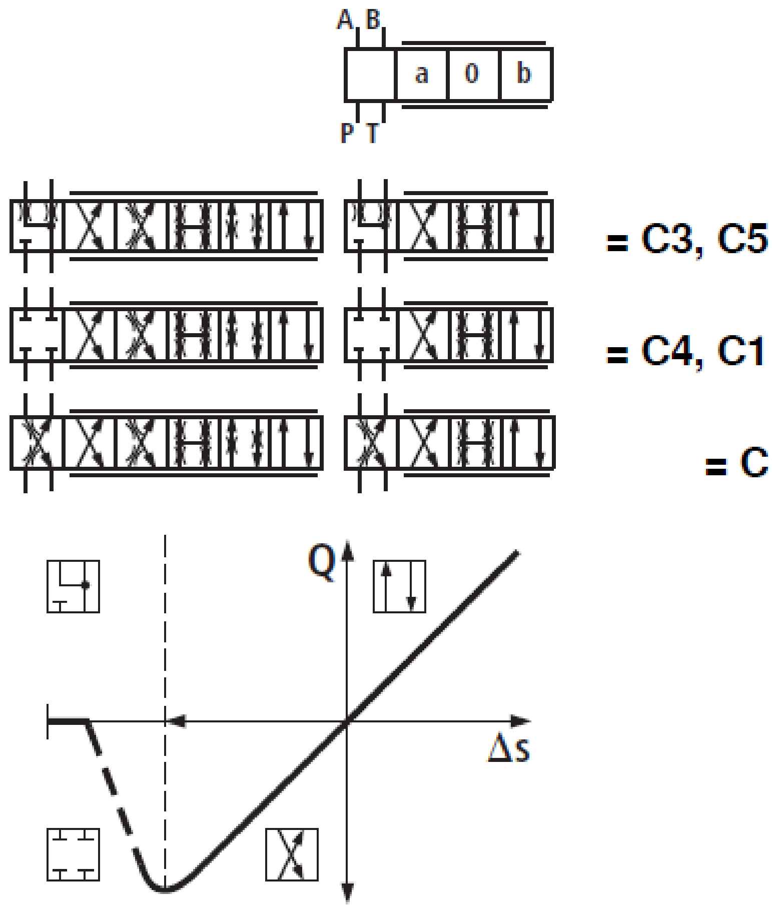
Spool/Sleeve in Direct Operated Servo Solenoid

- Zero overlap matched spool and sleeve
- Failsafe position with over-lap, by spring offset during power off / fault), which may eliminate need for an external blocking valve



C5, C1 have 2:1 flow ratios

Servo Solenoid - Direct Operated

- Smooth cross-over (through center) like Servo, important to
- Most Reliable OBE Available
- 25*g* mechanical shock and vibration for 24 hours in 3 Axis
- Long Service Life
- 60 to 100 Hz @ -90 Deg, small signal
- Ideal for many closed loop applications

4WRPH6, 4WRPEH6, 4WRPEH10
RE29035, RE29037

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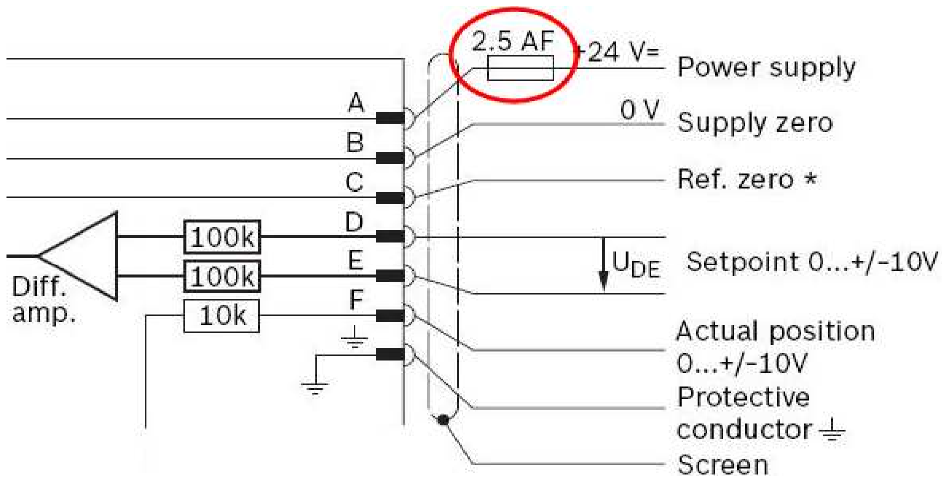
Fuse OBE on Servo Solenoids

- Protect each OBE with 2.5 Amp, Fast acting Fuse!



Servo Solenoid Valves

Pilot Operated Servo
Solenoid Valves

Servo Solenoid – Pilot Operated

- Main stage has proportional spool in cast housing
- Pilot stage has sleeve/spool (4WRPEH)
- Nominal Flow rated at 10 bar Δp for pilot operated Servo Solenoid valves
- E, W, V, Q4-spools like proportional
- V-spool at spring-center has 1 to 6% offset P-to-B
- Failsafe of pilot (C3) allows main spool to spring center

4WRLE
RE 29088
RE 29089

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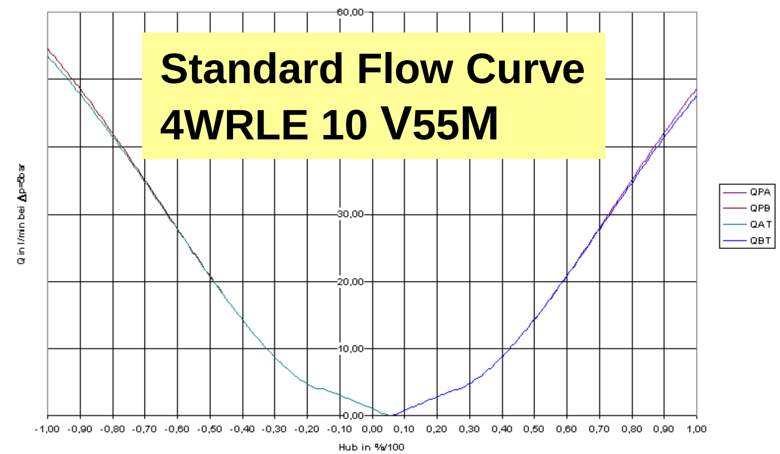
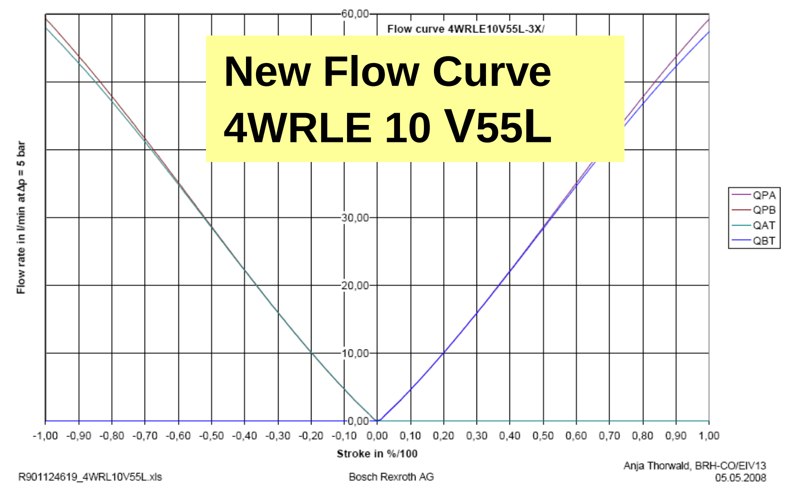
Linear Characteristic

- V-Spool with Linear flow characteristic can improve system performance
- Higher P-gain in controller reduces following error
- Easier tuning of close loop application





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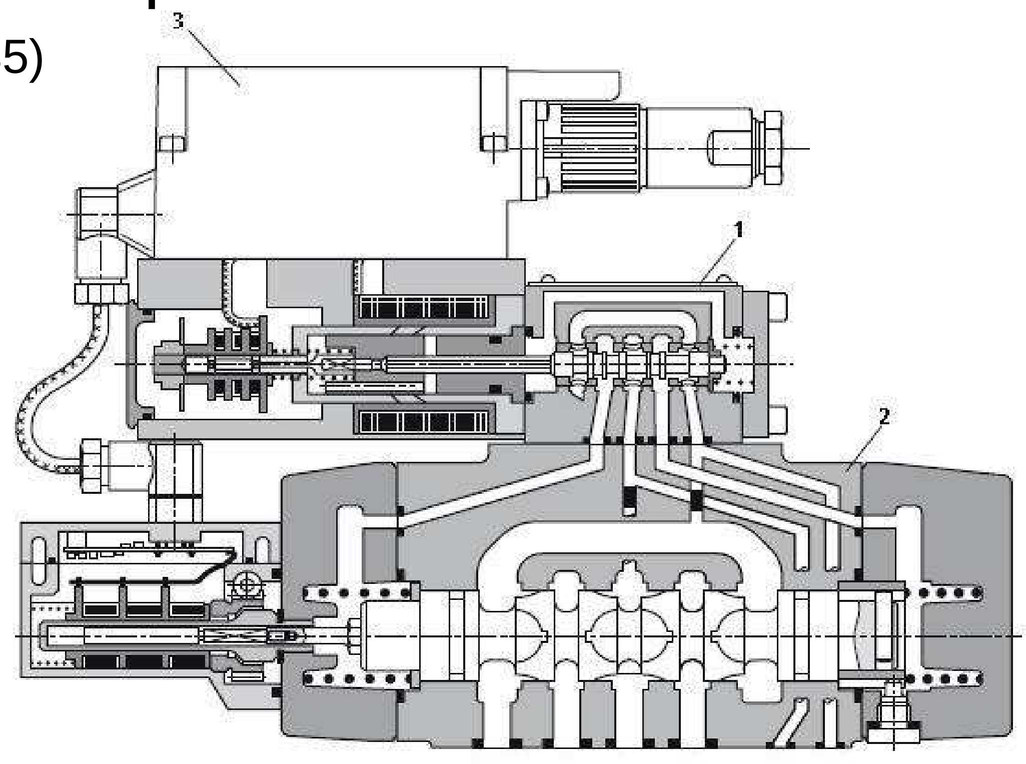
Servo Solenoid – Pilot Operated

- Nominal Flow (Size 10 to 35)
  - 50 to 1100 LPM
    @ 10 bar or 145 psi Δp,
    like a Proportional
- Main stage has LVDT feedback
- Many Same Advantages
  - Robust
  - Reliable



4WRLE - Pilot Operated

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Servo Solenoid Valves

High Response
Servo Solenoid Valves

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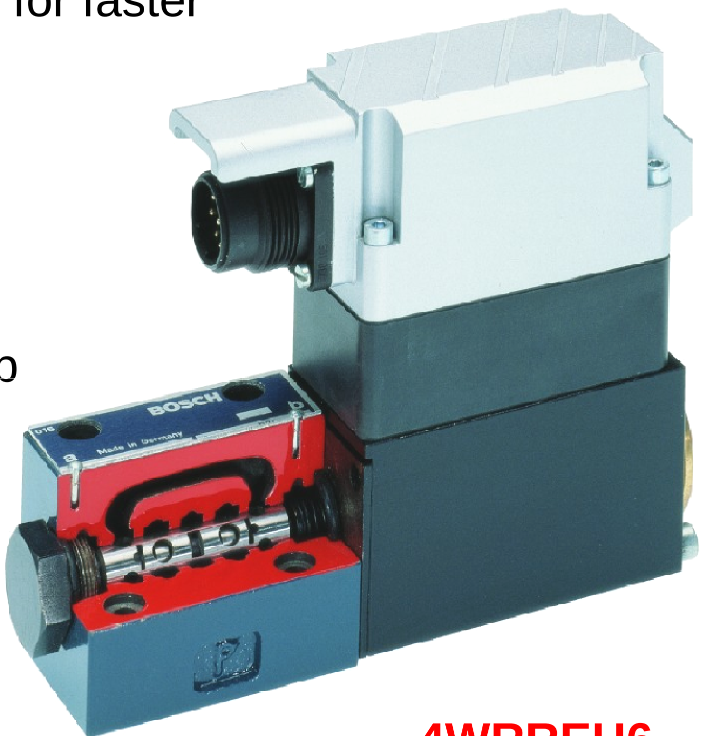
High Response Servo Solenoid - Direct Op

- 4WRREH 6: Push-pull, servo solenoid for faster response than 4WRPEH 6
  - 250 Hz @ -90 deg, small signal
  - Nearly as fast as 4WS2EM6
- Sleeve/spool assembly
- Nominal Flow 2 to 40 LPM @ 70 bar Δp



4WRREH6
RE29041

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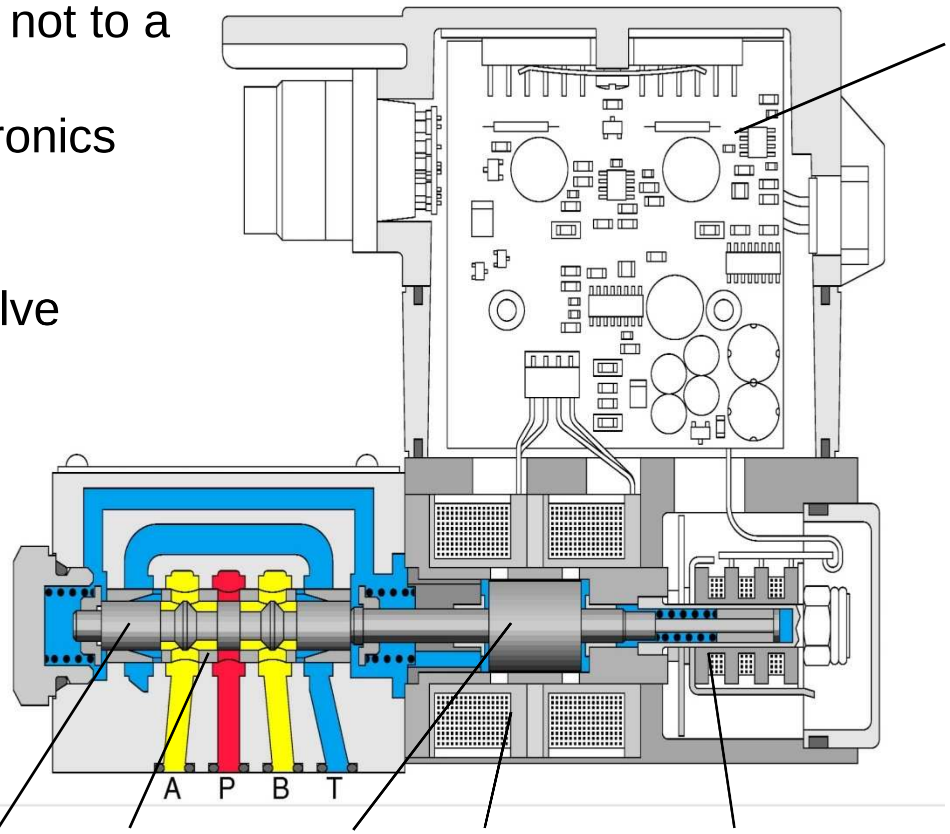
High Response Servo Solenoid - Direct Op

- Failsafe of spool is not defined
  - Spring centers, but not to a failsafe position
- 12-Pin Onboard Electronics
  - Enable input
  - Fault output
- Makes a great pilot valve

4WRREH6



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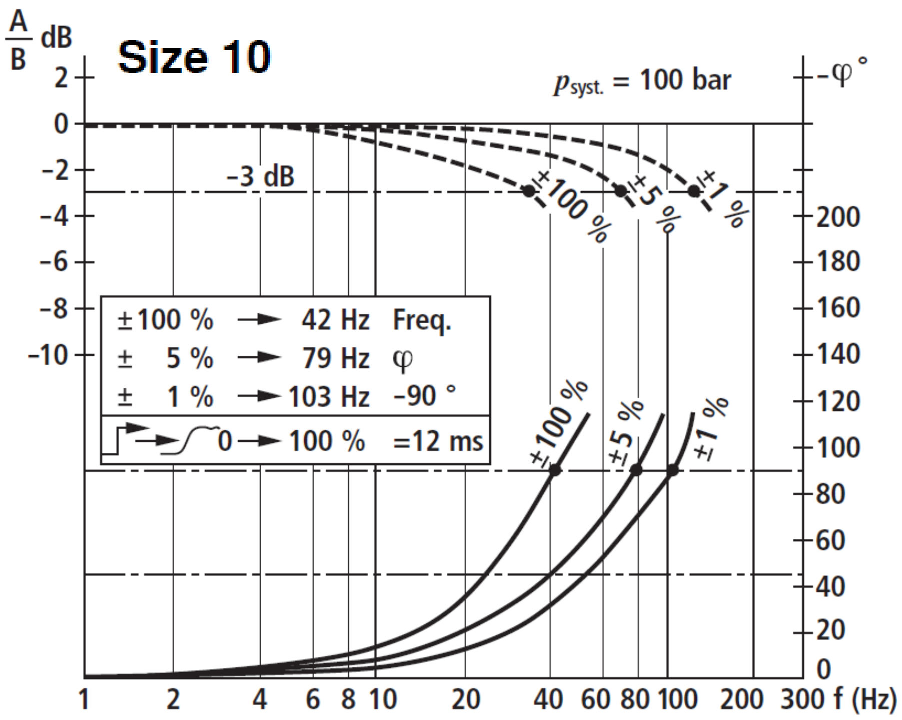
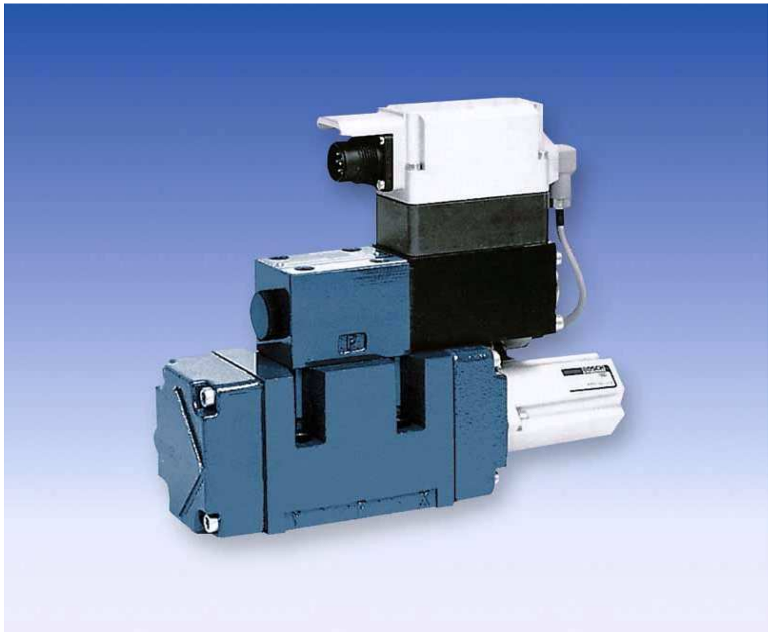
High Response Servo Solenoid - Pilot Op

- 4WRVE higher dynamics
  - Pilot 4WRREH 6
  - Main Stage Same as 4WRL





4WRVE

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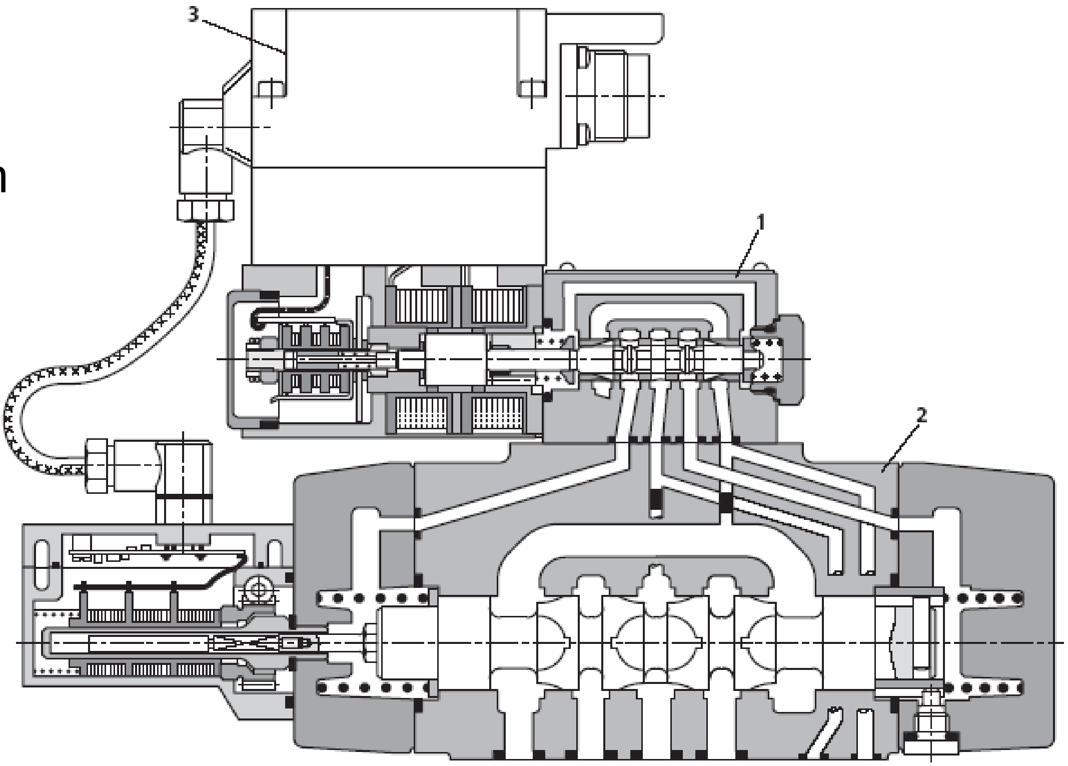
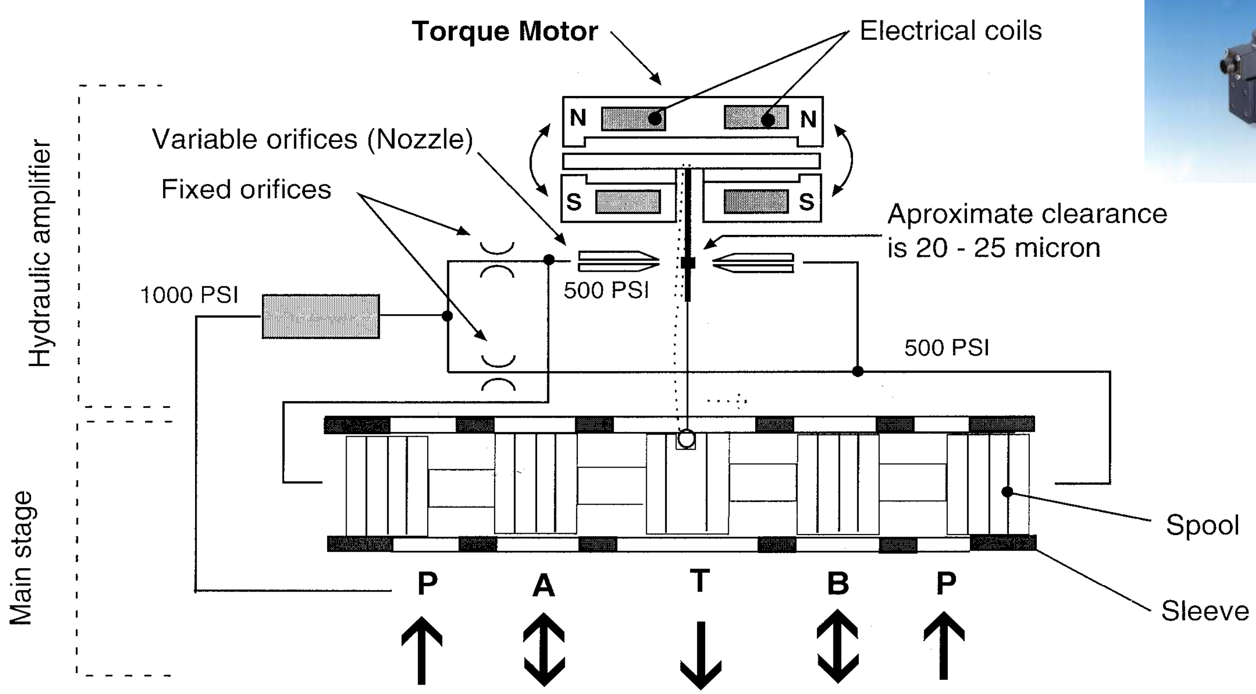
High Response Servo Solenoid - Pilot Op

- 12-pin Elec. Connector
- No Failsafe Position (Center main spool with Z4WE6 under pilot)
- Higher performance
- Sizes 10 to 25 Only
- Linear V-spool characteristic available
- Extremely Reliable OBE



Servo Valves Basics

Flapper-Nozzle Servo



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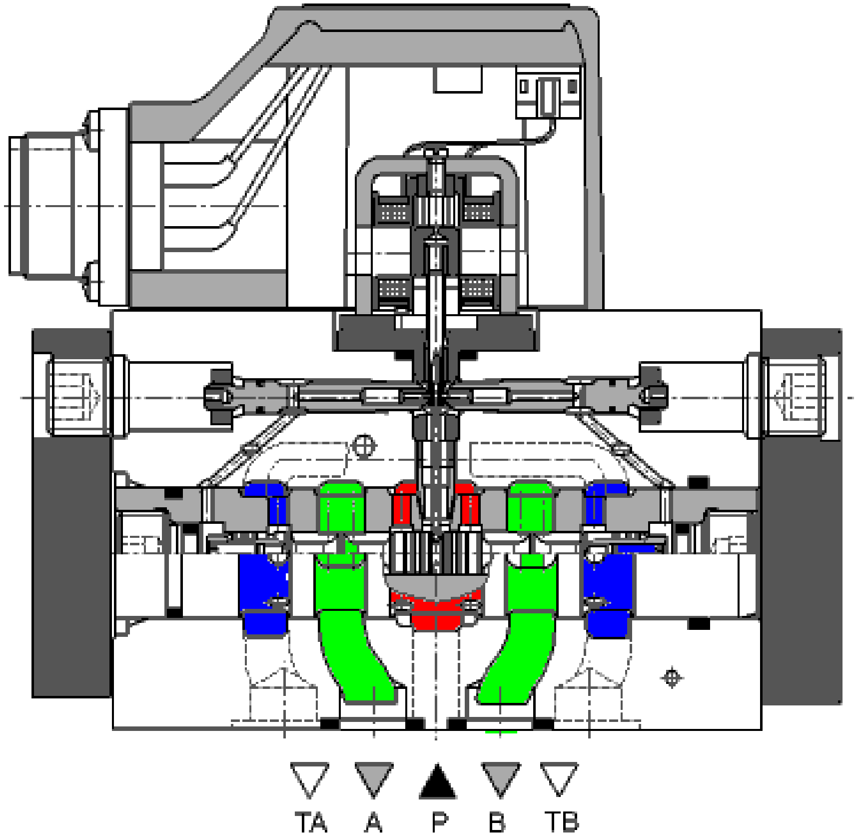
4WS2EM Servos

- Servo Valve always has a Sleeve and Spool in Main Stage
- Servo Torque Motor and Orifices Control Pressure Balance to Position Main Spool
- Small Signal Response @ -90 degrees = 200 to 300 Hz



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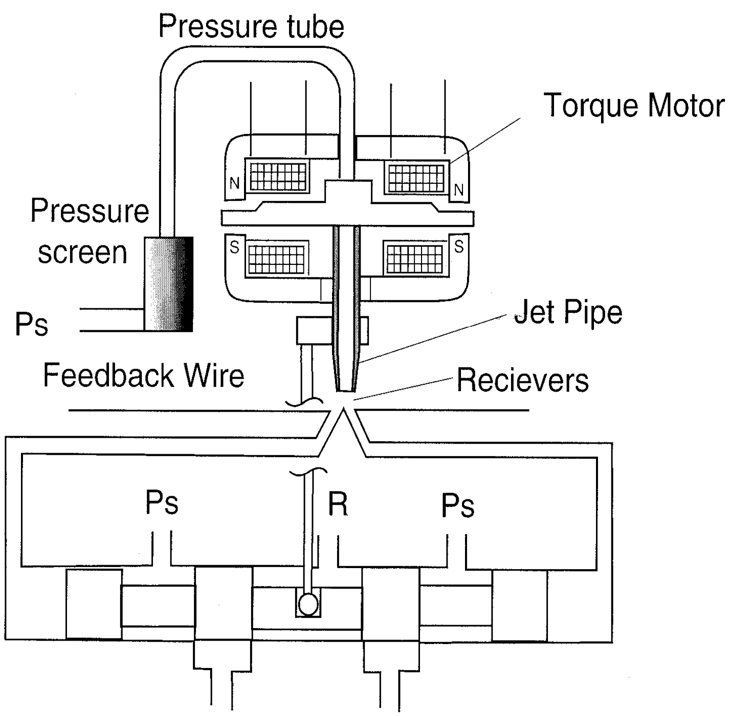
Jet Pipe Servo

Not from Bosch Rexroth



- The pressure tube feeds oil to the jet pipe In the null position the jet pipe sprays oil equally to two recievers (250 micron).
- The torque motor moves the jet pipe making the oil pressure in one reciever greater than the other, Thus causing spool movement.
- Feedback linkage, similar to that of the flapper - nozzle, centers the jet pipe after the spool has moved (1-3% hysteresis).
- There is a zero adjustment on the torque motor.
- There is a zero adjustment on the Main stage of the valve.
- Tank line pressure spikes affect the null.
- pressure line spikes affect the null.
- Wear occurs on the recievers.
- Internal filter requires cleaning.

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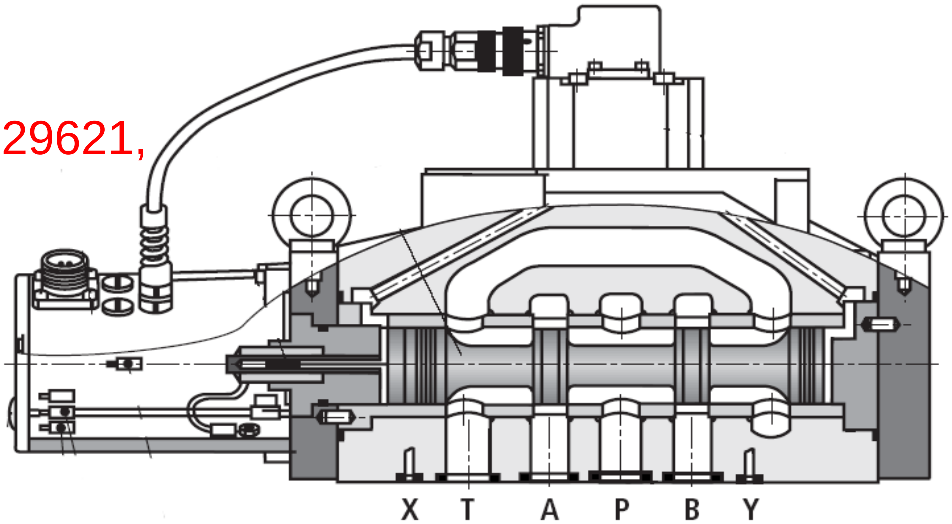
4WSE3E (16,25, 32) Servo

- Flows to 1000 Lpm at 70 bar Δp
- Sleeve/Spool in main stage
- Cast body reduces weight & cost
- Long life with HFC-water glycol, at high pressures
- Small Signal Response 100 to 140 Hz @ -90 degrees

4WSE3
RE29620, RE29621, RE29622



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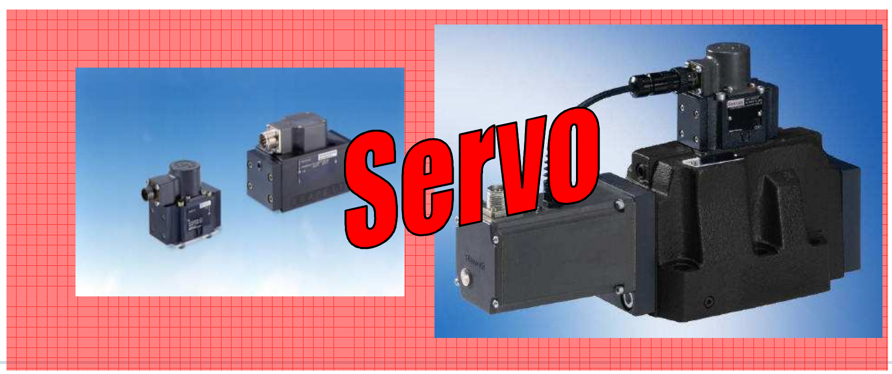
Proportional Valves and High Response Valves

- So Many Proportional and Servo Valves
- Where do I begin?



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Considerations for Basic Applications

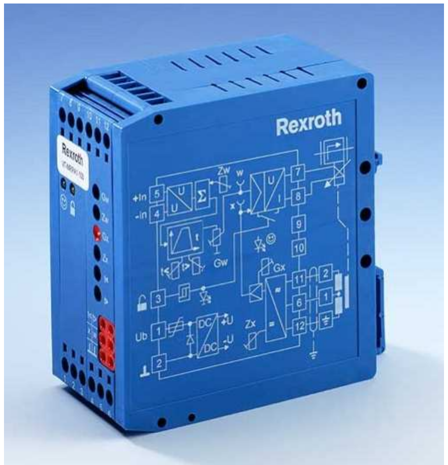
- Most Important Issues Are
  - Flow Requirement (Easy to Define)
    - Cycle Time or Desired Actuator Speed
    - Limits by Pump Flow, HP, Budget
  - Dynamic Performance
    - Acceleration
    - Repeatable Deceleration
    - Fast and Accurate (Productivity)
    - Especially in Closed Loop Applications
    - Higher performance normally requires Closed Loop

Amplifiers

Amplifiers Basics for Proportional Valves

Amplifier Format

- Different styles for application requirements
  - Modules (rail mount)
  - Plug-in Euro Cards
  - On-Board Electronics
  - Plug Amplifiers



Amplifier Functionality

OBE
On-Board Electronics

- Analog (10v or 4-20ma)

Module

- Ramp
- Enable Input
- Preset
- Zero Adj
- Status LED
- Test Points

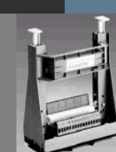
Euro Card analog

- 4 Presets
- Analog (10v or 4-20ma)
- More Ramps
- Discrete Inputs
- Status LED
- Configuration

Euro Card digital

- 16 Presets
- Software Setup
- Extended Configuration Options
- Backup
- Field bus (optional)

Card Holder



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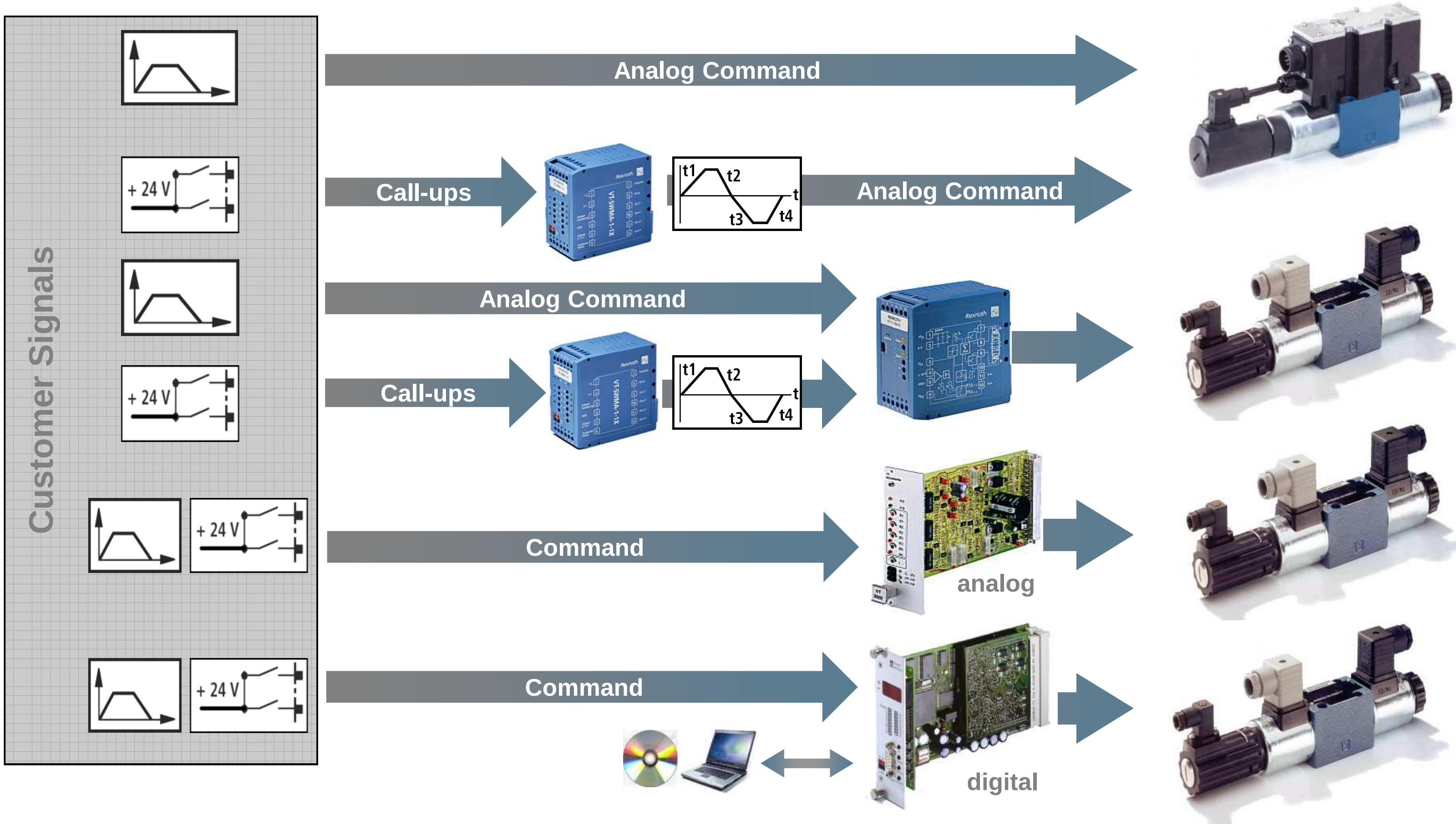
Amplifier Configuration Flexibility



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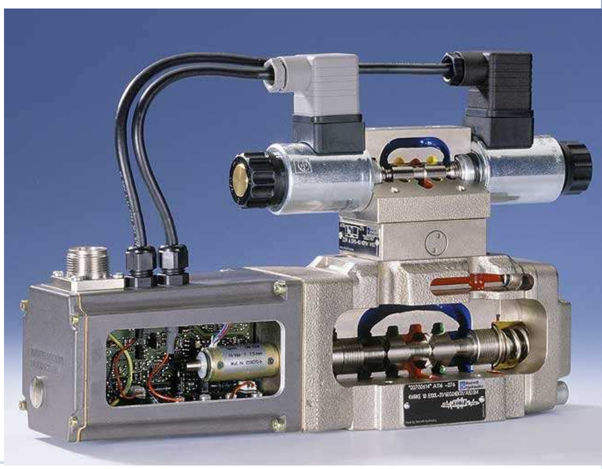
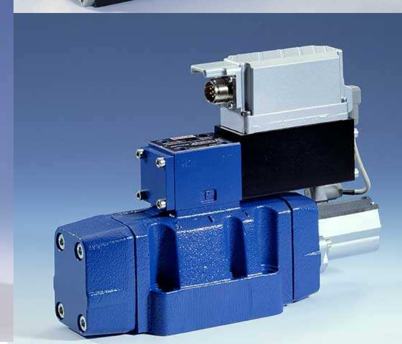
On-Board Electronics

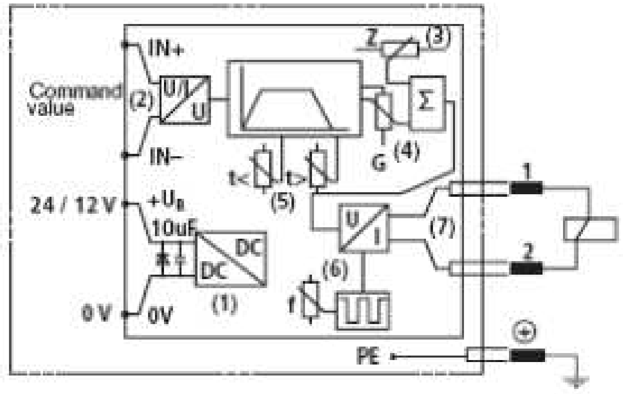
- Plug & play - No user adjustments required
- Factory set calibration simplifies installation and replacement





Plug Amplifiers

- Plug amplifiers are only possible with single, force solenoids (like a proportional relief valve)
- M12 electrical connector for simple installation with molded cables
- Low cost



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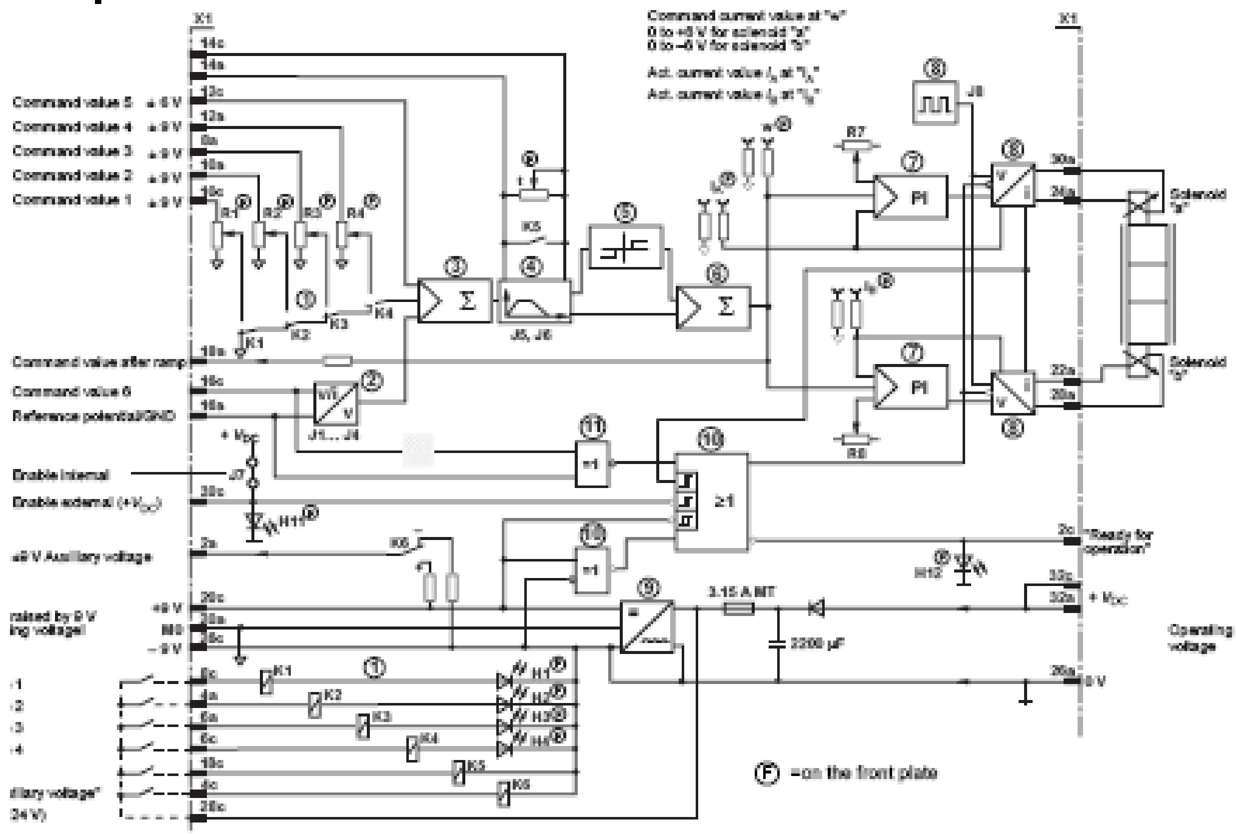
Euro Card Amplifiers

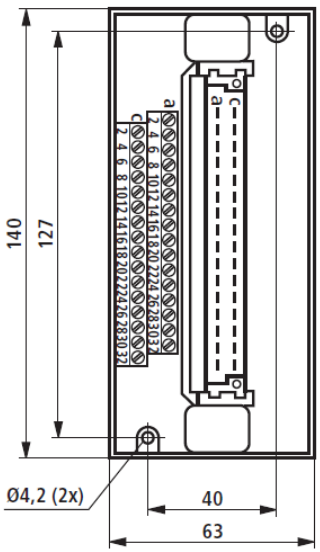
- More features included
- Match edge connector to correct card holder



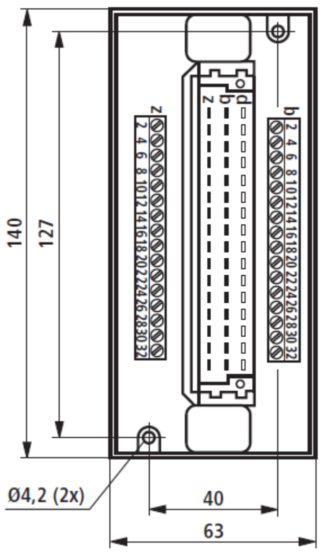
Card Holders

- Confirm edge connector form required on valve data sheet
  - 32D, 32F, 48F, 64G

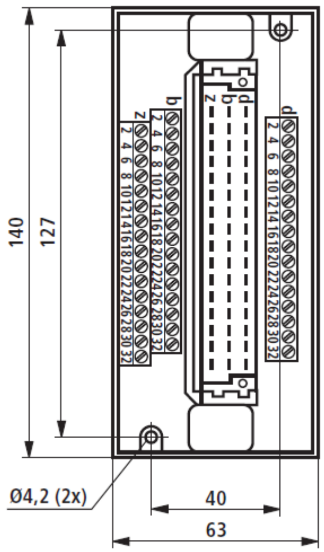
VT 3002-1-2X/32D



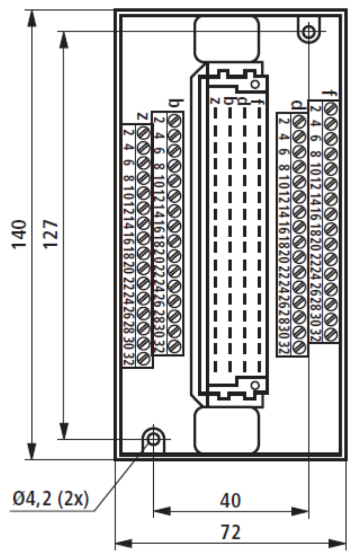
VT 3002-1-2X/32F



VT 3002-1-2X/48F



VT 3002-1-2X/64G



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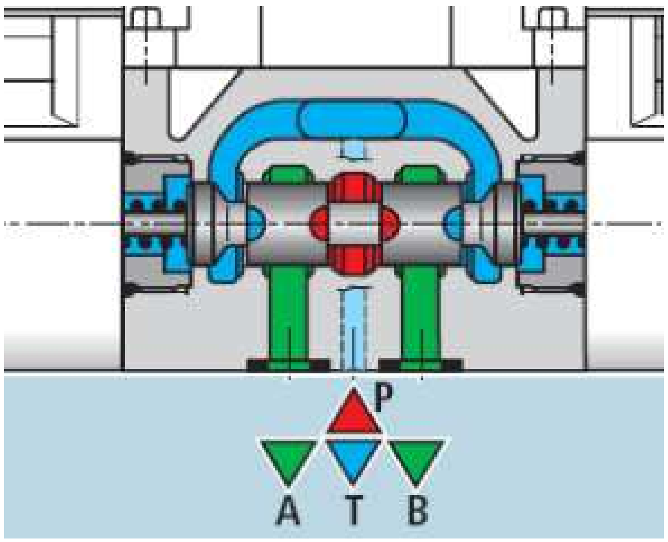
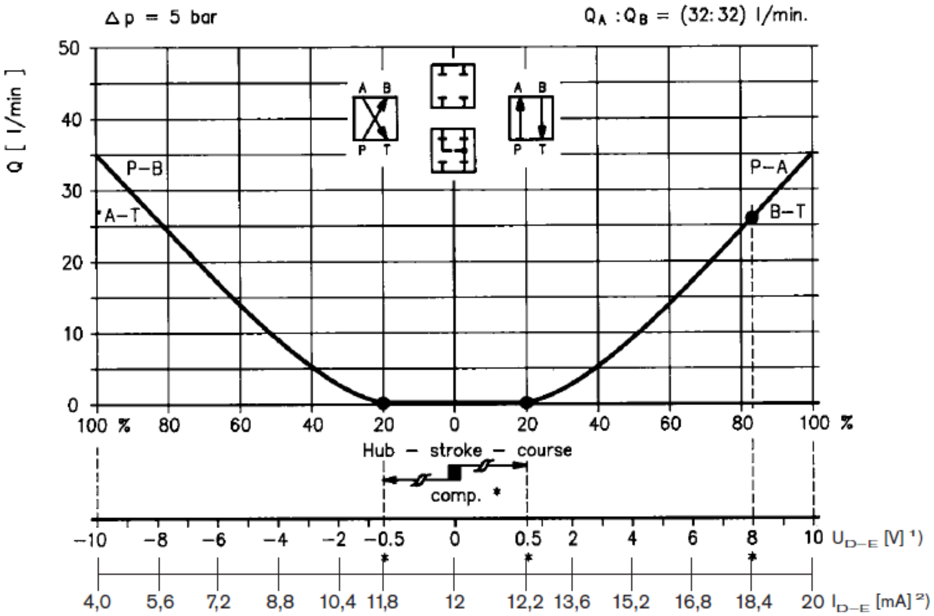
Jump Compensation in Amplifier

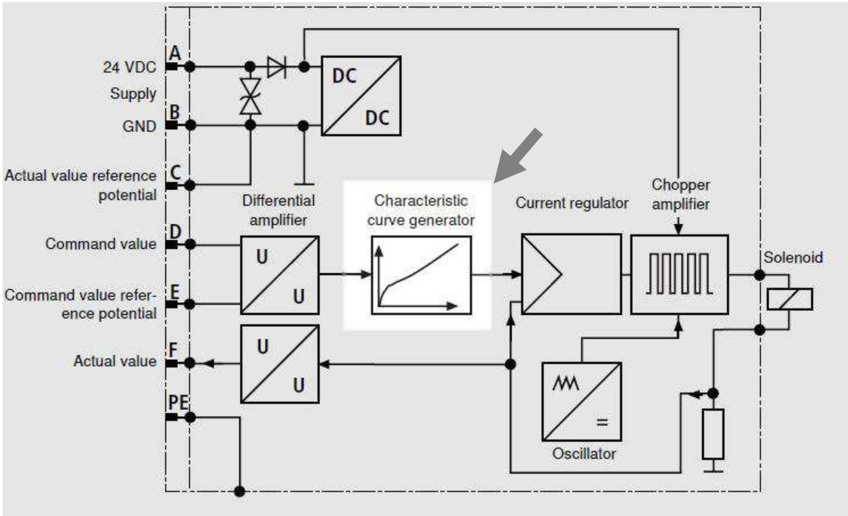
- E, W-spools have ±10% to ±20% overlap
- Jump Compensation reduces this deadband to about ±3 to ±5%

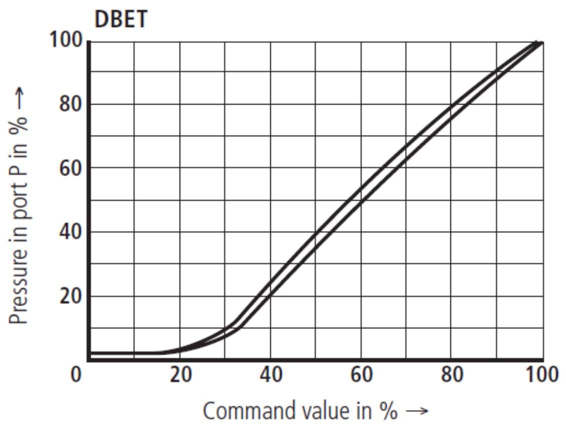


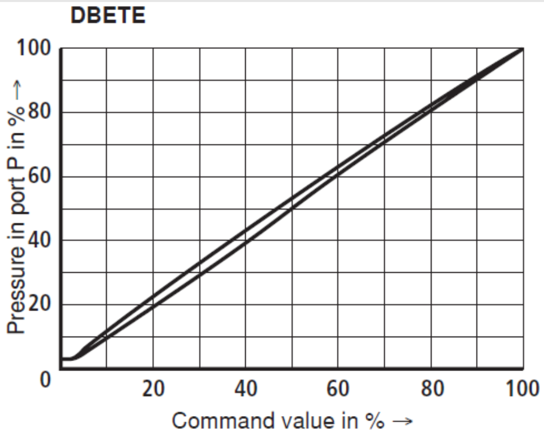


Characteristic Curve Generator

- Linearizes valve output
- Optimized for specific valve type







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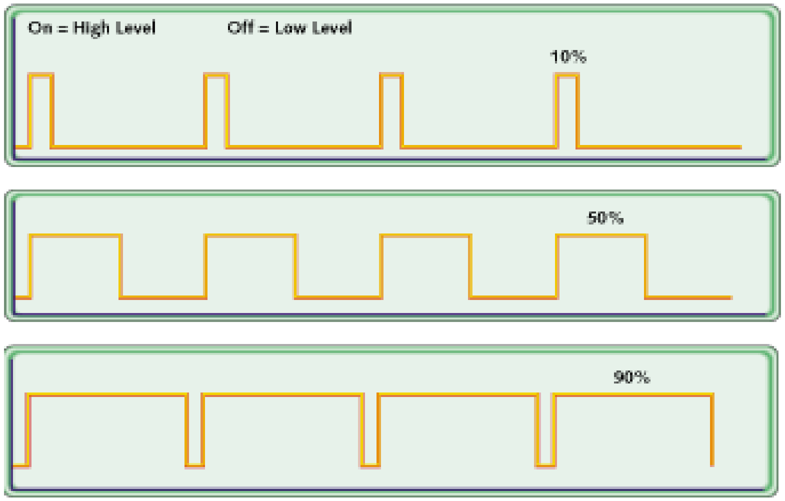
Pulse Width Modulation

- PWM adjusts the average output power to a DC prop. solenoid by switching a fixed DC voltage on-off
- On vs. Off time varies, within a fixed period
- PWM frequency is typically 100 Hz to 350 Hz, to minimize hysteresis
- Frequency must be high enough, so output is not disturbed
- Normally a factory setting, but some amplifiers permit user adjustment
- PWM is efficient, reducing heat generation



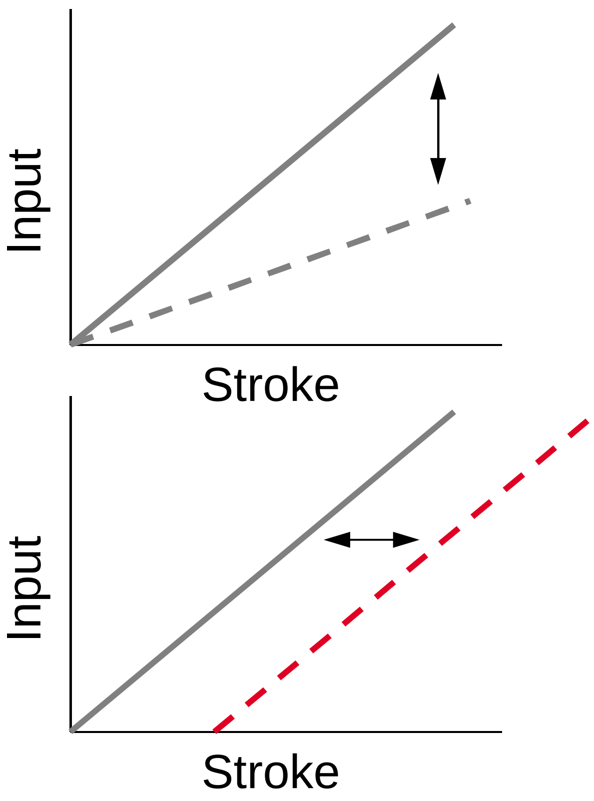
Dither

- Dither is used to create a PWM signal on proportional amplifiers
- Servo valve amplifiers do not require PWM, so a dither signal (sine wave) adds to the desired DC output
- Dither frequency is selected to minimize static friction, improving hysteresis

Amplifier Adjustments

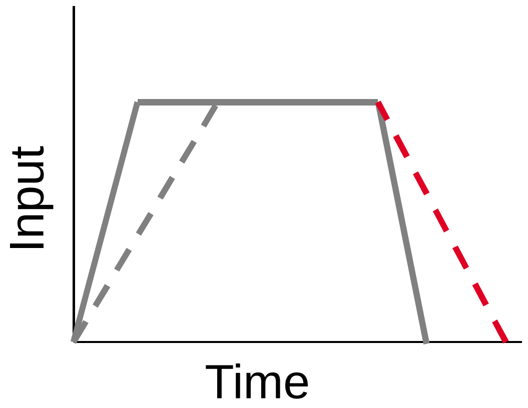
- Gain
  - Changes input vs. output ratio
  - Limits maximum output

- Zero (Null)
  - Offsets spool into a “0” hydraulic condition due to manufacturing tolerances



Amplifier Adjustments

- Ramp Time
  - Single ramp controls acceleration and deceleration
  - Dual ramps control acceleration (ramp up) separate from deceleration (ramp down)
  - Quadrant ramps change all 4 quadrants independently



Amplifier Overview RE29012-V

Valve type	Com-ponent series	Data sheet	Solenoid	Size	Electronics type	Design	Analog/ Digital	Data sheet	Card holder, Data sheet 29928
Proportional pressure control valves									
Proportional pressure relief valves									
direct operated, subplate mounting									
DBETX	1X	29161	1	6	VT-SSPA1-508-20/…	Plug	Analog	30264	
					VT-SSPA1-525-20/…	Plug	Analog	30264	
					VT-MSPA1-508-10/…	Module	Analog	30222	
					VT-MSPA1-525-10/…	Module	Analog	30222	
					VT-VSPA1-508-10/…	Card	Analog	30109	VT 3002-1-2X/32F
					VT-VSPA1-525-10/…	Card	Analog	30109	VT 3002-1-2X/32F
DBEP6(A/B)	1X	29164	1	6	VT-SSPA1-1-1X/…	Plug	Analog	30116	
					VT 2000-5X/…	Card	Analog	29904	VT 3002-1-2X/32D
					VT-VSPA1-1-1X/…	Card	Analog	30111	VT 3002-1-2X/32D
			1 or 2		VT 11118-1X/…	Module	Analog	30218	
					VT 3000-3X/…	Card	Analog	29935	VT 3002-1-2X/32D
					VT-VSPD-1-2X/…	Card	Digital	30523	VT 3002-1-2X/64G
DBET	6X	29162	1	6	VT-SSPA1-1-1X/…	Plug	Analog	30116	
					VT-MSPA1-1-1X/…	Module	Analog	30223	
					VT-VSPA1-2-1X…	Card	Analog	30115	VT3002-1-2X/32D
					VT-VSPD-1-2X/…	Card	Digital	30523	VT 3002-1-2X/64G
DBETR	1X	29166	1	6	VT-MRPA1-100-1X/…	Module	Analog	30221	
					VT-VRPA1-100-1X/…	Card	Analog	30118	VT 3002-1-2X/32D
direct operated, block installation									
KBPS.8A	A	18139-04	1		VT-SSPA1-5-1X/…	Plug	Analog	30116	
pilot operated, subplate mounting									
DBE(M)	5X	29160	1	10; 25	VT-SSPA1-1-1X/…	Plug	Analog	30116	
					VT 11131-1X/…	Module	Analog	29865	
					VT-VSPA1-1-1X/…	Card	Analog	30111	VT 3002-1-2X/32D
					VT-VSPD-1-2X/…	Card	Digital	30523	VT 3002-1-2X/64G
DBE(M)	3X	29142	1	32	VT-SSPA1-1-1X/…	Plug	Analog	30116	
					VT 11030-1X/…	Module	Analog	29741	
					VT 2000-5X/…	Card	Analog	29904	VT 3002-1-2X/32D
					VT-VSPA1-1X/…	Card	Analog	30111	VT 3002-1-2X/32D
					VT-VSPD-1-2X/…	Card	Digital	30523	VT 3002-1-2X/64G

RE 29012-V/12.10 | Overview

Hydraulics | Bosch Rexroth

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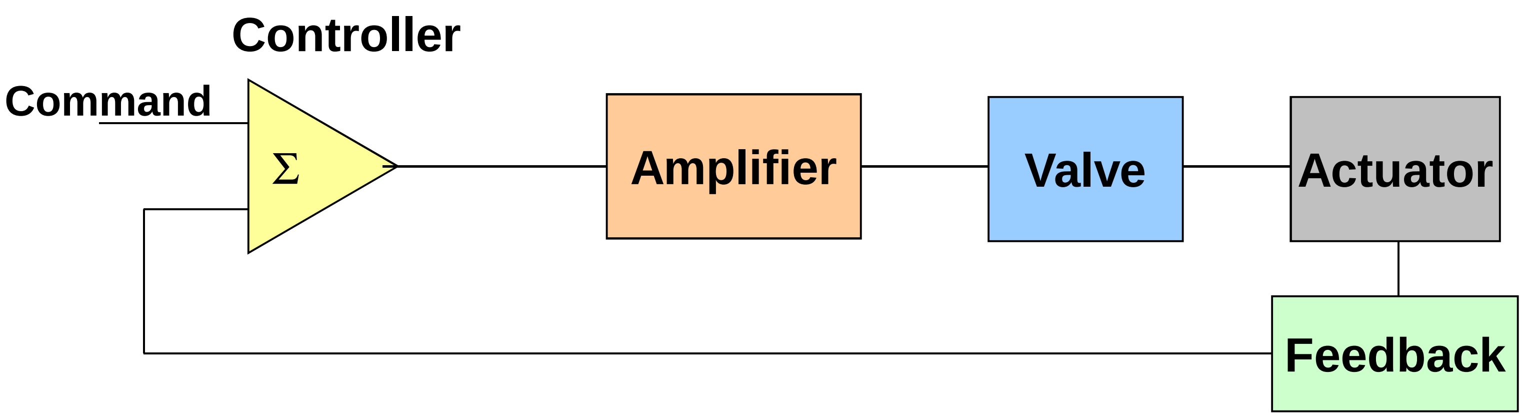
Control Valves and Systems

Closed Loop Applications

Closed Loop

Closed Loop Structure

- Closed Loop means automatic regulation of
  - Position
  - Force
  - Pressure
  - Velocity
  - Etc...
- Constant correction occurs from error generated



RE 08200 Position Control - Engineering Tool

- Valve Matrix & Project Worksheet (suitable for Hyvos simulation)

Electric Drives and Controls | Hydraulics | Linear Motion and Assembly Technologies | Pneumatics | Service

Rexroth Bosch Group

Position-controlled actuators with proportional directional valve and external closed-loop control electronics

RE 08200/09.07 1/12

Replaces: 10.06

Engineering aid

Valve Matrix

Matrix of proportional directional valves

	Valve model	Nominal flow (l/min)	Nominal Δp (bar)	Data sheet RE...	Overlap compensation (with E, W spool)	Valve dynamics (natural frequency) [1]	Typical application [2]: Open control loop	Typical application [2]: Closed-loop position control – With low precision	Typical application [2]: Closed-loop position control – With high precision	Typical application [2]: Closed-loop pressure control
Direct operated	4WRA(E)	Size 6: 7, 15, 30 Size 10: 30, 60	10	29055	Yes	Very low	✓	▽	STOP	STOP
Direct operated	4WRP(E)	Size 6: 8, 18, 32 Size 10: 50, 80	10	29022 29025	Yes	Low	✓	✓	STOP	STOP
Direct operated	4WRE(E)	Size 6: 4, 8, 16, 32 Size 10: 25, 50, 75	10	29061	No	Medium	✓	✓	✓	✓
Direct operated	4WRSE	Size 6: 4, 10, 20, 35 Size 10: 25, 50, 80	10	29067	No	High	STOP	▽	✓	✓
Direct operated	4WRPE(H)	Size 6: 2, 4, 12, 24, 40 Size 10: 50, 100	70	29035 29037 29028 29032	No	High	STOP	▽	✓	✓
Direct operated	4WRREH	Size 6: 4, 8, 12, 24, 40	70	29041	No	Very high	STOP	STOP	✓	✓
Direct operated	4WS(E)2E	Size 6: 2, 5, 10, 15, 20 Size 10: 10, 20, 30, 45, 60, 75, 90	70	29564 29583	No	Very high	STOP	STOP	✓	✓
	4WRZ(E)	Size 10: 25, 50, 85 Size 16: 100, 150 Size 25: 220, 325 Size 32: 360, 520 Size 52: 1000	10	29115	No	Very low	✓	▽	STOP	STOP

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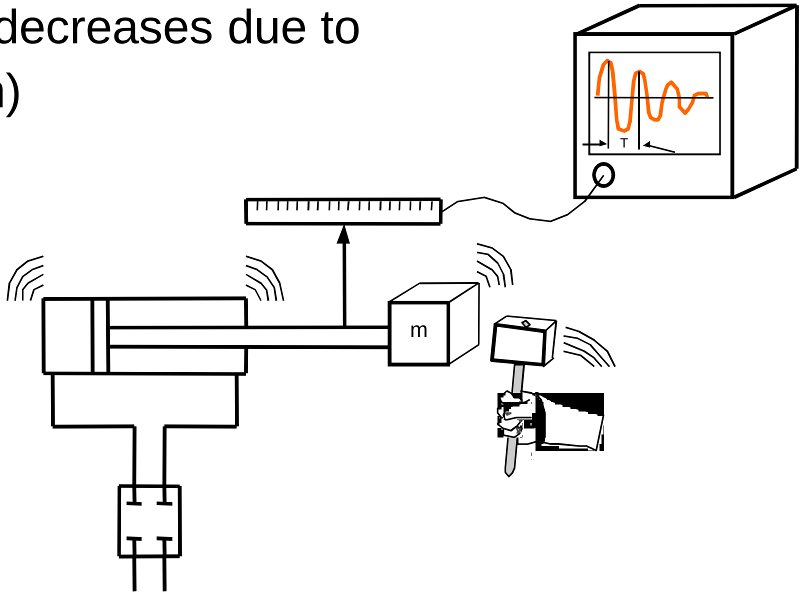
Hydraulic Response of Cylinder

- Closed Loop Hydraulic Response Could Be Tested
- f_h = Number of Oscillations per Second
- T = Time for one cycle (sec)
- This does not include the Control Valve response
- The amplitude of oscillation decreases due to Damping (resistance, friction)

$$f_h = \frac{1}{T}$$



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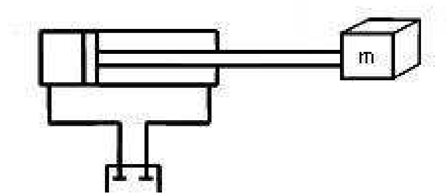
Modeling a Cylinder

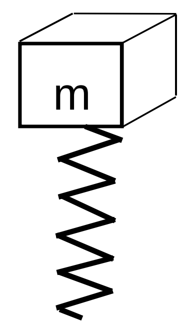
- Closed loop performance depends on valve and cylinder
  - Hydraulic Natural Frequency f_h (simplified as a mass-spring model)
    - C: Spring Constant of Fluid under Compression (fluid on each side of the piston acts like a spring)
    - m: Moving Mass

$$f_h = \frac{\sqrt{\frac{C}{m}}}{2\pi}$$

Hydraulic Natural Frequency



Hydraulic Mass-Spring Model



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Modeling a Cylinder System

- Spring Constant C (Hooke's Law)

$$C = \frac{\Delta x}{F_x}$$

Δx Displacement of Spring

F_x Force acting on Spring

$$\Delta x = \frac{\Delta V}{A} \qquad F_x = p\,A \qquad p = \frac{\Delta V \; E}{V_o}$$

$$f_h = \frac{\sqrt{\frac{C}{m}}}{2\pi} \qquad f_h = \frac{\sqrt{\frac{E\,A^2}{V_o\,m}}}{2\pi}$$

f_h = frequency of spring-mass model (hydraulic cylinder)

ΔV = Volume change in cylinder
A = Area of cylinder (each side)
E = Bulk modulus of fluid
V_o = Volume of trapped fluid
m = effective mass
2π radian/sec = 1 Hz

Calculations can get complicated
Results are only approximate

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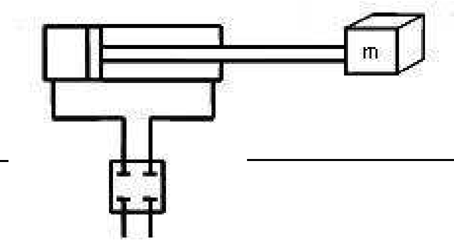
Modeling a Cylinder and Valve

- Closed loop response f_o depends on valve and cylinder
  - Hydraulic Natural Frequency f_h (simplified as a mass-spring model)
    - C: Spring Constant of Fluid under Compression (fluid on each side of the piston acts like a spring)
    - m: Moving Mass
  - Valve Frequency Response f_v (from data sheet, Bode plot)

$$f_o = \frac{f_v \; f_h}{(f_v + f_h)}$$

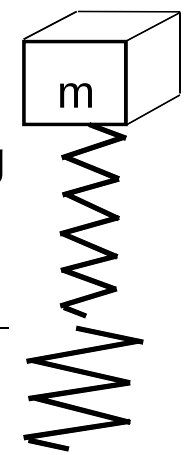
Hydraulic Natural Frequency

Valve Freq. Response



Hydraulic Mass-Spring Model

plus Valve Response



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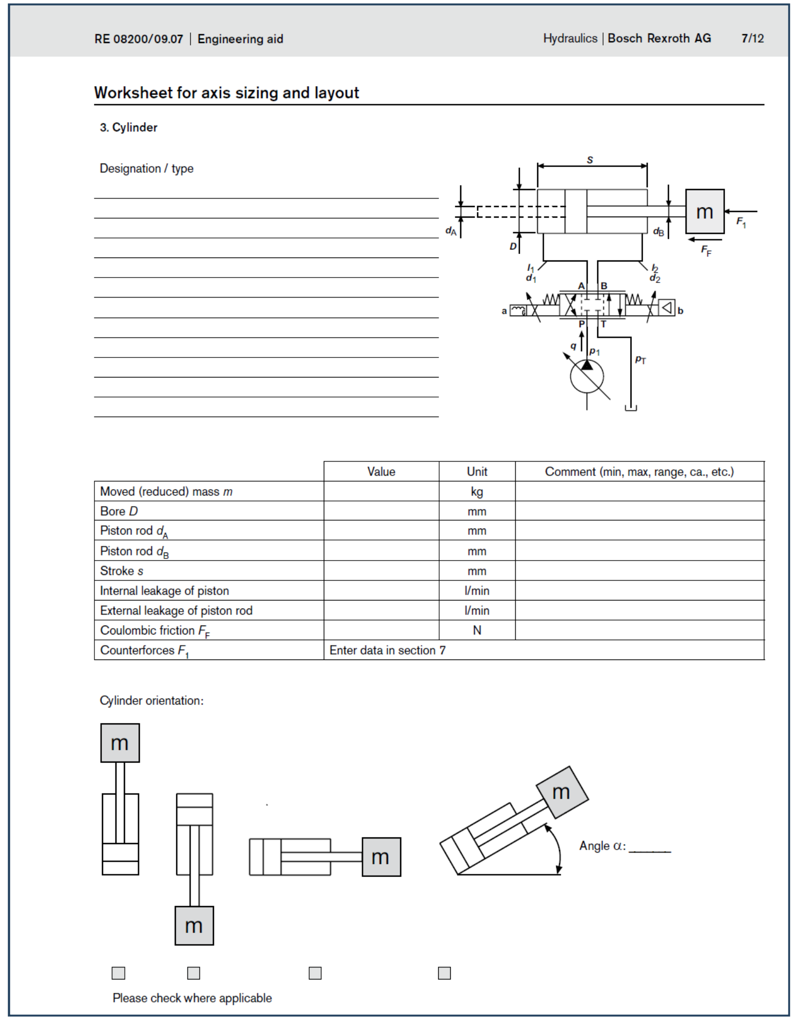
Axis Worksheet

- Define Customer and Application goals
- Cylinder Parameters
- Cylinder Orientation
- Moving Mass
- Frictions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Worksheet for axis sizing and layout

3. Cylinder

Designation / type

	Value	Unit	Comment (min, max, range, ca., etc.)
Moved (reduced) mass *m*		kg	
Bore *D*		mm	
Piston rod d_A		mm	
Piston rod d_B		mm	
Stroke *s*		mm	
Internal leakage of piston		l/min	
External leakage of piston rod		l/min	
Coulombic friction F_F		N	
Counterforces F_1	Enter data in section 7		

Cylinder orientation:

Angle α: ______

Please check where applicable

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Axis Worksheet

- Piping Parameters
- Supply Pressure
- Opposing Forces or Force Profile

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Worksheet for axis sizing and layout

4. Piping

	Value	Unit	Comment (min, max, range, ca., etc.)
Pipe length l_1		mm	
Pipe length l_2		mm	
Pipe diameter d_1		mm	
Pipe diameter d_2		mm	

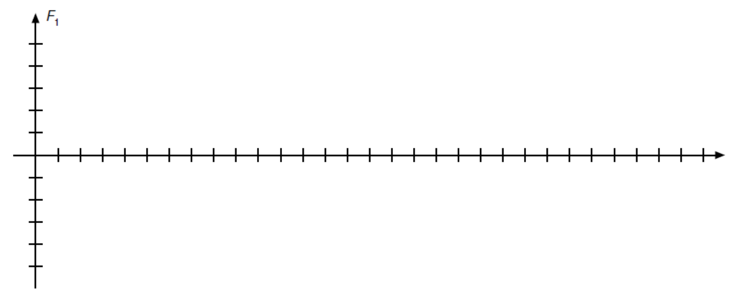
5. Pressure supply

	Value	Unit	Comment (min, max, range, ca., etc.)
System pressure p_1 (at valve)		bar	
Tank pressure p_T		bar	
Max. pump flow q		l/min	

6. Valve

Type:

7. Counterforces



Indication of counterforces F_1 as a function of position *s* or time *t*.
Enter only the forces, which result from the process (do not specify counterweights).
If there are several load cases, base the engineering work on the most critical one.
Do not forget the unit of the force (N or kN)!
Use this diagram or an additional page.

Axis Worksheet

- Command Profile
- Type of Feedback
- Desired Accuracy
- Position vs. Time Diagram
- Desired Velocities
- Acceleration Limits
- Desired Cycle Time

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Worksheet for axis sizing and layout

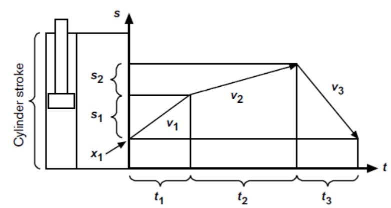
8. Command values

Type of open/closed-loop control: (Open-loop controlled operation, position, or other):

Feedback sensor:

Feedback resolution (incremental) or output of voltage/current:

Required positioning accuracy:



Parameter	Value	Unit	Comment (min, max, range, ca., etc.)
Distance between piston - cylinder cap x_1		mm	Starting point of the movement
Rapid advance speed v_1		mm/s	
Rapid advance distance s_1		mm	
Rapid advance time t_1		s	
Advance speed v_2		mm/s	
Advance distance s_2		mm	
Advance time t_2		s	
Rapid return speed v_3		mm/s	
Rapid return distance $s_3 = s_1 + s_2$		mm	
Rapid return time t_3		s	
Max. acceleration a_1		mm/^{2}	
Max. deceleration a_2		mm/^{2}	
Cycle time (for cyclical movements)		s	

Important:
- The table is only valid for closed-loop position controls; for other types of control use a separate, adapted sheet.
- For complex multi-step movements, continue the table accordingly

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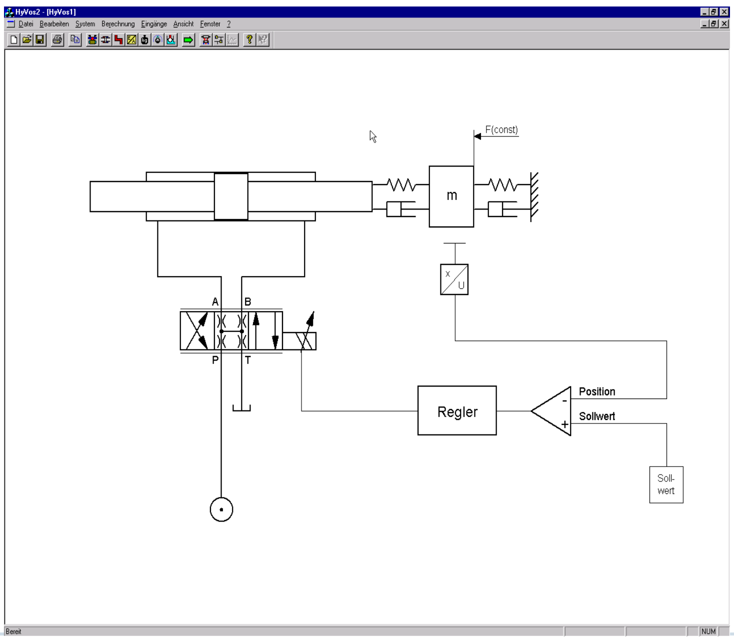
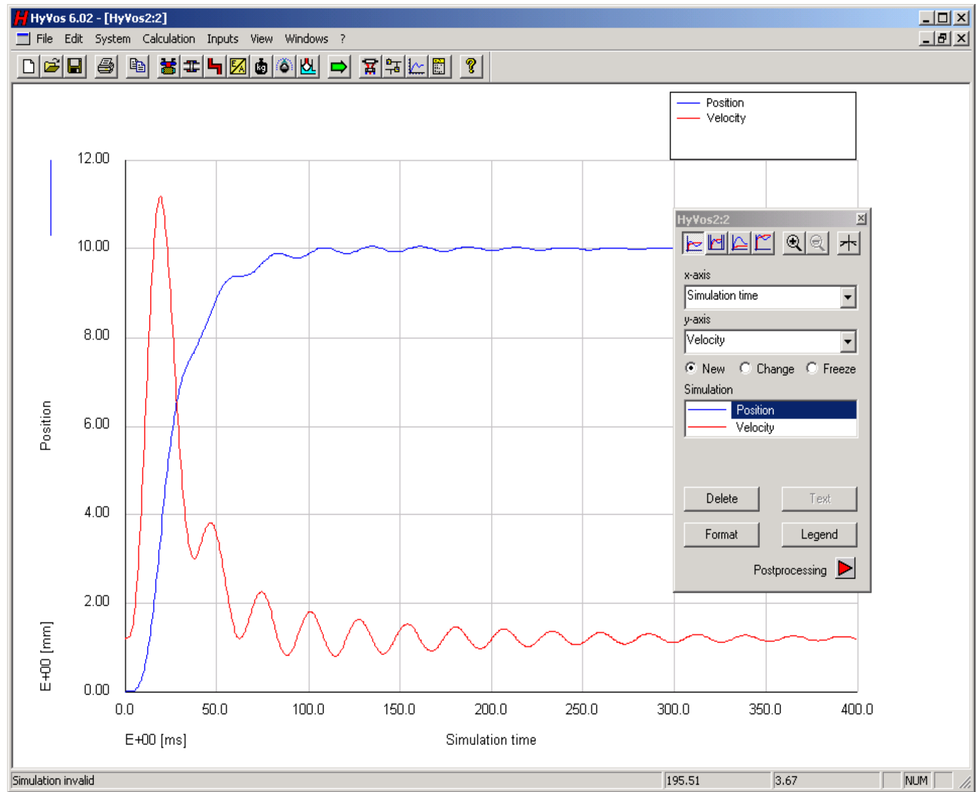
Hyvos simulation analysis

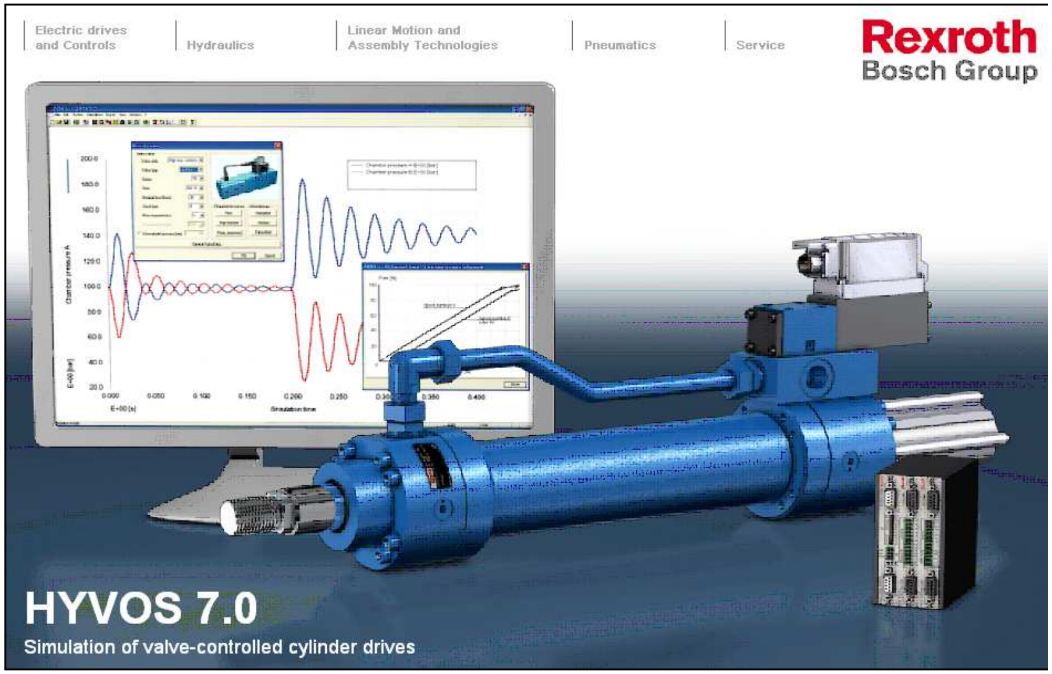
- For critical designs, use simulation to confirm proper valve selection and system response





Hyvos simulation analysis

- Collect all relevant machine information (Hyvos worksheet or RE 08200)
- Your system design should already use much of this information
- Critical systems can be confirmed by simulation.



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Updates

Other Updates

Hydraulic Training

www.boschrexroth-us.com/hydtraining

Principles of Hydraulics (POH)

Jan 23–27, 2012	BAVTS (PA)
Feb 13–17, 2012	BAVTS (PA)
Mar 12–16, 2012	BAVTS (PA)
Apr 16–20, 2012	BAVTS (PA)
May 14–18, 2012	BAVTS (PA)
Jun 11–15, 2012	BAVTS (PA)
Jul 16–20, 2012	BAVTS (PA)
Aug 13–17, 2012	BAVTS (PA)
Sep 10–14, 2012	BAVTS (PA)
Oct 8–12, 2012	BAVTS (PA)
Nov 12–16, 2012	BAVTS (PA)
Dec 3–7, 2012	BAVTS (PA)

Maintenance, Repair & Set-up of Industrial Hydraulic Systems (MRS)

Prerequisite: POH

Jan 30–Feb 3, 2012	BAVTS (PA)
Mar 5–9, 2012	BAVTS (PA)
Jun 18–22, 2012	BAVTS (PA)
Sep 24–28, 2012	BAVTS (PA)
Nov 5–9, 2012	BAVTS (PA)

Fundamentals & Servicing of Proportional Valves (FSP)

Prerequisite: POH

Apr 23–27, 2012	BAVTS (PA)
Oct 15–19, 2012	BAVTS (PA)

Mobile Hydraulic Technology (MHT)

Feb 6–10, 2012	BAVTS (PA)

Maintenance, Repair & Set-up of Mobile Hydraulic Systems (MRSM)

Prerequisite: POH or MHT

Mar 26–30, 2012	BAVTS (PA)

Proportional and Servo Circuit Design (PSD)

Prerequisite: DCH

Jul 30–Aug 3, 2012	BAVTS (PA)

Pump and Controls, Open Loop (PCO)

Prerequisites: POH and MRS

May 7–11, 2012	BAVTS (PA)
Aug 6–10, 2012	BAVTS (PA)

Pump and Controls, Closed Loop (PCC)

Prerequisites: POH and MRS

Aug 27–31, 2012	BAVTS (PA)

Design Considerations for Industrial Hydraulic Systems (DCH)

Prerequisite: POH

Jun 25–29, 2012	BAVTS (PA)

Electronic Controls for Hydraulic Systems (ECH)

Prerequisite: PSD

Sep 17–21, 2012	BAVTS (PA)

Design Considerations for Mobile Hydraulic Systems (DCHM)

Prerequisite: POH

Oct 29–Nov 2, 2012	BAVTS (PA)

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Hydraulics Technical Training Schedule – 2012

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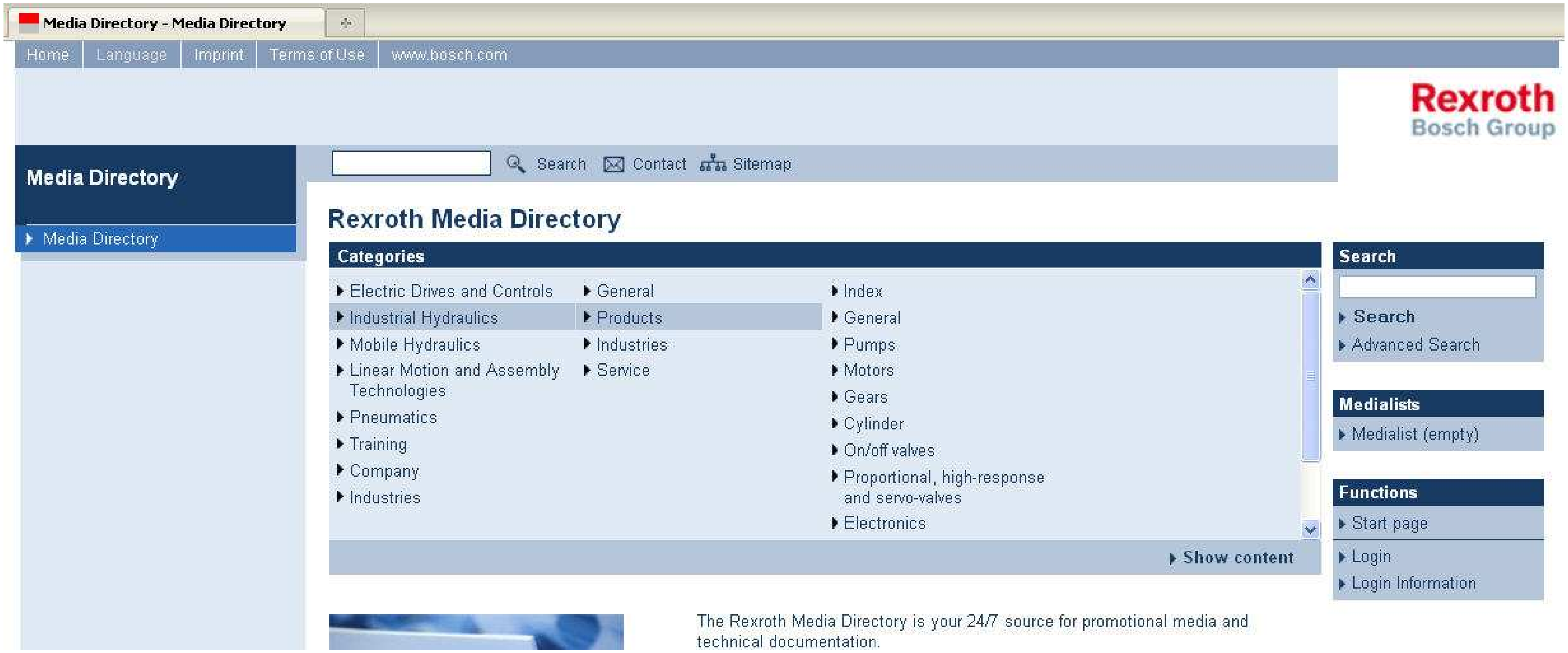
Update

Documentation Resource

- www.boschrexroth.com/MediaDirectory



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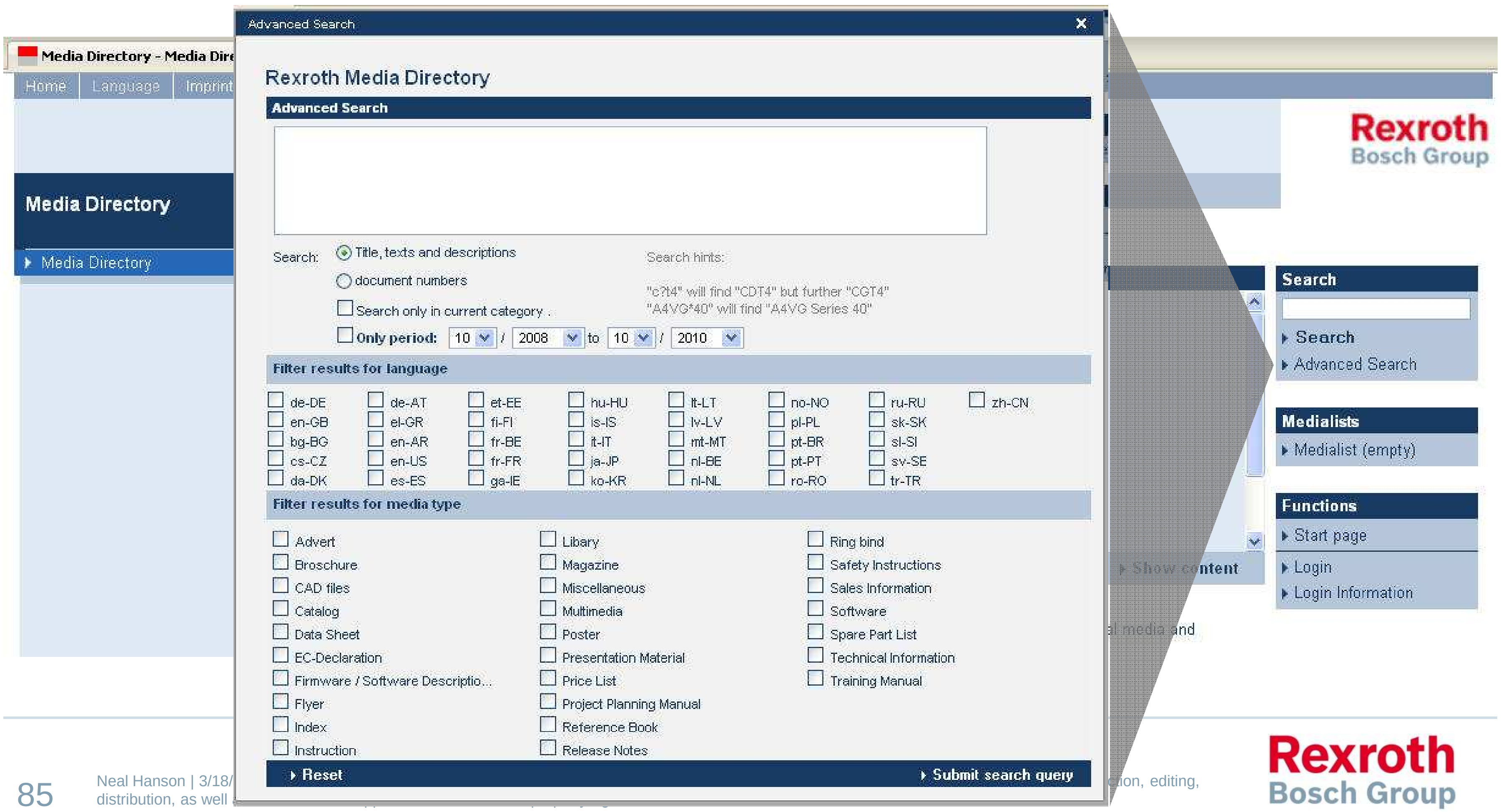

Thank You

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