A comparative study on dither signals and their parameterisation

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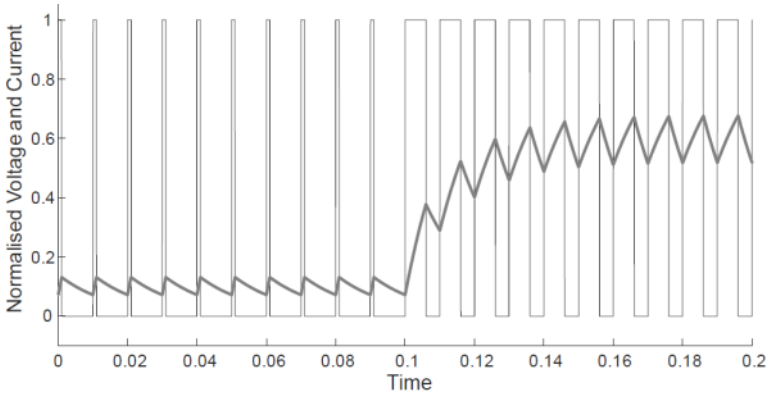
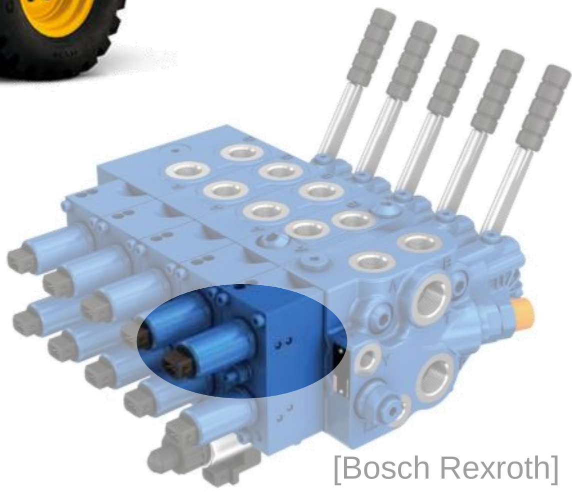


Introduction

[Volvo]



[Bosch Rexroth]

Introduction

[ifm]

Electromechanical proportional valve actuator

Dynamics

Costs

Linearity

Power density

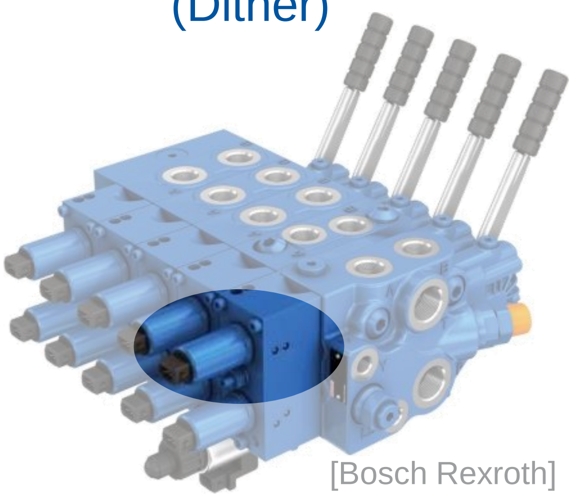
Hysteresis

Over excitation

Electronic controller

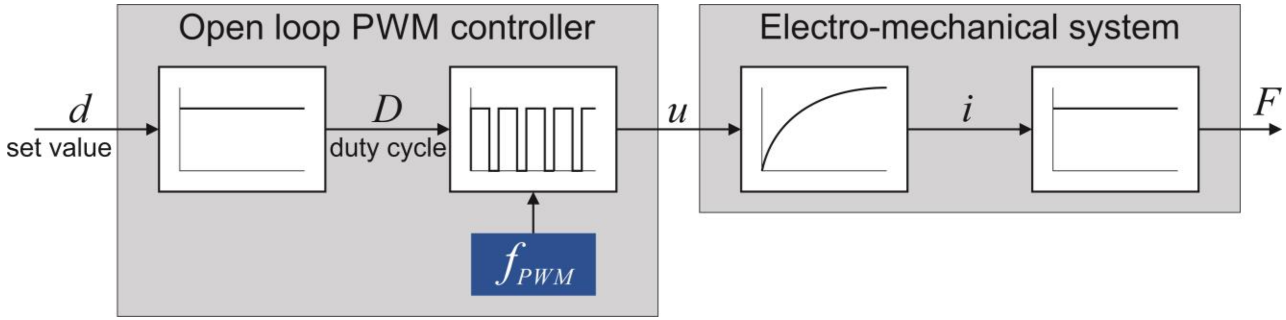
Dynamic Excitation (Dither)

- Need for parameterisation rules
  - Changing parameters for differing control schemes
- Especially relevant for
  - Open loop Pulse Width Modulation (PWM)
  - Closed loop current control



[Bosch Rexroth]

Open Loop PWM Control



Benefit

- Simple and inexpensive

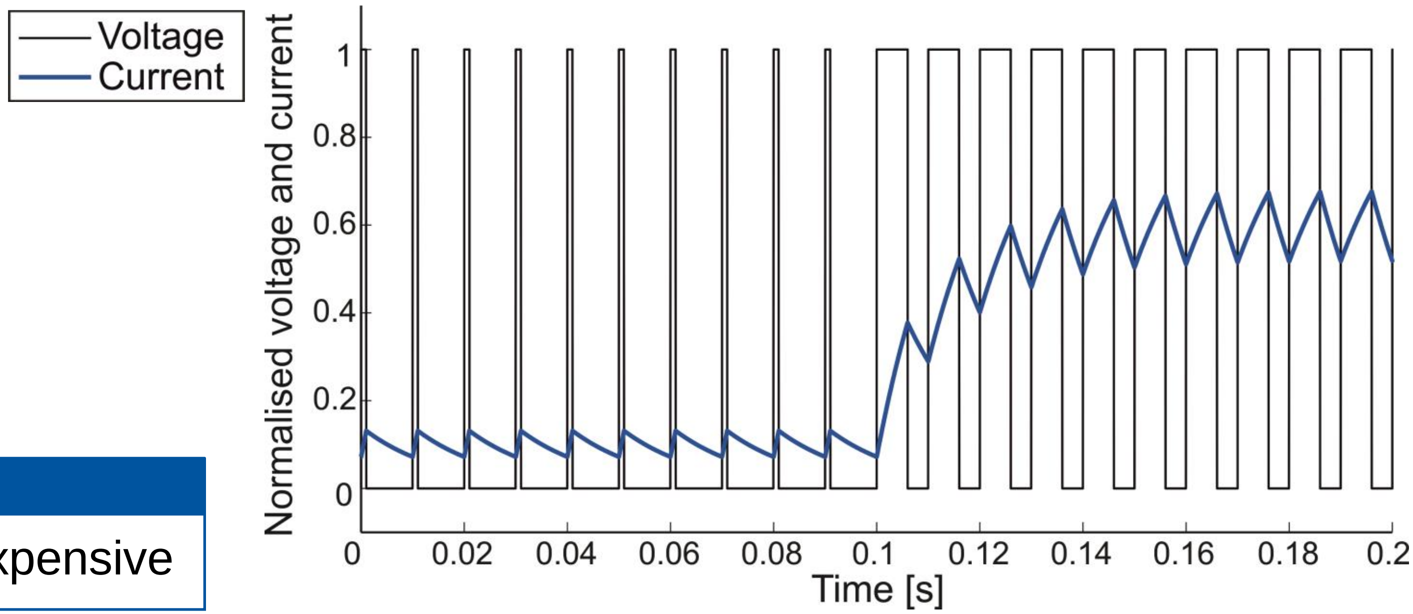
Disadvantages

- Deviation in output force due to electro-mechanical disturbances
  - Change in resistance over temperature

Dither parameters

- PWM frequency f_{PWM}
- Driving voltage
- Suppressor voltage

Open Loop PWM Control



Benefit

- Simple and inexpensive

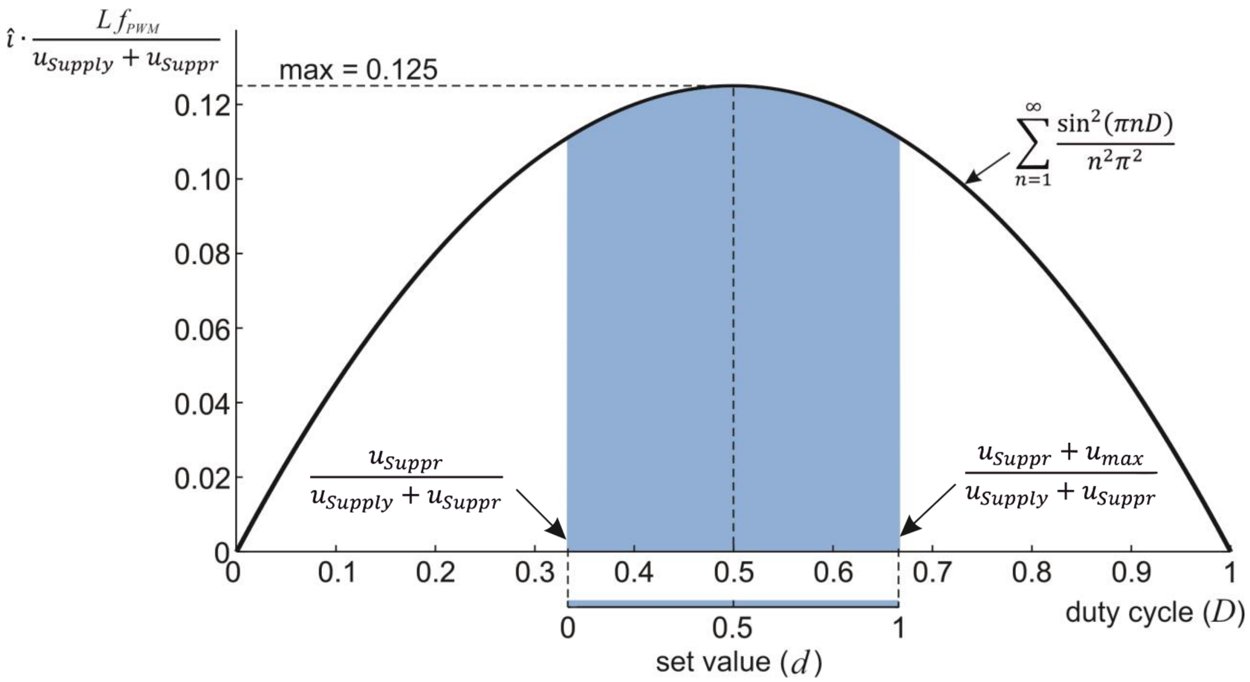
Disadvantages

- Deviation in output force due to electro-mechanical disturbances
  - Change in resistance over temperature
- Slow current build-up (first order)
- Changing dynamic excitation

Dither parameters

- PWM frequency f_{PWM}
- Driving voltage
- Suppressor voltage
- To prevent system from oscillations
  → f_{PWM} > coil's natural frequency

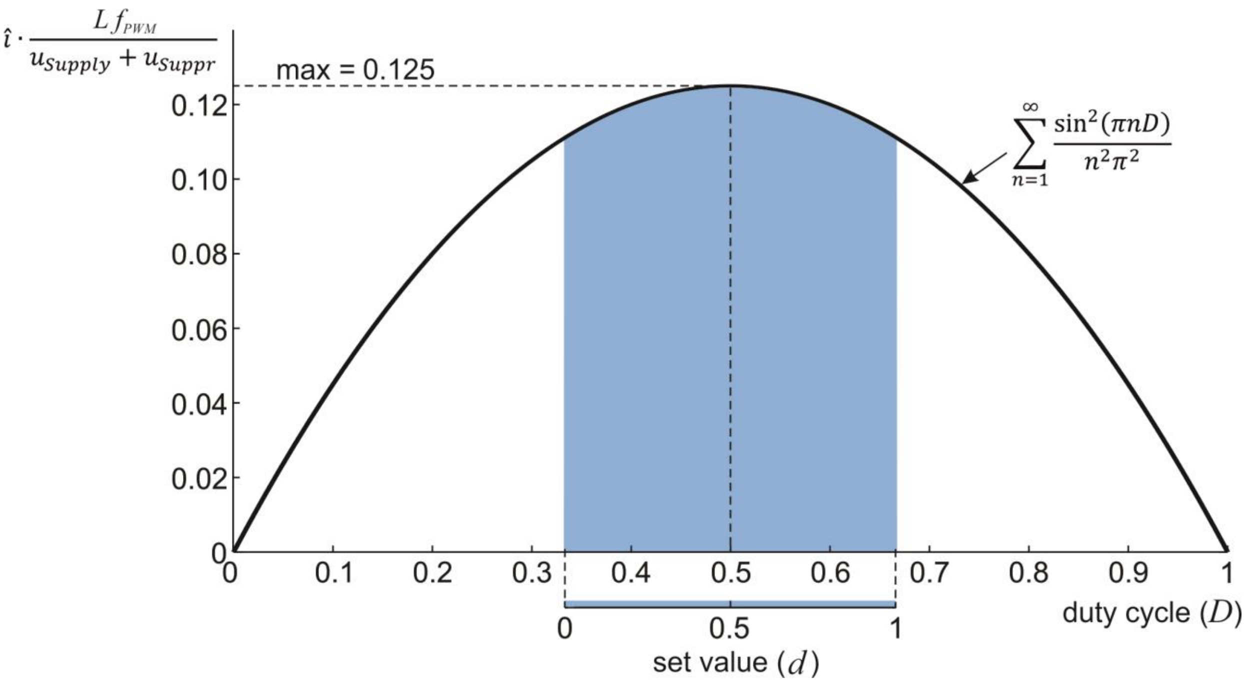
Open Loop PWM Control - Excitation



Observation
▪ Maximum amplitude at D = 50%

Optimisation
▪ Narrow operational range around D = 50% → Reduced change in excitation over the command signal d

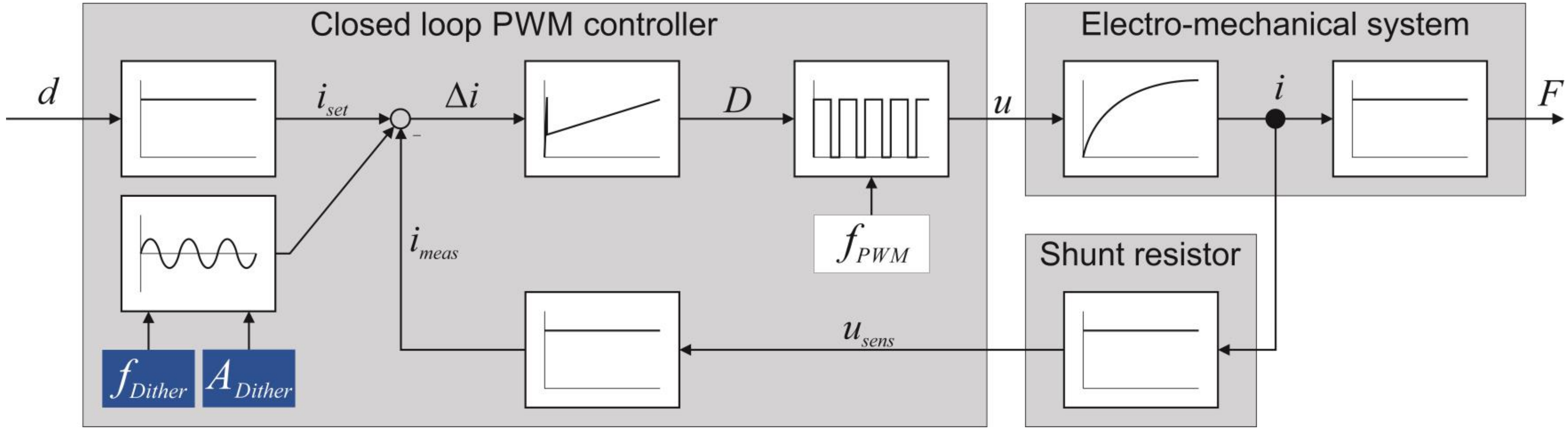
Open Loop PWM Control - Excitation



- Exemplary parameters:

Rated coil voltage	u_{max}	12 V
Supply voltage	u_{Supply}	24 V
Suppressor voltage	u_{Suppr}	12 V
Amplitude change	±5.5%	

Closed Loop Current Control

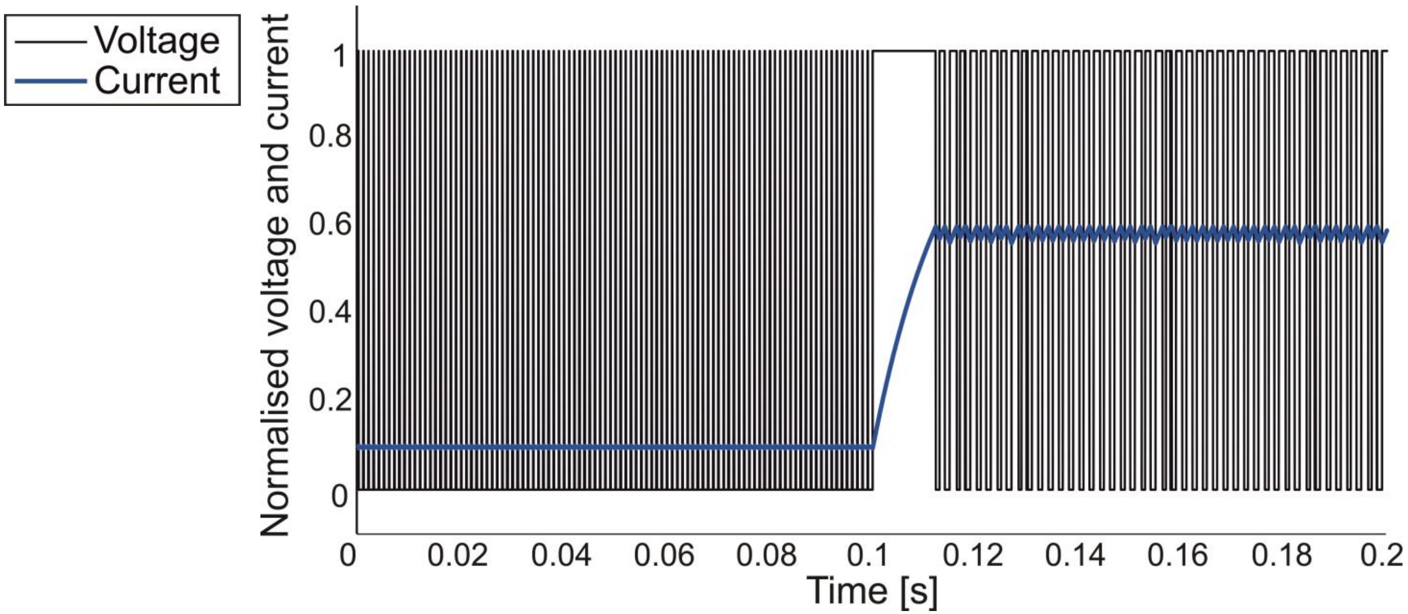


Benefits
▪ Force independent on coil resistance

Disadvantage
▪ More expensive

Dither parameters
▪ Dither frequency ▪ Dither amplitude

Closed Loop Current Control



Benefits

- Force independent on coil resistance
- Fast response
- Minimal system immanent excitation
- Defined constant dither

Disadvantage

- More expensive

Dither parameters

- Dither frequency
- Dither amplitude

1	Open Loop PWM Control
2	Closed Loop Current Control
3	**Parameterisation Rules & Experimental Validation**
4	Conclusion

Parameterisation Rules – Open loop PWM

Maximum duty cycle

$$D_{max} = \frac{i_{max} \cdot R + u_{Suppr}}{u_{Supply} + u_{Suppr}}$$

f_{PWM} for a given current amplitude

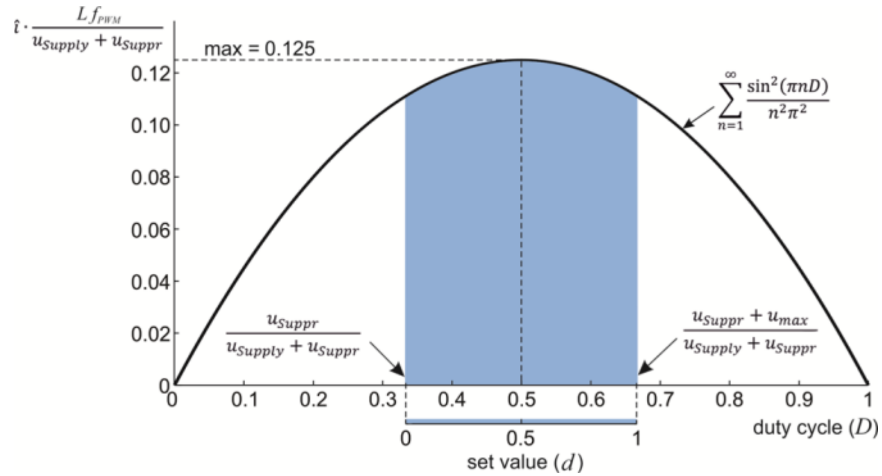
- Rough approximation for constant inductance L

$$f_{PWM} = \frac{u_{Supply} + u_{Suppr}}{8L\hat{\imath}}$$

f_{PWM} for constant current amplitude

- $f_{PWM,\ DS}$ given for specific voltages

$$f_{PWM} = \frac{u_{Supply} + u_{Suppr}}{u_{Supply,DS} + u_{Suppr,DS}} \cdot f_{PWM,DS}$$



PRV with constant pressure amplitude

- Hydro-mechanical system

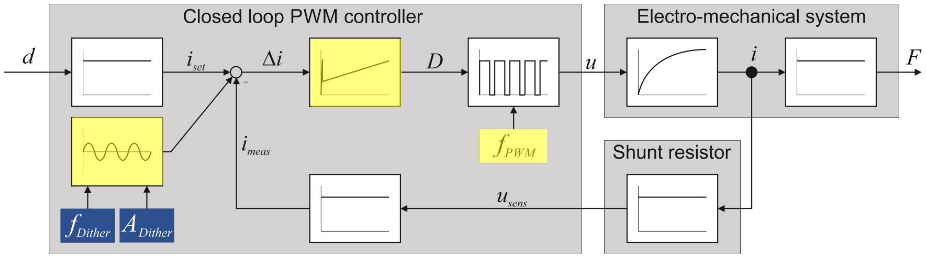
$$\hat{p} \approx \frac{\hat{\imath}}{f_{PWM}^{2}}$$

$$f_{PWM} = \sqrt[3]{\frac{u_{Supply} + u_{Suppr}}{u_{Supply,DS} + u_{Suppr,DS}}} \cdot f_{PWM,DS}$$

Parameterisation Rules – Closed loop Control

Maximum duty cycle

$$D_{max} = \frac{i_{max} \cdot R + u_{Suppr}}{u_{Supply} + u_{Suppr}}$$



f_{Dither}

- Dither frequency smaller than open loop PWM frequency

A_{Dither}

- For proportional valves up to 10% of maximum current
- For servo valves 2-5%

Current Controller

- Sufficient control gain required for the dither signal to be active
- Sufficient voltage headroom required

f_{PWM}

- Several kilohertz
- At least 5-10 times the dither frequency

Validation of the Open Loop Parameterisation

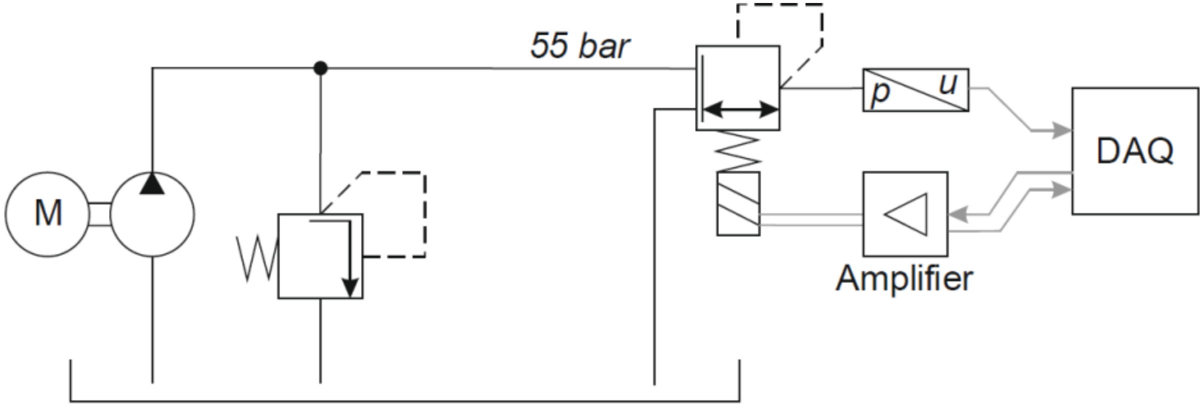
- Test object:

HYDAC Pressure reducing valve (Type PDMC05S30A-11)

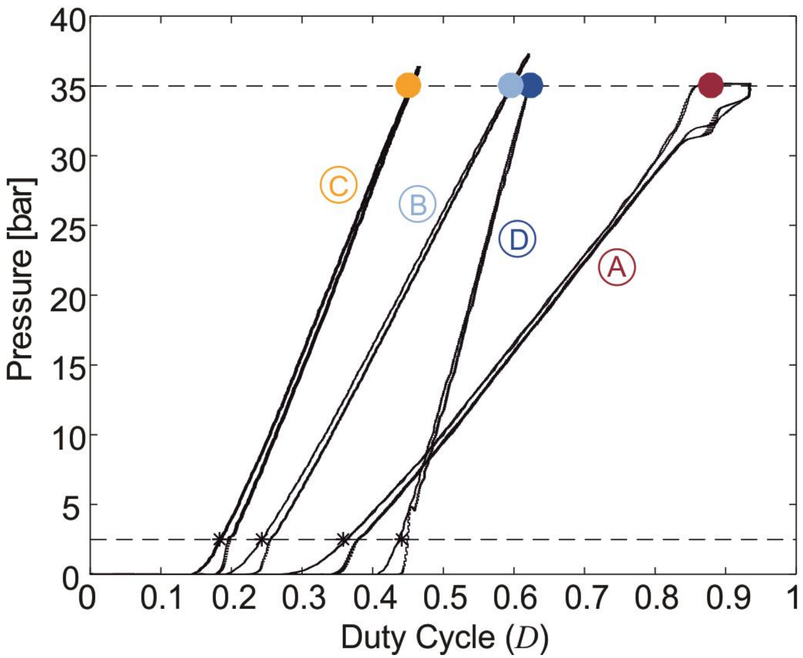
Maximum current	950 mA
Inductance (no load)	105 mH
Resistance (coil + shunt)	10.5 Ω + 0.5 Ω
Rated supply voltage	24 V
Rated PWM frequency	110 Hz
Outlet pressure range	0 - 35 bar above Tank

[Hydac]

- ´Test-rig:

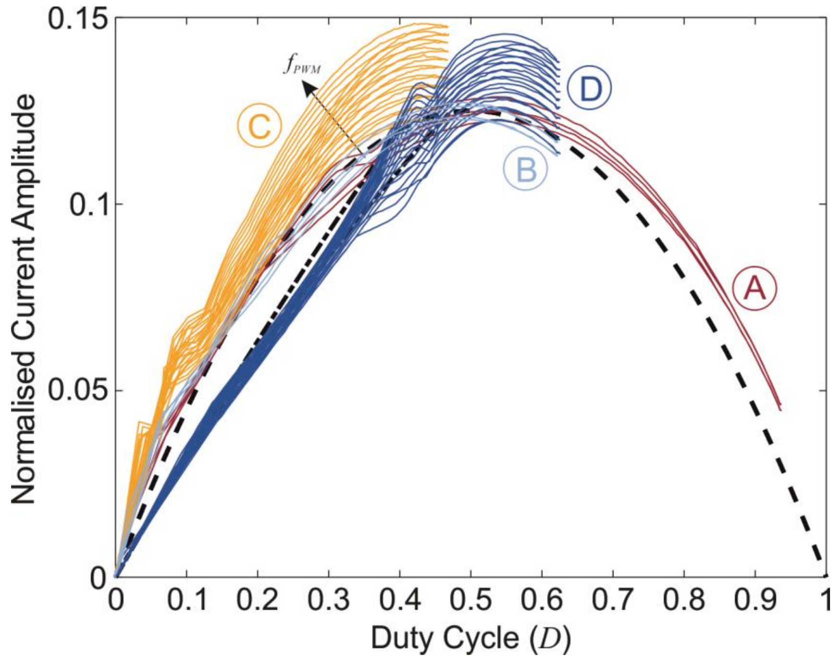


Validation of D_{max}



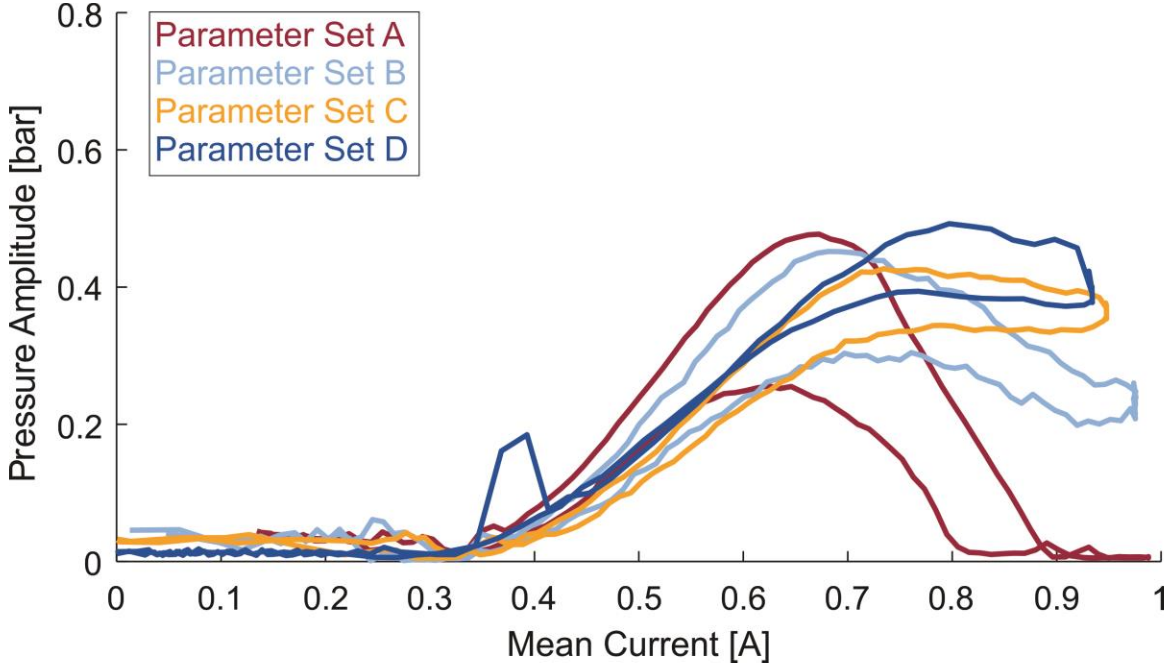
Parameter set	A	B	C	D
Supply voltage	12 V	18 V	24 V	24 V
Suppressor voltage	0.7 V (Diode)			12 V Z-Diode
Maximum Duty-Cycle	88 %	60 %	45 %	62 %

Current Amplitude (with variable Inductance $L(i)$)



Parameter set	A	B	C	D
Supply voltage	12 V	18 V	24 V	24 V
Suppressor voltage	0.7 V (Diode)			12 V Z-Diode
Maximum Duty-Cycle	88 %	60 %	45 %	62 %
PWM Frequency	90 – 120 Hz	100 – 130 Hz	100 - 200 Hz	100 - 200 Hz

Pressure Amplitude



Parameter set	A	B	C	D
Supply voltage	12 V	18 V	24 V	24 V
Suppressor voltage	0.7 V (Diode)			12 V Z-Diode
Maximum Duty-Cycle	88 %	60 %	45 %	62 %
PWM Frequency	104 Hz	118 Hz	130 Hz	147 Hz

1	Open Loop PWM Control
2	Closed Loop Current Control
3	Parameterisation Rules & Experimental Validation
4	**Conclusion**

Conclusion

- Two widely used electronic control schemes for electromechanical valve actuators have been presented
- Parameters for the dynamic excitation depend on control design
- Fundamental parameterisation rules for open loop PWM and closed loop current control have been shown and validated

Open loop PWM	Closed loop current control
Simple implementation	Better dynamics
Lower dynamics	Smaller temperature drift
Changing dynamic excitation over duty cycle	Constant dynamic excitation
Temperature drift	More complex

Thank you for your attention!

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