Computer-assisted modeling and automatic controller adjustment for hydraulic drives based on an innovative nonparametric identification method

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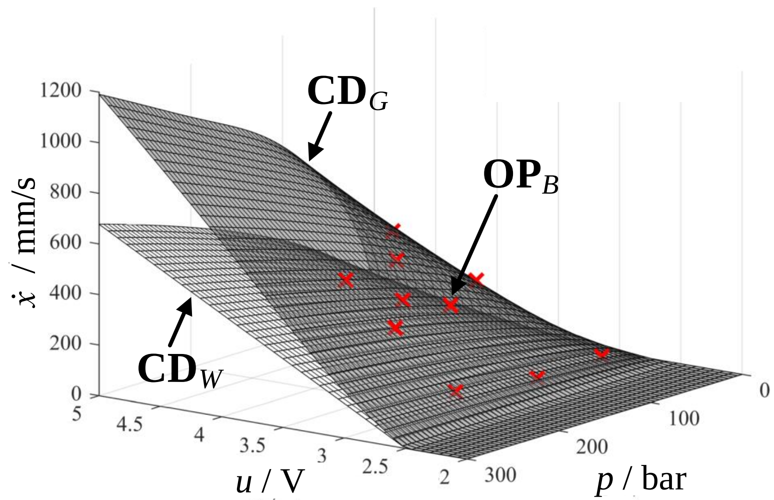

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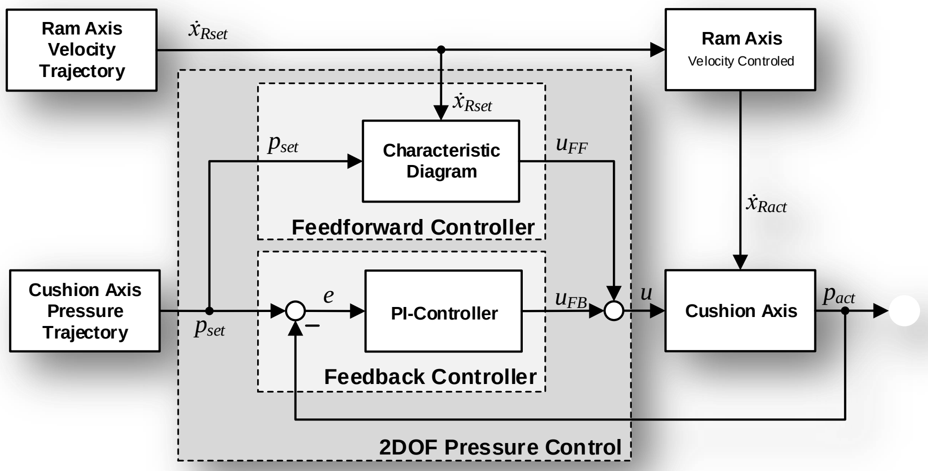
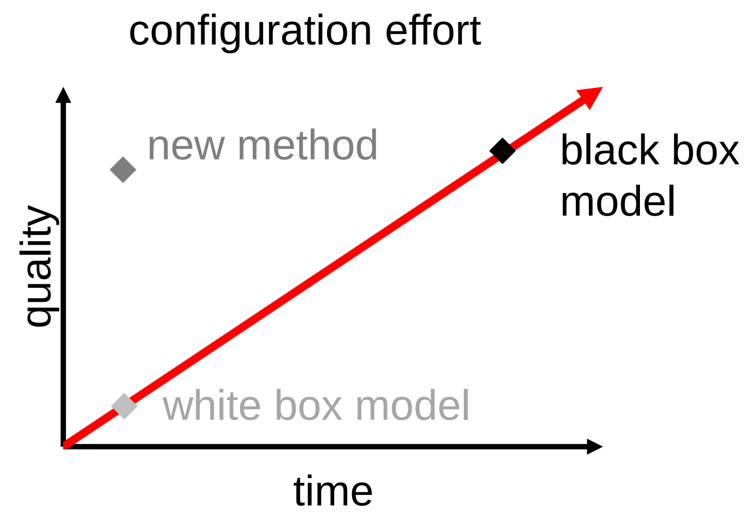
Introduction and motivation





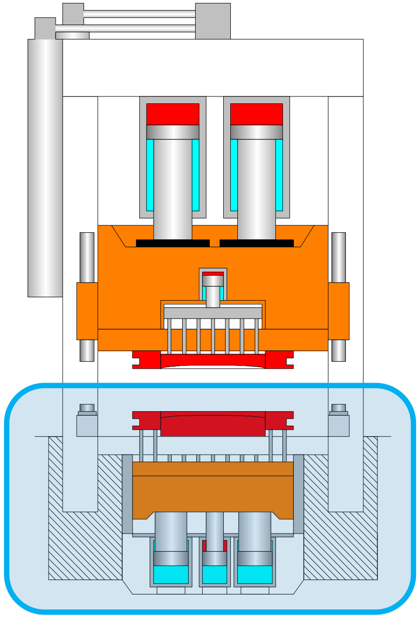
- pressure control for drawing cushion requires highly dynamic behavior
- solution:
  feedforward controller + feedback controller
  (90%) (10%)

- quality of feedforward controller depends on configuration effort
- solution:
  innovative method of identifying characteristic diagram with less effort

Observed drive system

Year of manufacture	2006
Ram (force, stroke)	21.000 kN, 1500 mm
Speed (pressing, rapid down)	500 mm/s, 350 mm/s
Cushion (force, stroke)	6.000 kN, 350 mm

- try-out press Müller-Weingarten ZE2100.45.2.2
- 4 separate ram cylinders
- accumulator drive for forming stroke
- 8 separate pressure cylinders for drawing cushion

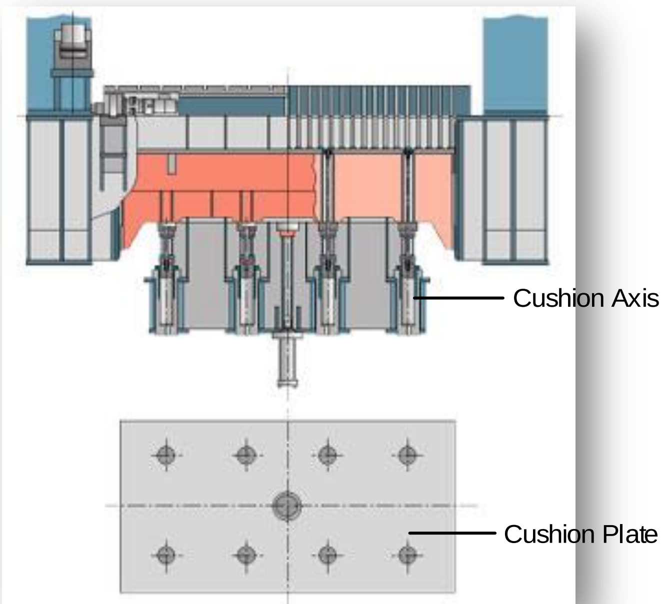


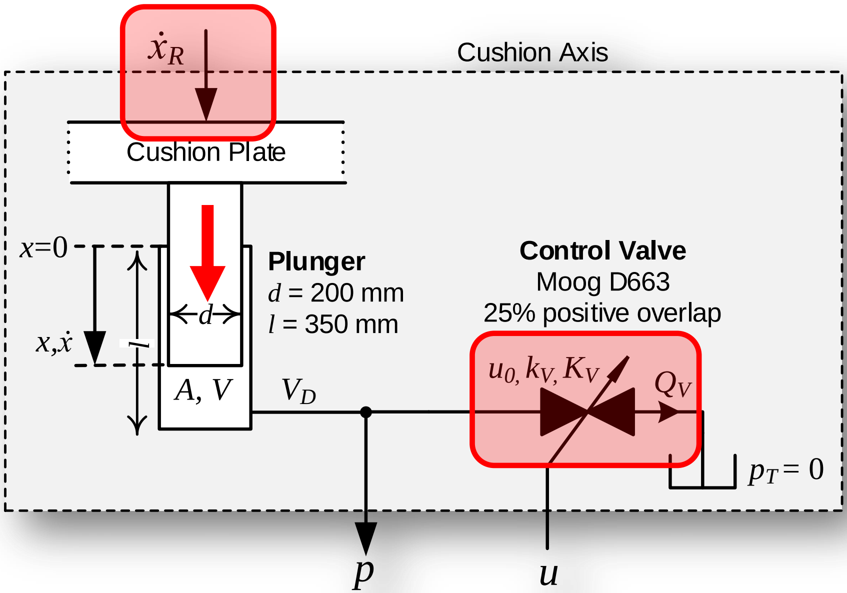
drawing cushion

Observed drive system

Drawing cushion in detail

- drive axis consists of plunger and highly dynamic control valve
- movement of drawing cushion is impressed by ram
- pressure build up through fluid compression
- valve regulates pressure via discharging plunger





Modeling, identification and optimization of the drive characteristic diagram

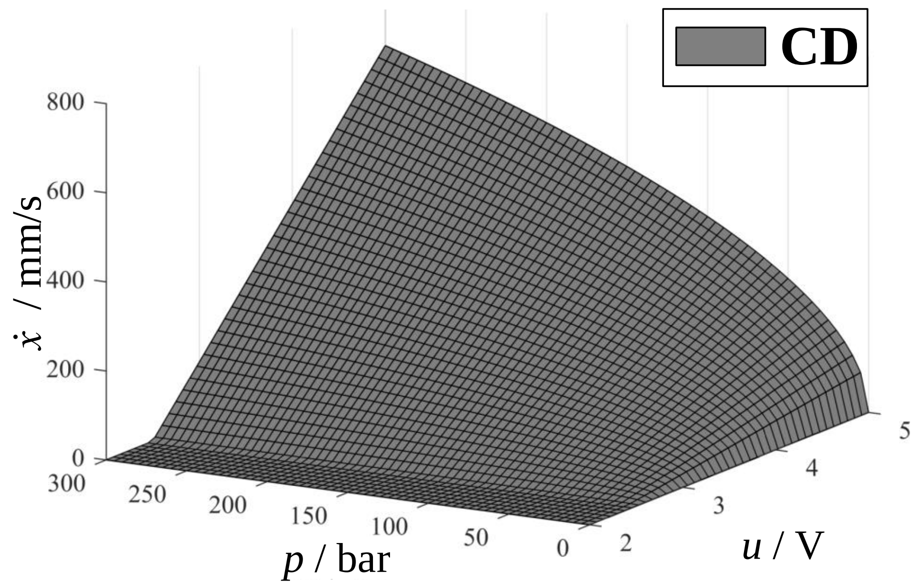
Characteristic diagram

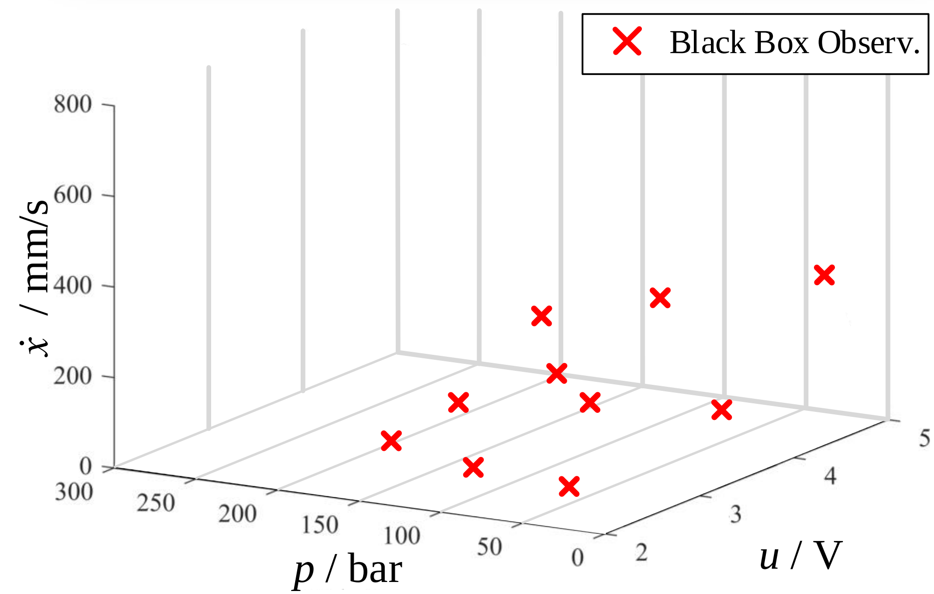
- **OP** – operating point
- **CD** – characteristic diagram

$$\boxed{\mathbf{OP} \in \mathbf{CD}}$$

- white box model = calculated **CD**
- black box model = measured **CD**

CD	$u_1 = u_{\min}$	u_2	$\cdots$	$u_n = u_{\max}$
$p_1 = p_{\min}$	$\dot{x}_{11}$	$\dot{x}_{12}$	$\cdots$	$\dot{x}_{1n}$
p_2	$\dot{x}_{21}$	$\dot{x}_{22}$	$\cdots$	$\dot{x}_{2n}$
p_3	$\dot{x}_{31}$	$\dot{x}_{32}$	$\cdots$	$\dot{x}_{3n}$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
$p_m = p_{\max}$	$\dot{x}_{m1}$	$\dot{x}_{m2}$	$\cdots$	$\dot{x}_{mn}$

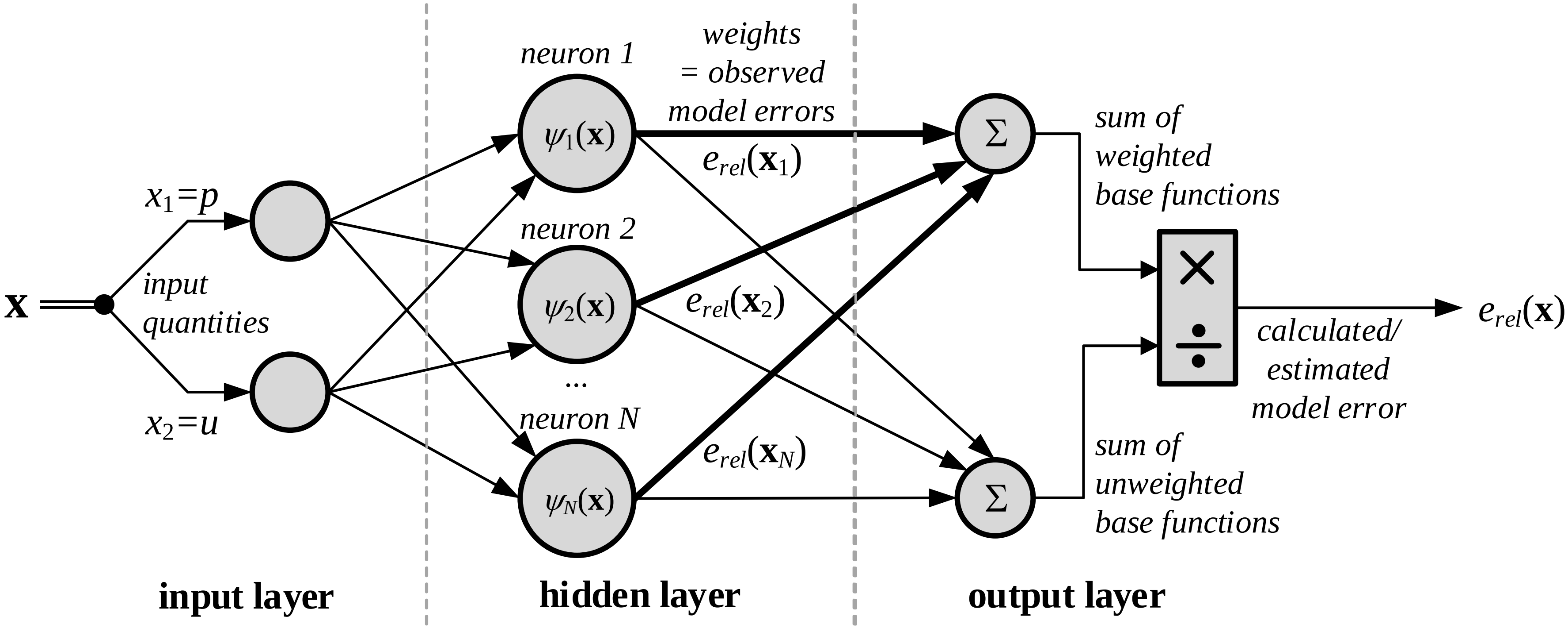




Modeling, identification and optimization of the drive characteristic diagram

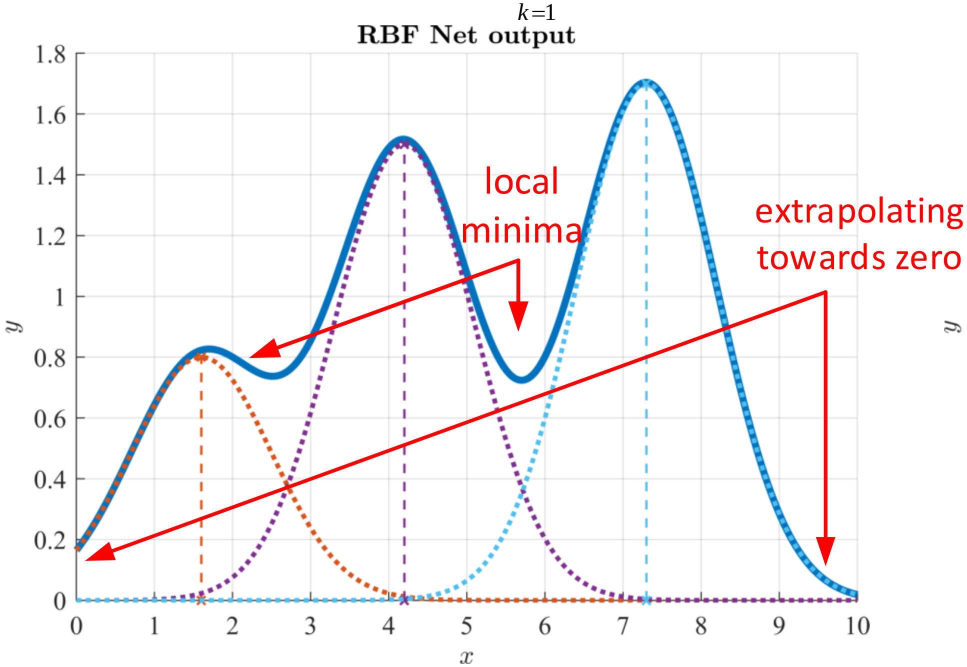
Solution

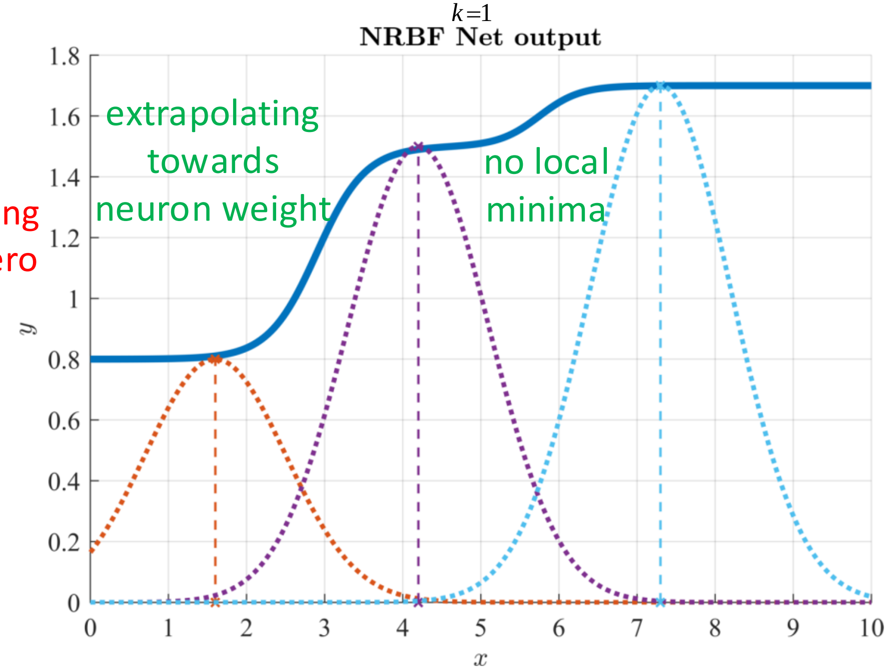
- measuerement based optimization of white box model
- white box model = qualitatively plausible description of **CD**
- correction of white box model with few (N ≈ 10-15 or even less) black box obser.
- optimization of **CD** via **NRBF** (Normalized Radial Basis Function Network)



Modeling, identification and optimization of the drive characteristic diagram

	Unormalized	**Normalized**
Distance:	$d(x) = \lvert x - v_k \rvert$	
Base-Function:	$\psi_k(x) = \dfrac{d(x)^2}{2\sigma_k^2}$	$y(x) = \dfrac{\sum_{k=1}^{c} w_k \cdot \psi_k(x)}{\sum_{k=1}^{c} \psi_k(x)}$
Net Output:	$y(x) = \sum_{k=1}^{c} w_k \cdot \psi_k(x)$	





Modeling, identification and optimization of the drive characteristic diagram

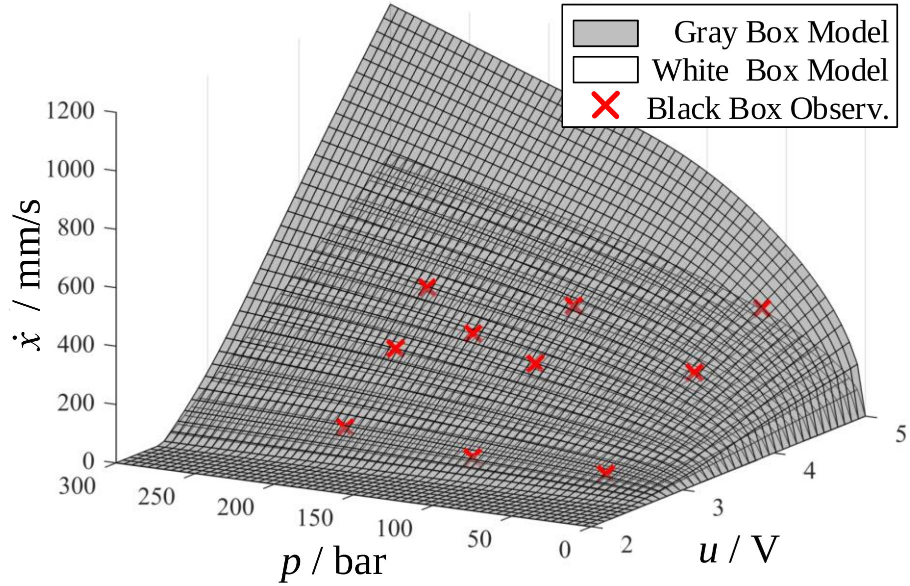
Gray box model

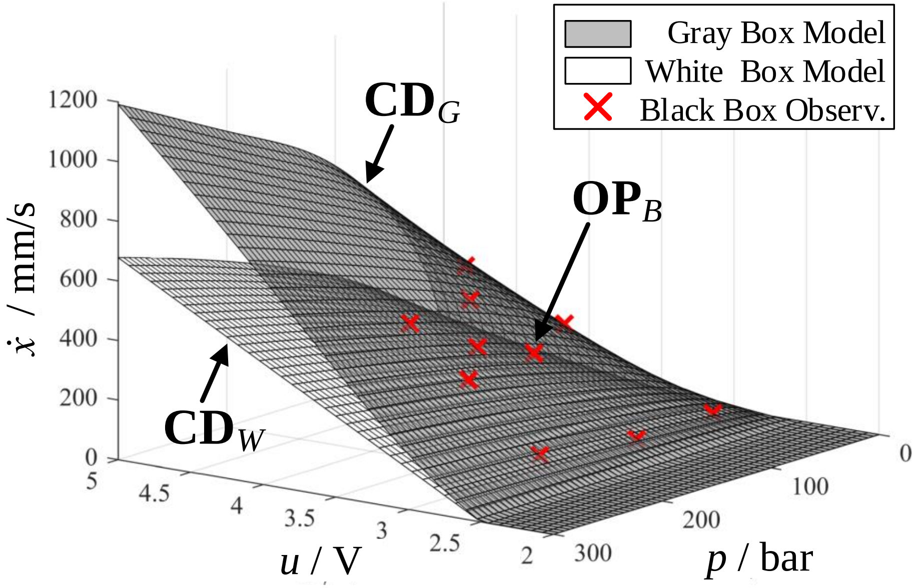
- combines advantages of

white box model + black box model

$\boxed{\text{quickly accessible + highly precise}}$

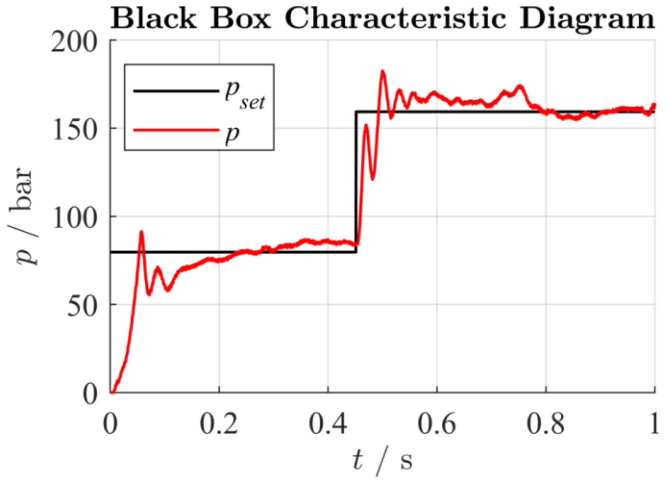
- only few identified **OP** are needed for identification and optimization of **CD**
- **OP**$_B$ are very vell „matched“ & relevant information is meaningfully genrealized

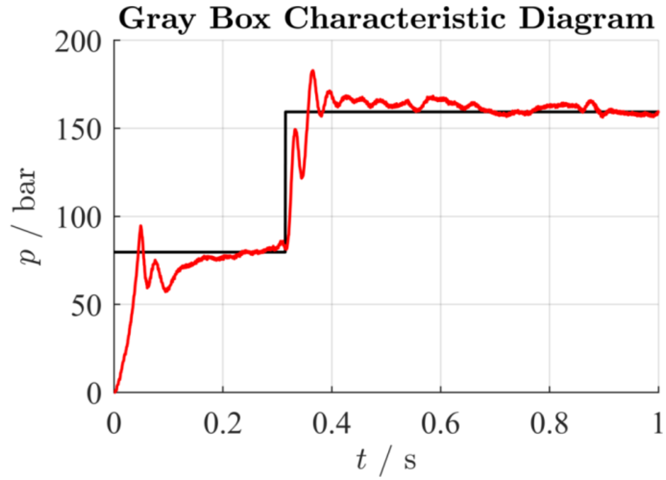




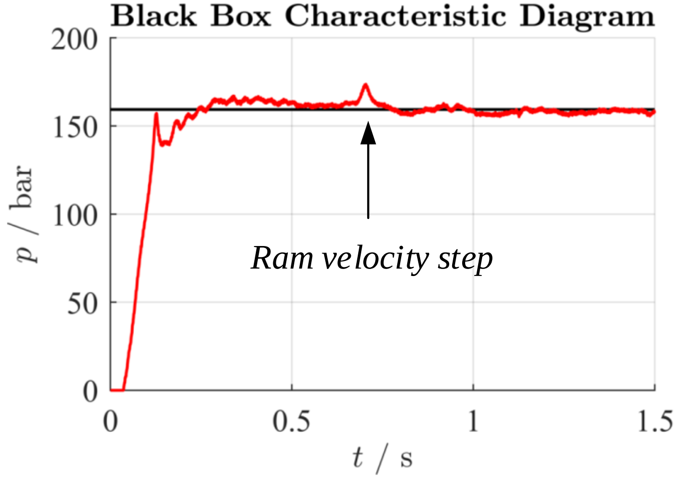
Modeling, identification and optimization of the drive characteristic diagram

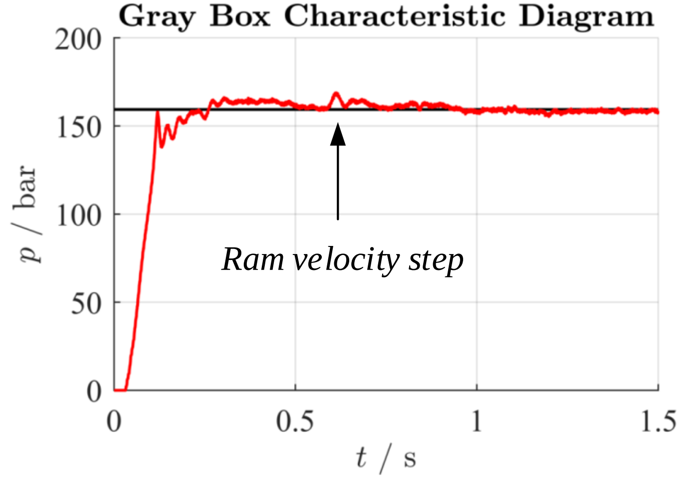
a) alternating pressure setpoint: p_{set} = 80 bar → 160 bar **constant ram velocity:** $\dot{x}$ = 200 mm/s





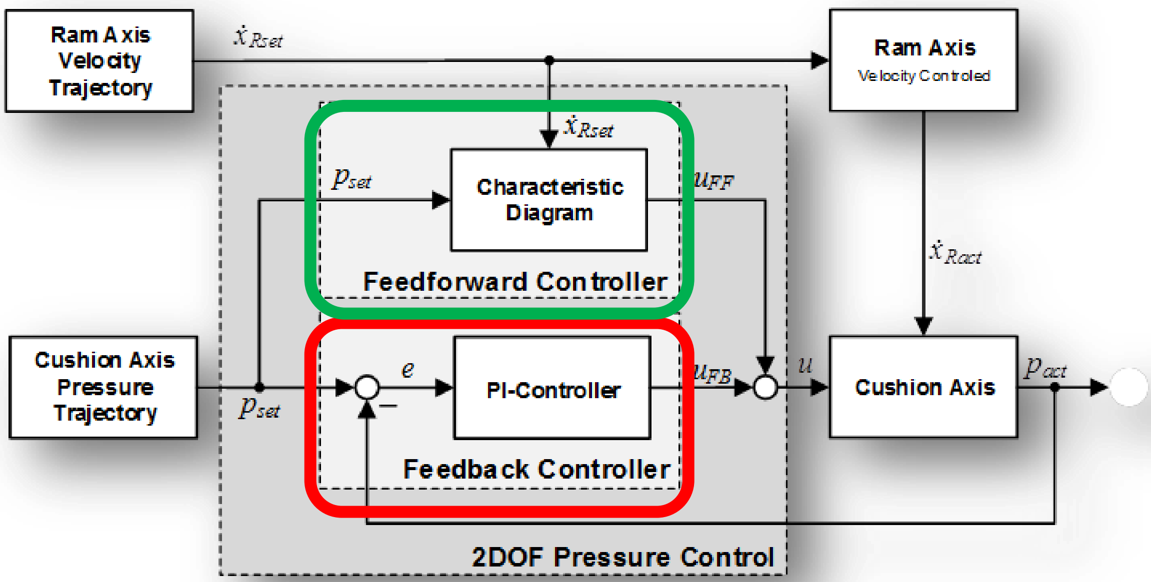
b) constant pressure setpoint: p_{set} = 160 bar **alternating ram velocity:** $\dot{x}$ = 150 → 75 mm/s





Operating point-dependent adaptation of the feedback control parameters

Controller design



General observations

- PI-controller „sees“ piston as stationary
- pressure adapts set course „miraculously by itself“
- hydraulic capacity nevertheless changes over time

Operating point-dependent adaptation of the feedback control parameters

Linearized control system

$$G_S(s) = \frac{p(s)}{u(s)} = \frac{K_S}{T_S \cdot s + 1}$$

PI-controller

$$G_R(s) = K_R \cdot \frac{T_{ZR} \cdot s + 1}{s}$$

Feedback control parameters

$$\boxed{T_{ZR}(K_p, x) = \frac{V(x)}{E_{Fl} \cdot K_p}}$$

$$\boxed{K_R(K_p, K_u) = -\frac{K_p}{k \cdot T_V \cdot K_u}}$$

Parameters can be designed/adapted with the help of

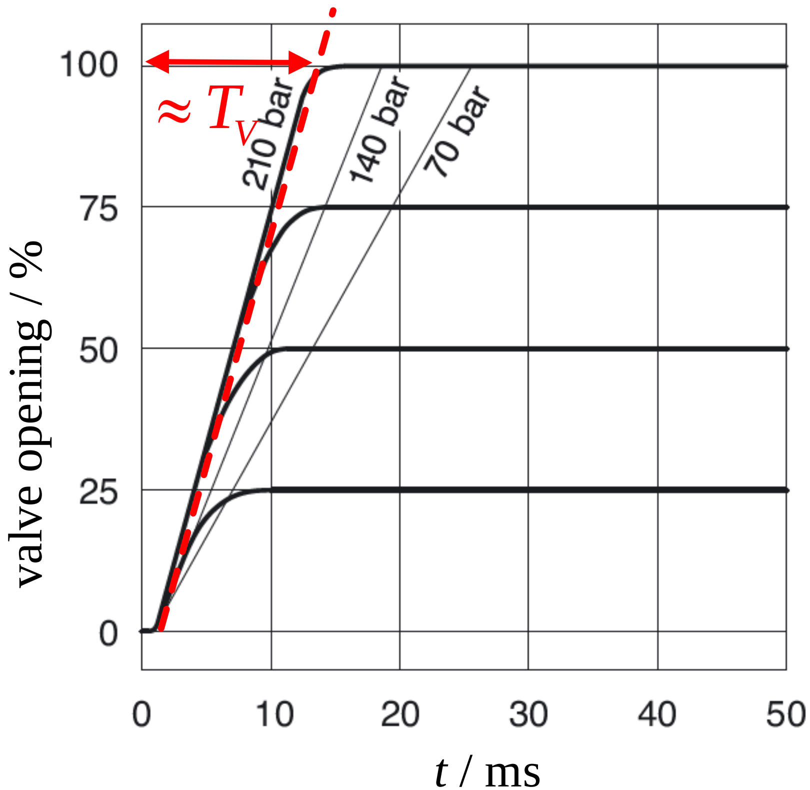
- piston position x (→ current hydraulic capacity)
- characteristic diagram gradients $K_p = dQ/dp$ and $K_u = dQ/du$

Dynamics are only limited by dynamics of actuator (valve time constant T_V)

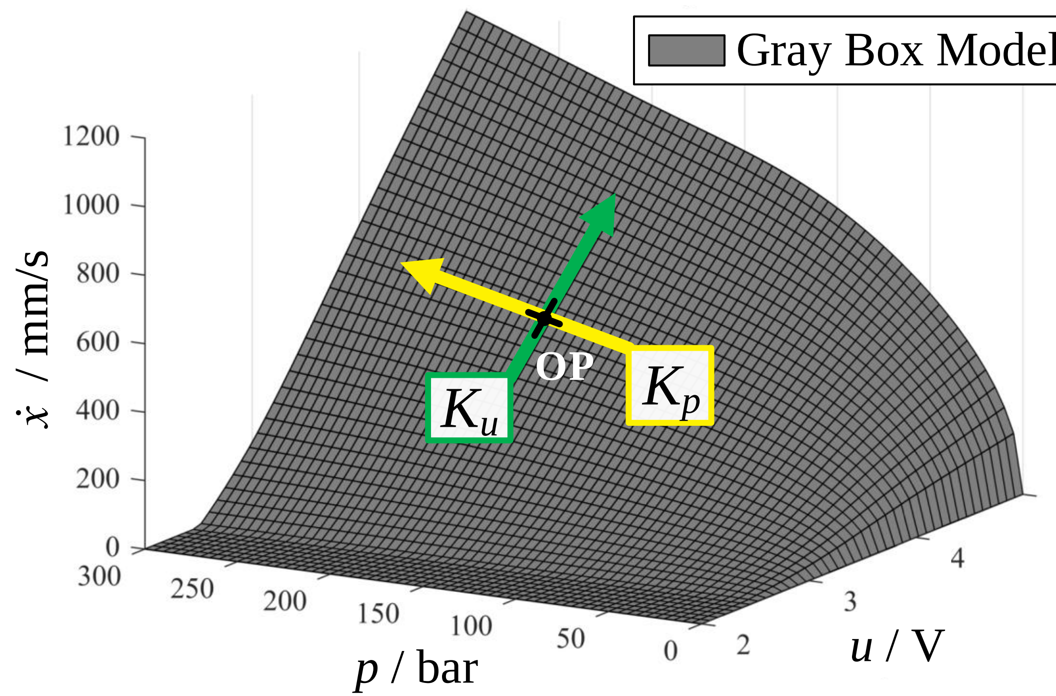
Operating point-dependent adaptation of the feedback control parameters

Operating-point dependent parameter adaption

a) Estimation of valve timeconstant



b) Calculation of linearization parameters / gradients



Summary and conclusion

Feedforward controller

- very good results using stationary **CD** as model-based feedforward control
- only few measured data needed for identifying **CD**
- reduced effort for identification of **CD** (around 10% of original value)

Feedback controller

- operating point-dependent adaption of feedback control parameters

2DOF control design can be considered as a coherent and logical overall concept.

<u>Both methods are not limited to hydraulic presses and can be transferred to other drive systems.</u>

Thank you for your attention!

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