Design and Modeling of Fluid Power Systems

ME 597/ABE 591 - Lecture 8

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Content

Instantaneous cylinder pressure – conservation of mass

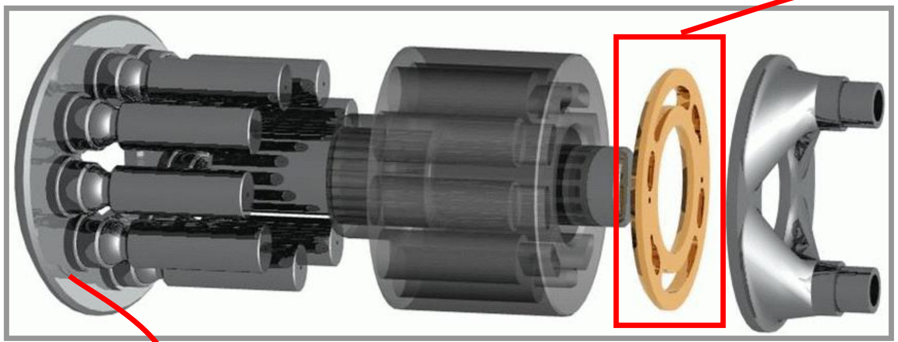
Gap flow calculation

Valve plate design issues

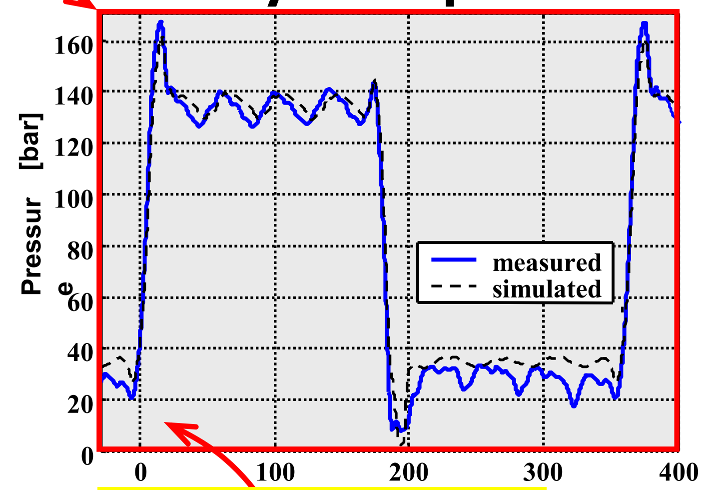
Aim: Derivation of basic equations for gap flow and calculation of Gap flow parameters (pressure and velocity distribution, load ability, gap flow and viscous friction)

Basic knowledge about the gap design and simulation models

Noise generation in piston pumps

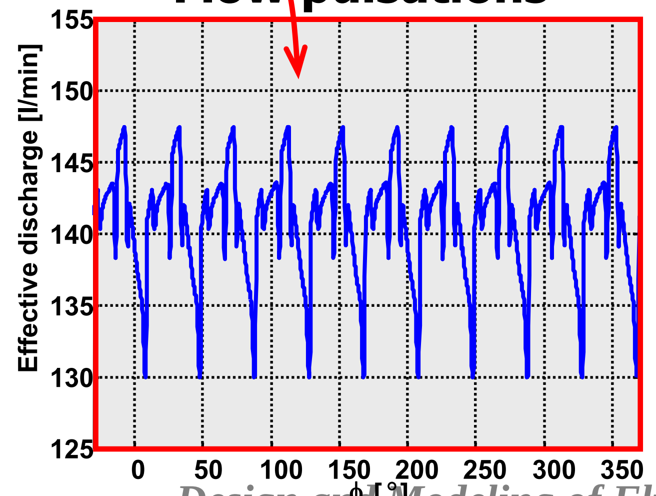


Inst. cylinder pressure

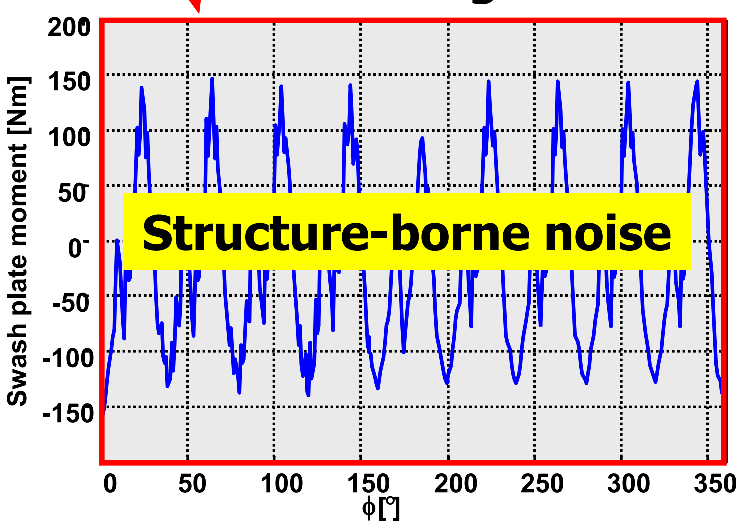


fluid-borne noise

Flow pulsations



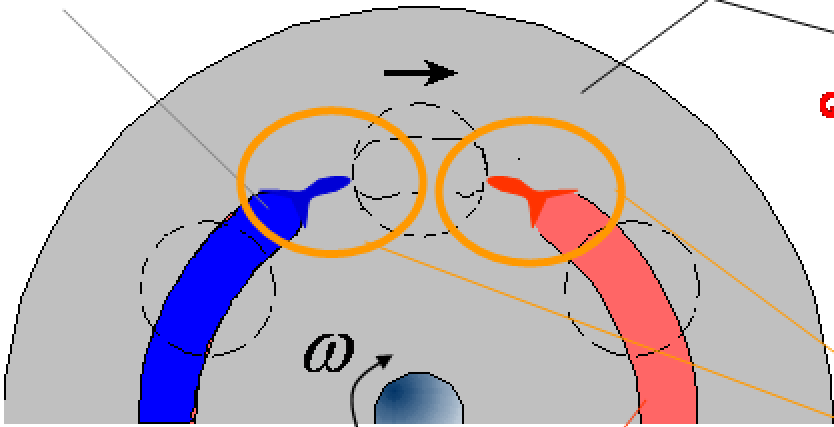
Oscillating forces

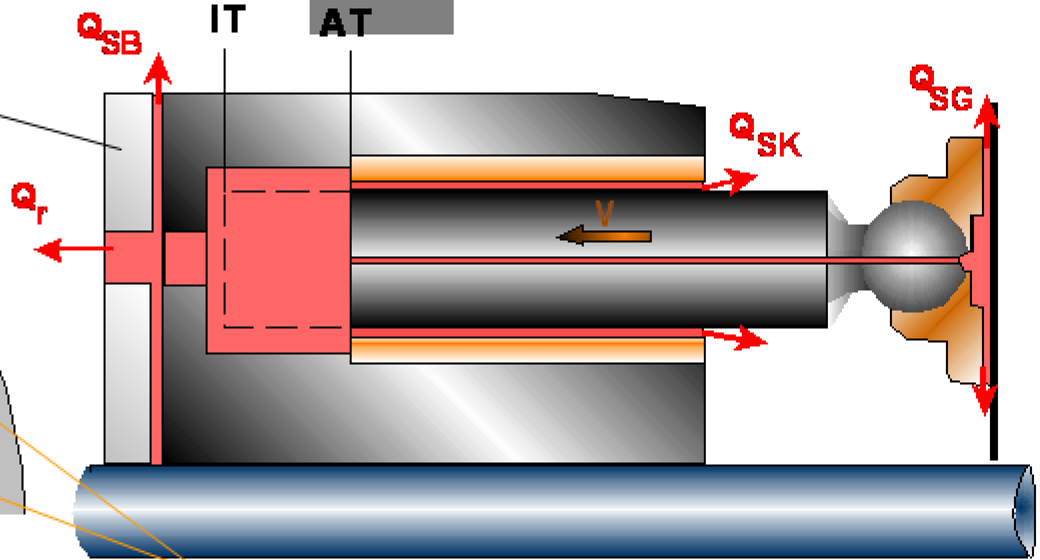


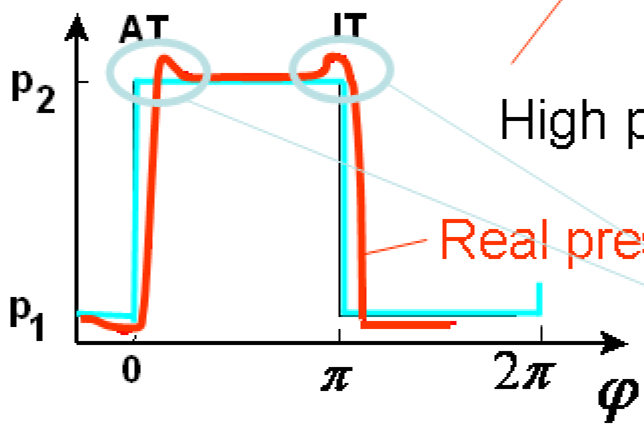
Instantaneous cylinder pressure

Suction port

Valve plate







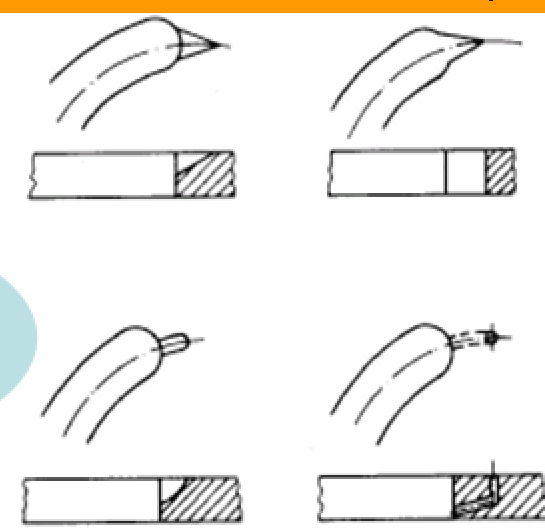
High pressure port

Real pressure profile

Ideal pressure profile

Design measures of valve plate

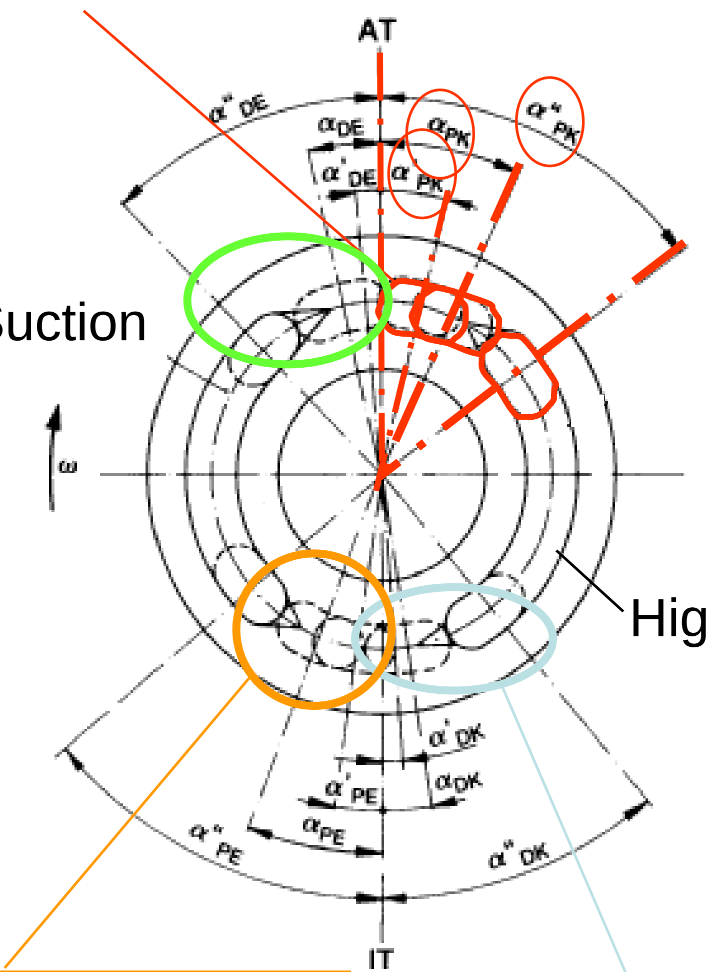
To avoid pressure peaks



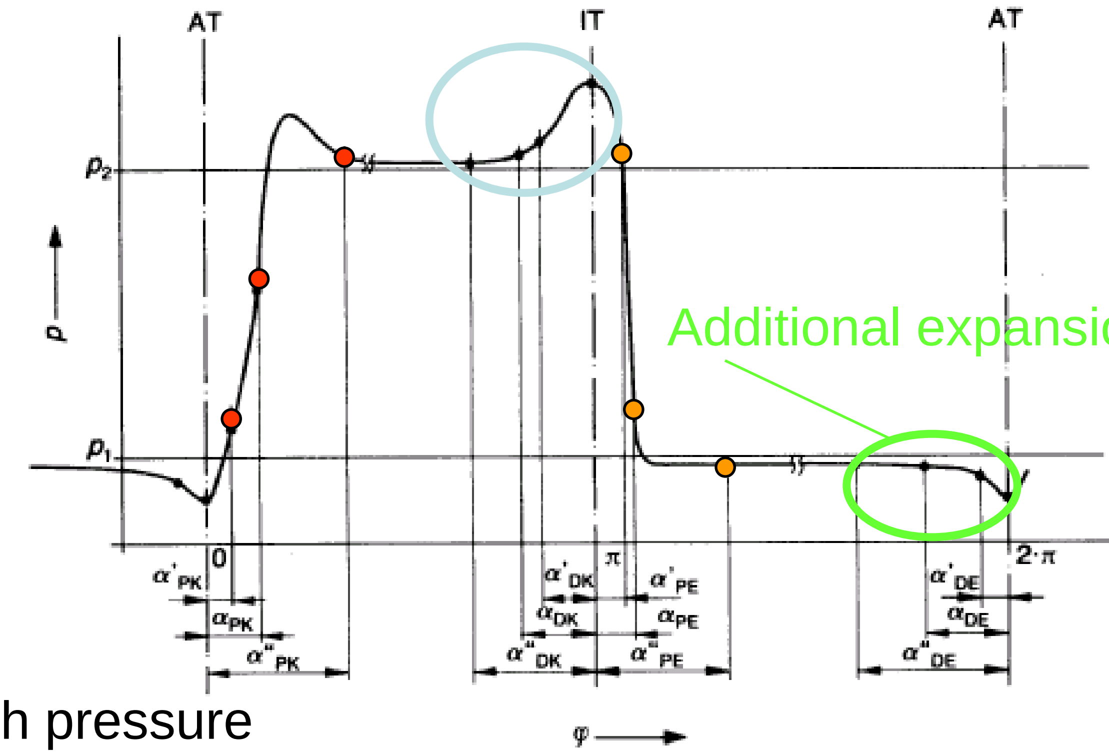
Instantaneous cylinder pressure

Openings in cylinder

Suction



High pressure



Additional expansion

α'_{PK} Start of opening of precompression

α_{PK} End of precompression opening

α''_{PK} Pressure port full open

Pre-expansion

Additional compression

Instantaneous cylinder pressure

Conservation of mass:

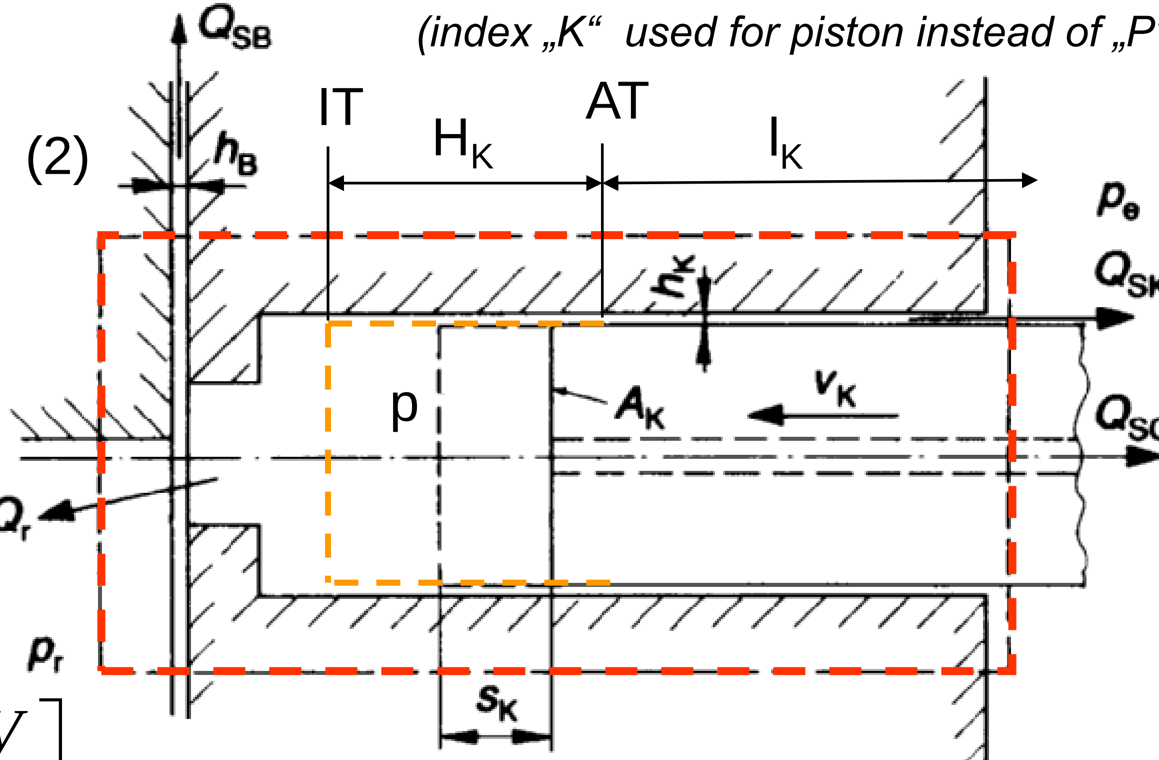
$$-Q_{mr} - Q_{mSB} - Q_{mSK} - Q_{mSG} + \frac{d}{dt}(V \cdot \rho) = 0 \quad (1)$$

$$Q_m = \rho \cdot Q$$

(index „K“ used for piston instead of „P“)

$$\frac{d}{dt}(V \cdot \rho) = V \cdot \frac{d\rho}{dt} + \rho \cdot \frac{dV}{dt} \quad (2)$$

Q_m ... mass flow



$$\frac{d\rho}{dt} = \frac{\rho}{K} \cdot \frac{dp}{dt} \quad (3)$$

$$\frac{d}{dt}(V \cdot \rho) = \rho\left[\frac{V}{K} \cdot \frac{dp}{dt} + \frac{dV}{dt}\right] \quad (4)$$

$$dV = \frac{1}{K} \cdot V \cdot dp$$

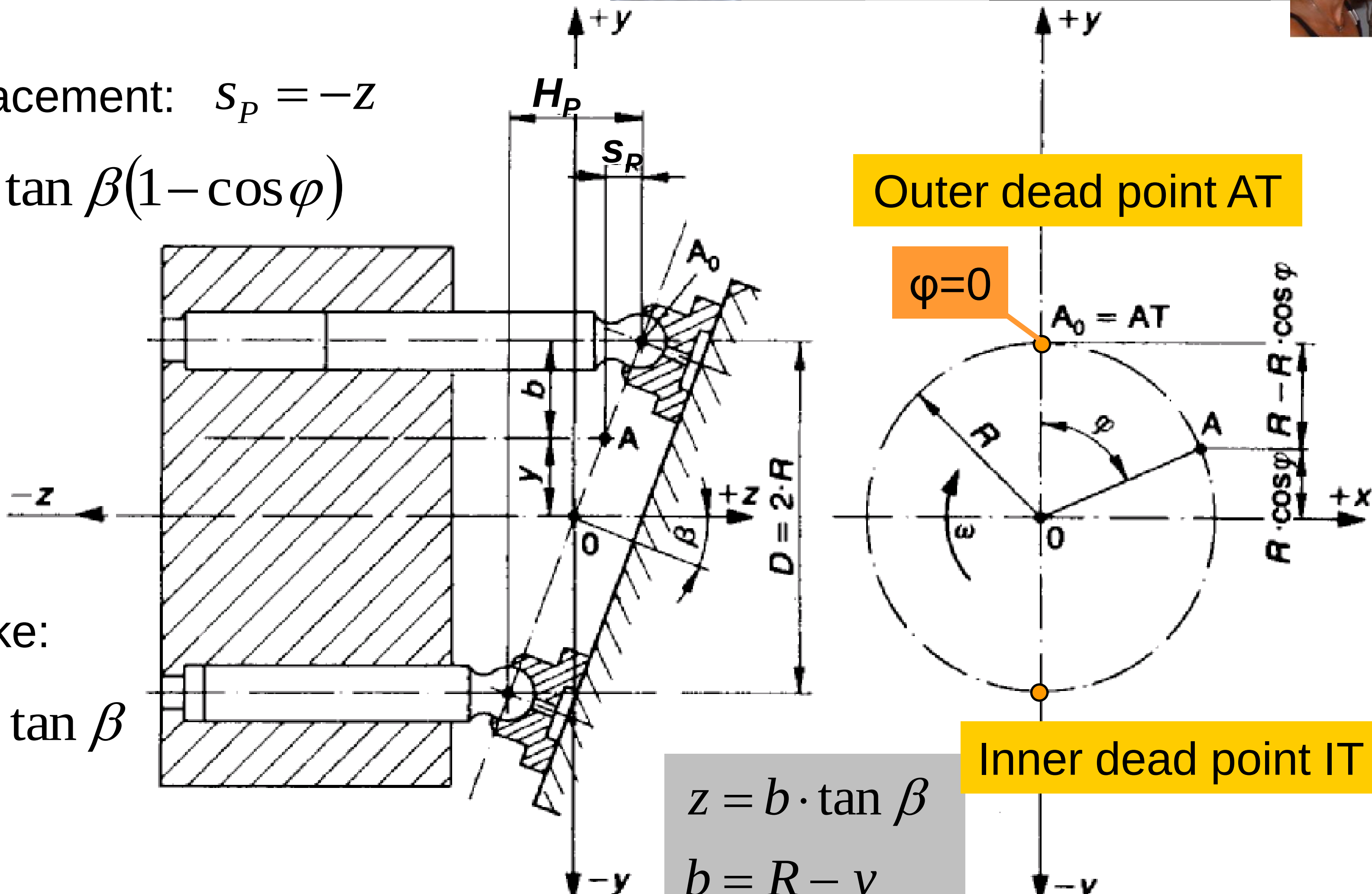
$$-\rho(Q_r + Q_{SB} + Q_{SK} + Q_{SG}) + \rho\left[\frac{V}{K} \cdot \frac{dp}{dt} + \frac{dV}{dt}\right] = 0 \quad (5)$$

Axial Piston Machine

Kinematics

Piston displacement: $s_P = -z$

$$s_P = -R \cdot \tan\beta\left(1-\cos\varphi\right)$$



Piston stroke:

$$H_P = 2 \cdot R \cdot \tan\beta$$

$$z = b \cdot \tan\beta$$

$$b = R - y$$

$$y = R \cdot \cos\varphi$$

R … pitch radius

Instantaneous cylinder pressure

$$-\rho\left(Q_r + Q_{SB} + Q_{SK} + Q_{SG}\right) + \rho\left[\frac{V}{K}\cdot\frac{dp}{dt} + \frac{dV}{dt}\right] = 0 \quad (5)$$

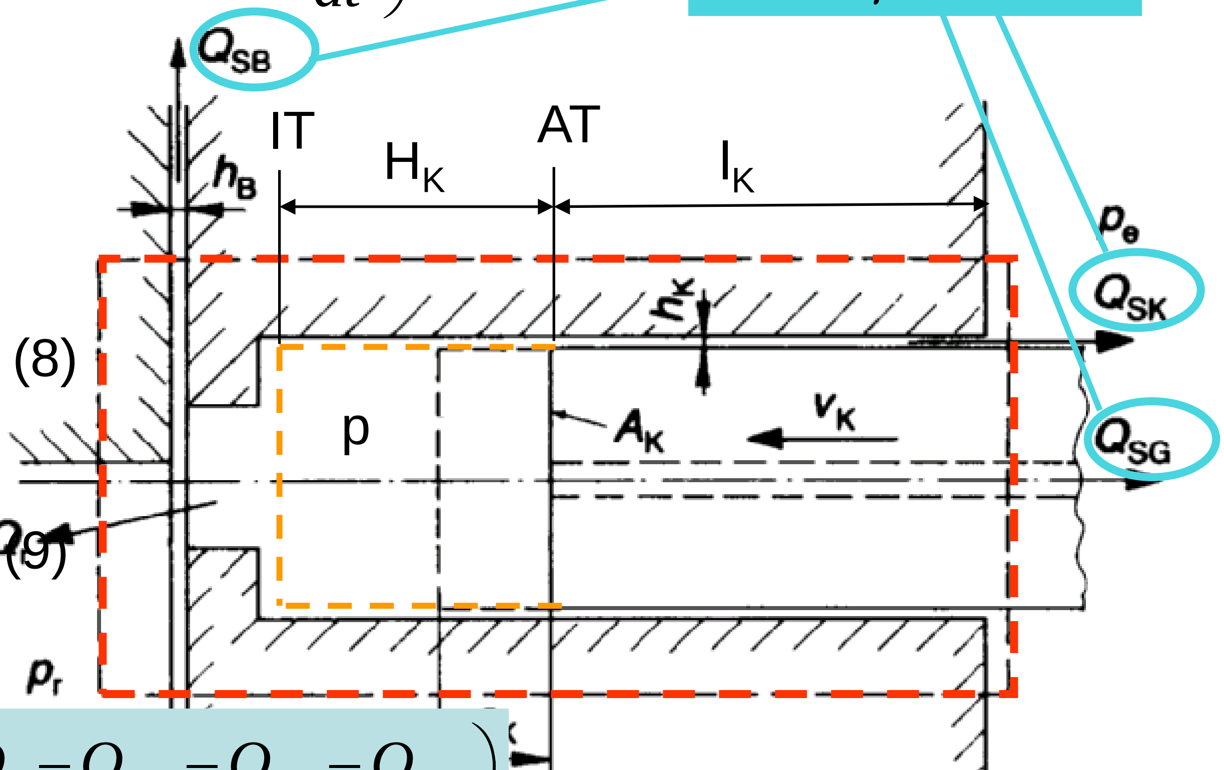
$$\frac{dp}{dt} = \frac{K}{V}\left(Q_r + Q_{SK} + Q_{SB} + Q_{SG} - \frac{dV}{dt}\right) \quad (6)$$

$$Q = \frac{1}{12\cdot\mu}\cdot\frac{\partial p}{\partial x}\cdot b\cdot h^3$$

$$\frac{dV}{dt} = v_K \cdot A_K \quad (7)$$

$$V = V_0 - s_K \cdot A_K \quad (8)$$

$$V_0 = V_T + H_K \cdot A_K \quad (9)$$



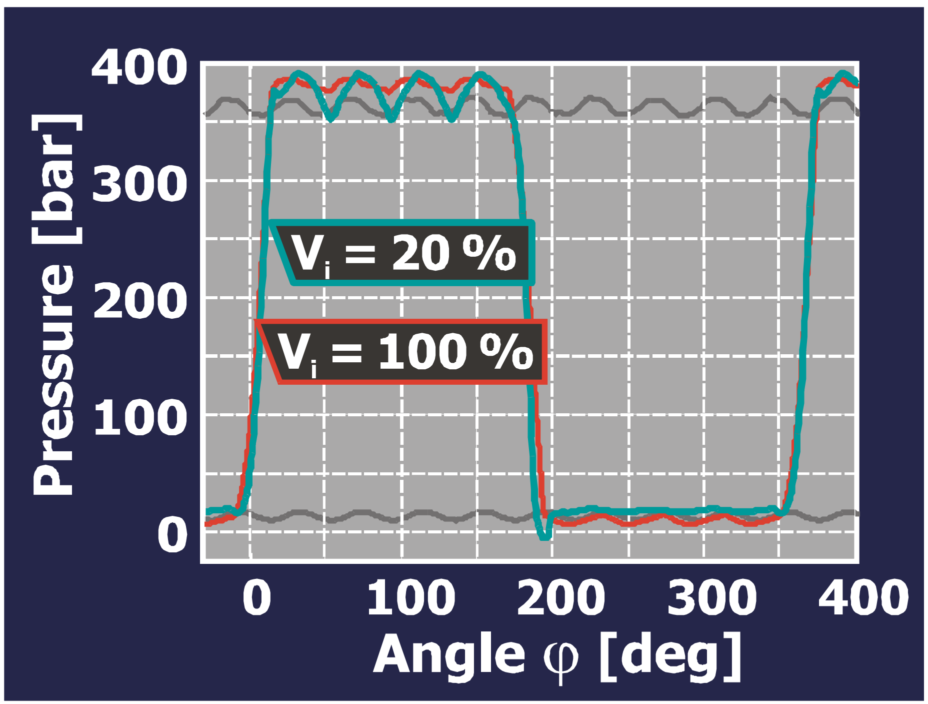
$$\frac{dp}{d\varphi} = -\frac{K}{\omega}\left(\frac{v_K \cdot A_K - Q_r - Q_{SK} - Q_{SB} - Q_{SG}}{V_0 - s_K \cdot A_K}\right) \quad (11)$$

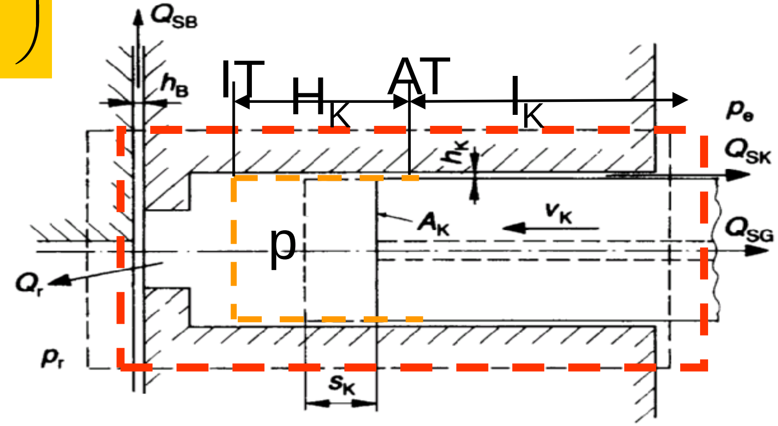
$$d\varphi = \omega \cdot dt \quad (10)$$

Instantaneous cylinder pressure

$$\frac{dp}{d\varphi} = -\frac{K}{\omega}\left(\frac{v_K \cdot A_K - Q_r - Q_{SK} - Q_{SB} - Q_{SG}}{V_0 - s_K \cdot A_K}\right) \qquad (11)$$

$$s_P = -R \cdot \tan\beta(1-\cos\varphi)$$





$$V_0 = V_T + H_K \cdot A_K$$

$$H_K = 2 \cdot R \cdot \tan\beta$$

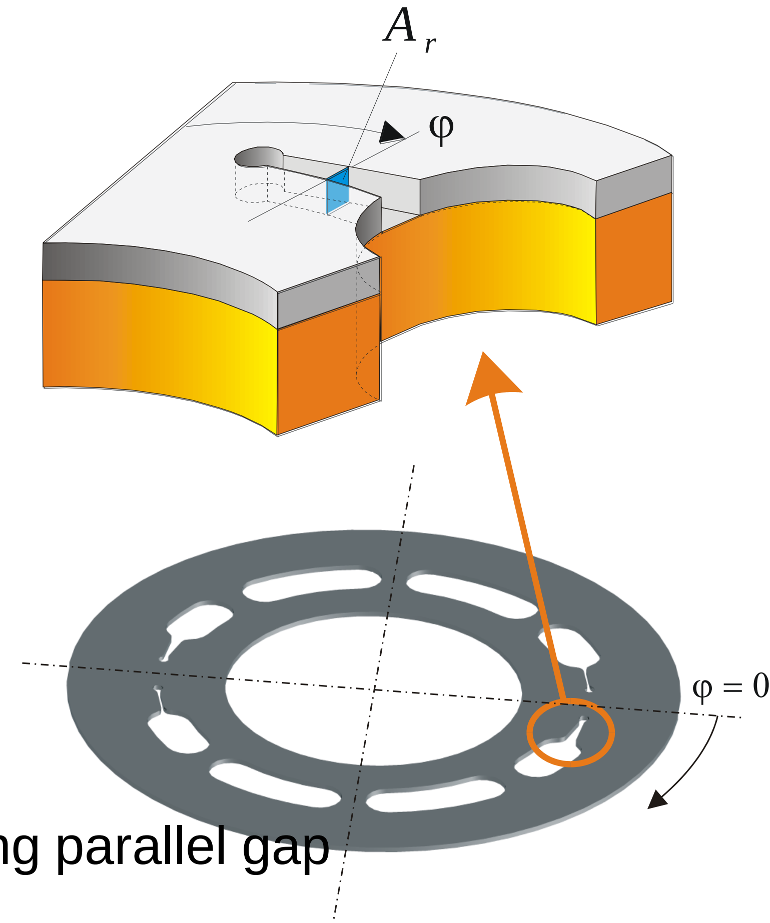
Instantaneous cylinder pressure

Flow from displacement chamber through valve plate openings to pressure port

Turbulent flow – orifice equation:

$$Q_r = \alpha_D \cdot A_r \cdot \sqrt{\frac{2}{\rho}} \cdot \sqrt{(p - p_r)} \cdot \mathrm{sgn}(p - p_r)$$

$$A_r = f(\varphi)$$



Gap flows – laminar flow:

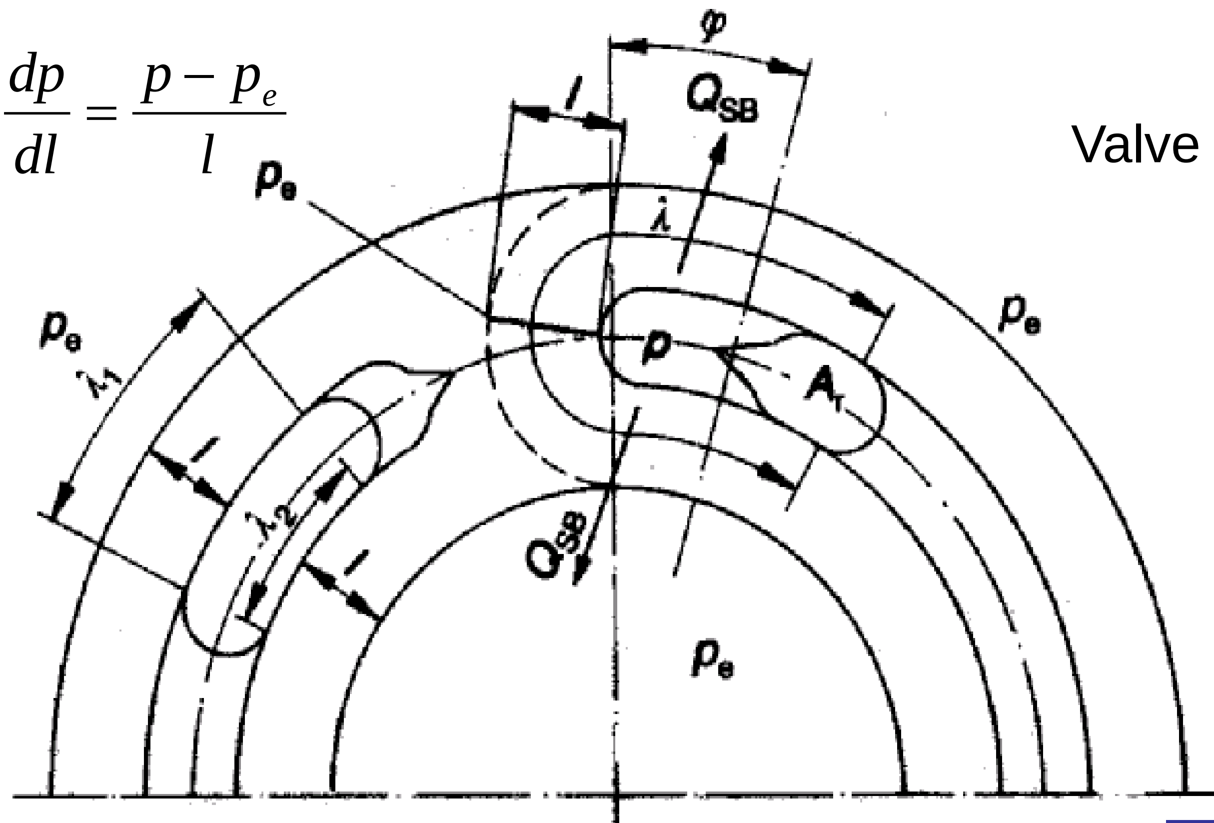
$$Q = b\int_0^h v \cdot dz = -\frac{1}{12\mu} \cdot \frac{\partial p}{\partial x} \cdot b \cdot h^3 + v_0 \cdot \frac{h}{2} \cdot b$$

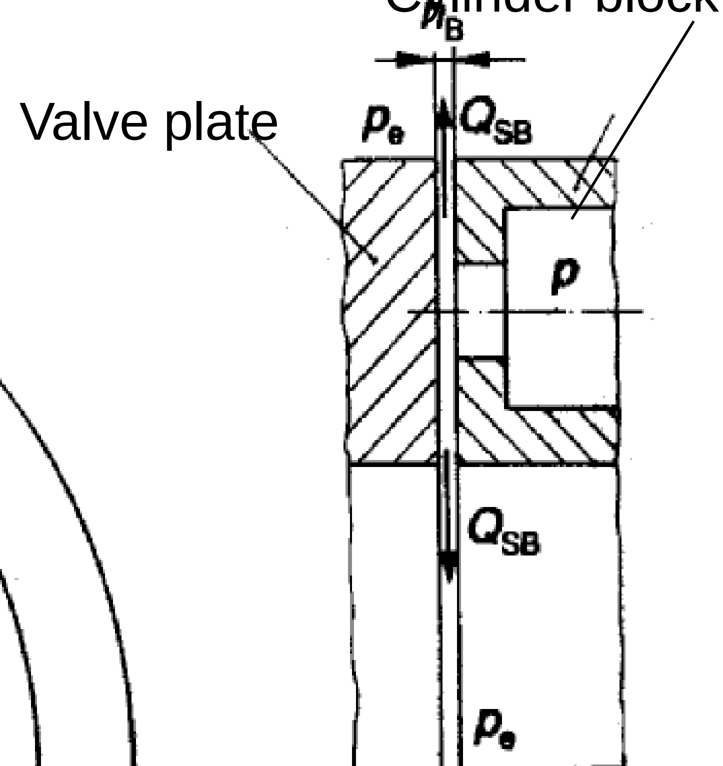
Gap flow between piston and cylinder assuming parallel gap

$$Q_{SK} = \frac{\pi \cdot d_K \cdot h_K^3}{12 \cdot \mu \cdot l_K} \cdot (p - p_e) - \frac{\pi \cdot d_K}{2} \cdot h_K \cdot v_K$$

Gap flow through the gap between cylinder block and valve plate

$$\frac{dp}{dl} = \frac{p - p_e}{l}$$



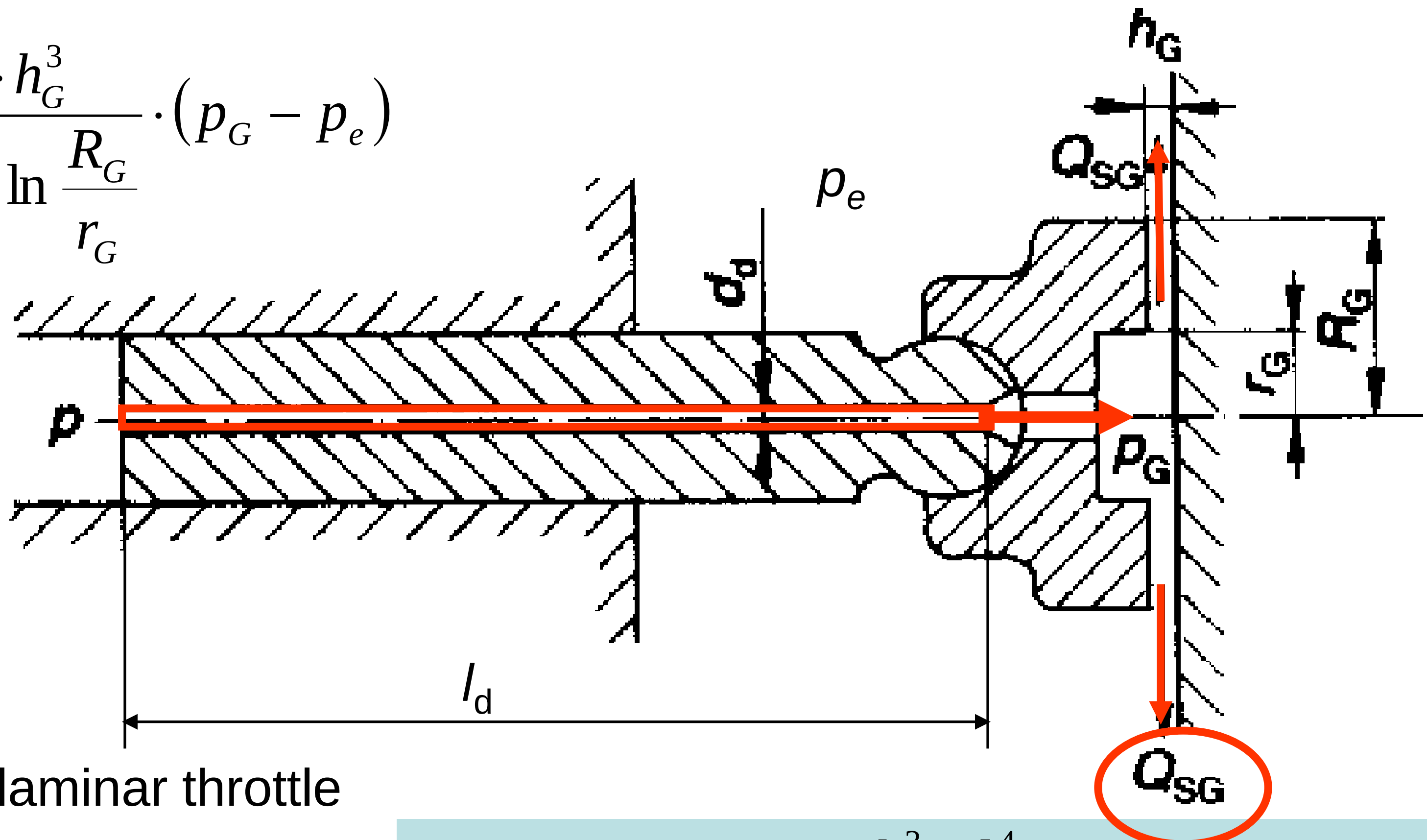


Assuming a parallel gap

$$Q_{SB} = \frac{h_B^3}{12 \cdot \mu} \cdot (p - p_e) \cdot \int_\lambda \frac{1}{l} \cdot d\lambda \quad \text{where } l = f(\lambda)$$

Gap flow through the gap between slipper and swash plate

$$Q_{SG} = \frac{\pi \cdot h_G^3}{6 \cdot \mu \cdot \ln \frac{R_G}{r_G}} \cdot (p_G - p_e)$$

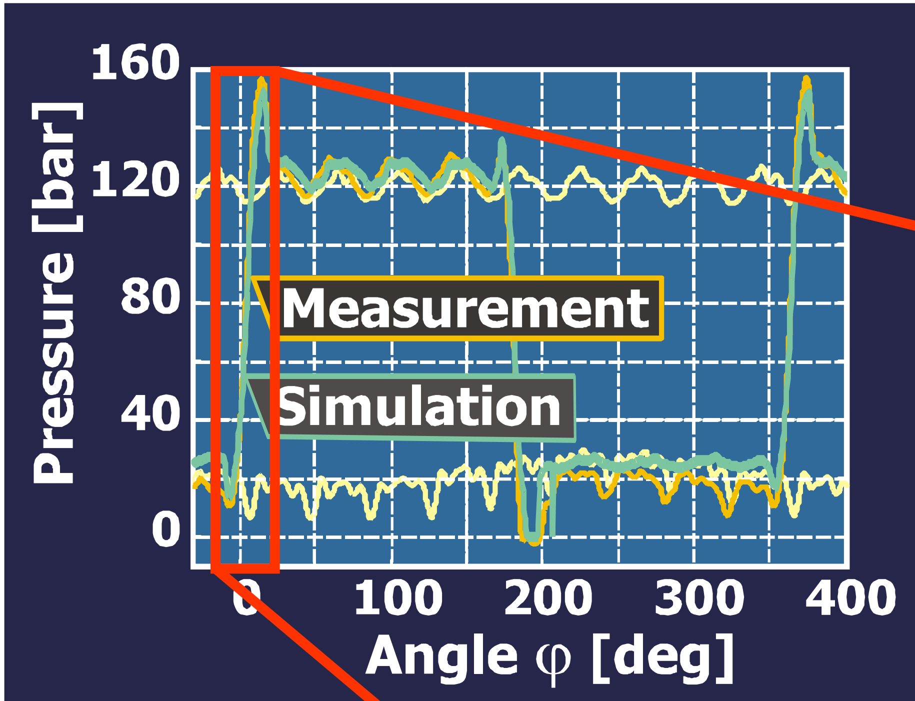


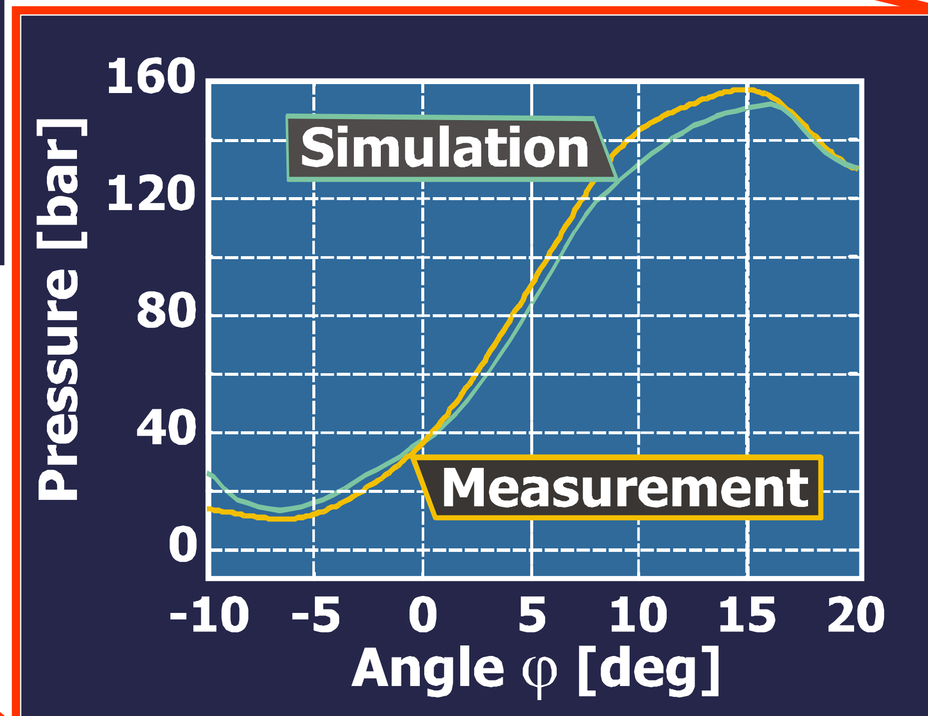
Flow through laminar throttle

$$Q_{SG} = \frac{\pi \cdot d_d^4}{128 \cdot \mu \cdot l_d} \cdot (p - p_G)$$

$$Q_{SG} = \frac{\pi \cdot h_G^3 \cdot d_d^4}{\mu \cdot \left(6 \cdot d_d^4 \cdot \ln \frac{R_G}{r_G} + 128 \cdot h_G^3 \cdot l_d \right)} \cdot (p - p_e)$$

Measurement Results – Pressure Profile





V_i = 100 %

Δp = 100 bar

n = 2000 rpm