Design and Modeling of Fluid Power Systems
ME 597/ABE 591 - Lecture 8

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Content

Instantaneous cylinder pressure – conservation of mass

Pump Noise Sources

Valve plate design issues

Aim: Derivation of instantaneous cylinder pressure
application of basic equations for gap flow calculation
Basic knowledge about valve plate design and effect on pump
noise sources
Noise generation in piston pumps

Oscillating forces

Structure-borne noise

Inst. cylinder pressure

Flow pulsations

Fluid-borne noise

Effective discharge [l/min]
Instantaneous cylinder pressure

Suction port

Valve plate

Design measures of valve plate

High pressure port

Real pressure profile

Ideal pressure profile

To avoid pressure peaks
Instantaneous cylinder pressure

Openings in cylinder

Suction

High pressure

Pre-expansion

Additional compression

$\alpha'_{PK}$ Start of opening of precompression

$\alpha_{PK}$ End of precompression opening

$\alpha''_{PK}$ Pressure port full open
**Instantaneous cylinder pressure**

Conservation of mass:

\[
\frac{d}{dt} (V \cdot \rho) = V \cdot \frac{dp}{dt} + \rho \cdot \frac{dV}{dt}
\]  \hspace{1cm} (2)

\[
Q_m = \rho \cdot Q
\]

\[
\frac{dp}{dt} = \frac{\rho}{K} \cdot \frac{dp}{dt}
\]  \hspace{1cm} (3)

\[
\frac{d}{dt} (V \cdot \rho) = \rho \left[ \frac{V}{K} \cdot \frac{dp}{dt} + \frac{dV}{dt} \right]
\]  \hspace{1cm} (4)

\[
- \rho (Q_r + Q_{SB} + Q_{SK} + Q_{SG}) + \rho \left[ \frac{V}{K} \cdot \frac{dp}{dt} + \frac{dV}{dt} \right] = 0
\]  \hspace{1cm} (5)

(index "K" used for piston instead of "P")

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Axial Piston Machine

Kinematics

Piston displacement: \( s_P = -z \)

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

Piston stroke:

\[
H_P = 2 \cdot R \cdot \tan \beta
\]

\( R \) … pitch radius

Outer dead point AT

\( \varphi = 0 \)

Inner dead point IT

\[
z = b \cdot \tan \beta
\]

\[
b = R - y
\]

\[
y = R \cdot \cos \varphi
\]
Instantaneous cylinder pressure

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

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

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

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

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

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

\[d\varphi = \omega \cdot dt \quad (10)\]
Instantaneous cylinder pressure

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

(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:

\[ Q_r = \alpha_D \cdot A_r \cdot \sqrt{\frac{2}{\rho}} \cdot \sqrt{(p - p_r)} \cdot \text{sgn}(p - p_r) \]

\[ A_r = f(\varphi) \]

Gap flows – laminar flow:

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

Gap flow between piston and cylinder assuming parallel gap:

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

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Instantaneous cylinder pressure

Gap flow through the gap between cylinder block and valve plate

\[ \frac{dp}{dl} = \frac{p - p_e}{l} \]

Assuming a parallel gap

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

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

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

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Measurement Results – Pressure Profile

\[ V_i = 100 \% \]
\[ \Delta p = 100 \text{ bar} \]
\[ n = 2000 \text{ rpm} \]