EFRC Training Workshop

Basic Training of Reciprocating Compressor Systems

Gas Compression and Thermodynamics Johannes Strecha–Hoerbiger Wien GmbH Vienna, Austria













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Compression cycle

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- p(t) curve, p-V diagram Mass-flow rate & power consumption ٠



Losses

- Valve losses
- Blow-by leakage
- Packing leakage





Pressure and temperature

- Pressure: acts in every direction ~ kinetic energy of the gas molecules bouncing on the containers walls
- Temperature: related to kinetic energy of the gas molecules (including rotational & vibrational components)
- Are well-defined thermodynamic/physical quantities (i.e. state variables), with links to kinetic gas theory
- Popular units: p in bar, Pa, psi; T in K, °C, °F
- Can be field quantities p = p(x,y,z)

Beware: Thermodynamic/Physical relations are expressed in absolute pressures and temperatures!



Equation of state (EoS)

- Relate state variables of a phase to each other, e.g. p·V = m·R·T (ideal-gas equation)
- Some EoS allow to calculate phase equilibria (vapour-liquid equilibrium)
- all real gases behave approximately as ideal gases for not too high pressures and temperatures ⇒ ideal gas law is asymptotic limiting law for real gases

Process

• Change of state, e.g. from state 1 to state 2

Balance equations

- Govern how such a transition can occur
- C.f. first & second law of thermodynamics















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CE re-expansion phase

- Both valves are closed
- Remaining gas (clearance volume!) expands from p2 to p1
- Change of state is isentropic

Discussion

 Why is re-expansion always steeper than compression?













Delivered mass-flow rate



Mass flow rate

$$M_{\rm ad} = V_{\rm SW} \rho_1 \cdot \lambda_{\rm V} \cdot \frac{rpm}{60}$$

- M_{ad} adiabatic mass flow (kg/s)
- rpm compressor speed
- V_{SW} swept volume (m³)
- volumetric filling efficiency (-)

Volumetric filling efficiency $\lambda_{\rm V} = 1 - \sigma \left(\left(\frac{p_2}{p_1} \right)^{1/\gamma} - 1 \right)$ y isentropic exponent

- isentropic exponent V
- clearance volume referred to swept volume σ

Generalised filling efficiency

$$\lambda = \lambda_{\rm V} \cdot \lambda_{\rm p} \cdot \lambda_{\rm H} \cdot \lambda_{\rm L}$$

- Volumetric filling efficiency
- Pressure loss (SV)
- Heating
- Leakages



4.0

Dependence of the filling efficiency on σ and p_2/p_1







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Increasing σ , p_2/p_1 : •Longer re-expansion phase •Longer compression phase •Shorter suction and delivery phases

There's a $p_2/p_1 - \sigma$ combination where $\lambda \rightarrow 0!$

Discussion: •How does the p-V diagram look like when $\lambda \rightarrow 0$? •Practical limits of p_2/p_1 (upper), σ (lower)

p2/p1=2

Required driver power



$$m_i, h_1 \rightarrow \longrightarrow m_o, h_2$$

By the first law of thermodynamics: •State $1 \rightarrow 2$:

$$U_2 - U_1 = \int_1^2 \left(-p\dot{V} + \sum_i \dot{m}_i \left(\underbrace{u_i + \frac{p_i}{\rho_i}}_h \right) \right) dt$$

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•H: "Enthalpy" = internal energy + p/ρ, H = H(T, p)
•Cycle:

$$W = H_o - H_i = -\oint p \mathrm{d}V$$

•Enclosed area of the pV diagram equals the work done in the cycle (ABCDA, isentropic compression)

Adiabatic power (ideal gas, no losses, no heat transfer)

$$P_{\rm ad} = \frac{\gamma}{\gamma - 1} \frac{p_1}{\rho_1} M_{\rm ad} \left(\left(\frac{p_2}{p_1}\right)^{(\gamma - 1)/\gamma} - 1 \right)$$







Leaking DV valve

Hot, compressed gas flows into the compression chamber



- Faster compression, slower reexpansion
- Suction gas is heated up (in the compression chamber)
- Discharge temperature increases



Leaking SV valve

Hot, compressed gas flows into the intake manifold



- Slower compression, faster reexpansion
- Suction gas is heated up (in the intake-manifold)
- Discharge temperature increases

Packing leakage

- Similar in appearance, but doesn't increase the discharge temperature.
- CE Side only.

Blow-by leakage

Hot, compressed gas flows into the compression chamber



- "S" curve in the compression line
- Suction gas is heated up (in the compression chamber)
- Discharge temperature increases





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Discussion

- Which data is available typically?
- Analyzing p-V diagrams from the field

P-V diagrams in the field

Double-acting pistons:

Over piston position (left)

Further deviations:

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Over shifted piston position (right) .

HE/CE differences due to losses, etc. -





COMPRESSORS

Witt3-25bar-Druck -

Two-stage compressor





COMPRESSORS

Discussion

- Selecting the number of stages
- Compressor sizing approaches



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Thank you for your attention



