EFRC Training Workshop

State-of-the-art Design of Reciprocating Compressor Systems

Options for capacity control

Klaus Stachel - HOERBIGER

HOERBIGER

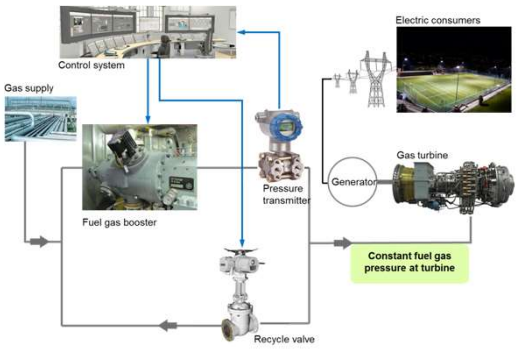
Options for Capacity Control

1. Why is capacity control required?
2. Stepwise and stepless control options
3. Comparison of features
4. Considerations for compressor engineering

Why is compressor capacity control required?

We want to compress only as much gas as to meet the process demand:

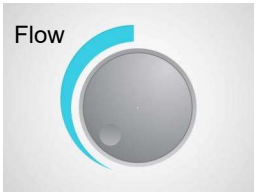
- Maintain control variables such as discharge pressure, suction pressure or flow or ...
- Limit power consumption



EFRC Training

Why is compressor capacity control required?

- Match production and process turn-down requirements
- Start-unloading:
  Avoid overload of main motor
- Switch over from running to stand-by compressor:
  Ideally without interference with the process (bumpless)
- Process gas industry: Compensate 10 to 15% surplus capacity of new compressors (as margin for performance losses and degradation)
- Control compressor interstage pressures
  - Rod-load
  - Rod-load reversal
  - Discharge temperatures



Discrete steps or stepless control can be used.

EFRC Training

Overview methods and systems

Method	Valve unloading / Cylinder clearance (FVCP)	Recycle valve	Variable speed	Stepless valve unloading / cylinder clearance (VVCP)
Stepless		●	●	●
Control range	0, (25), 50, (75), 100%	0-100%	60 to 100%	25 to 100%
Energy efficiency	moderate	poor	high	high
CAPEX of system	medium	low	Higher (dependent on motor power)	Higher (dependent on no. of valves)
OPEX of compressor	medium	high	low	low
Comments	Simple ; Limited operational flexibility	Simple; Risk of condensation depend. on gas; Larger noise emissions	Compressor valves reliability risks; Changes flow on all stages simultaneously; Special cons. in torsional and pulsation/vibration studies; In combination with valve unloading for start unloading	Enabler for multi-service compressors; Precise process control; Special cons. in torsional and pulsation/vibration studies; Stepless valve unloading more dynamic than VVCP;

Note:
Typical information only;
Information may differ for specific application.

EFRC Training

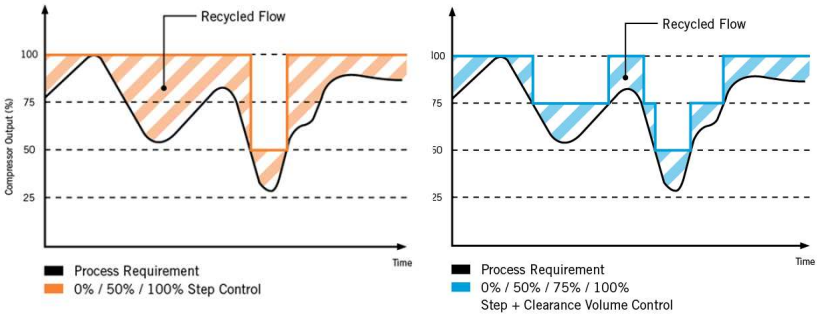
What is the appropriate system?

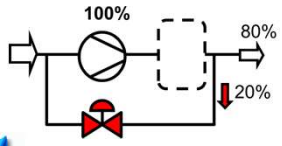
The selection of the appropriate control system and the applied technology depends on

- Technical applicability of the system itself
- Various engineering/design aspects of the compressor
- Flexibility to meet control variable settings
- Needs of production (air compressor in PET industry vs. H2 make up compressor in refinery)
- Standards and practices in the specific industry
- Reliability and maintenance requirements
- Legislation and approvals
- Energy efficiency
- Total-cost-of-ownership (CAPEX, OPEX)

EFRC Training

Stepwise: Efficiency determined by the number of load steps





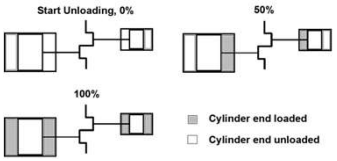
- Process gas compressor: Step-control always in combination with recycle valve control
- Number of cylinder ends per stage defines max. possible load steps.
- Only efficient if process demand is equal to adjusted load

EFRC

EFRC Training

Stepwise options

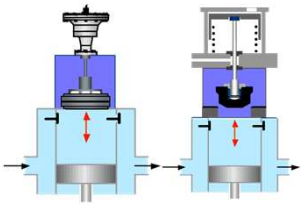
Suction valve unloading



- Capacity variation by unloading of one or several cylinder ends. Hold suction valve open and prevent cylinder end from compressing.

  A) Valve unloaders
  B) Suction port unloaders (bypass suction valves)

Fixed volume clearance pockets (FVCP)

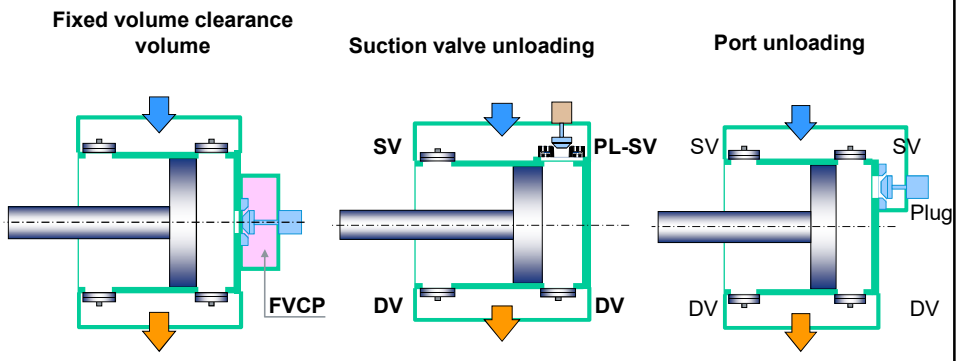


- Fixed clearance volume added/reduced by pneumatically controlled compressor valves or plug unloaders
- Often combined with valve unloading for larger load steps
- Load steps depend on pressure ratio

EFRC

EFRC Training

Stepwise configurations



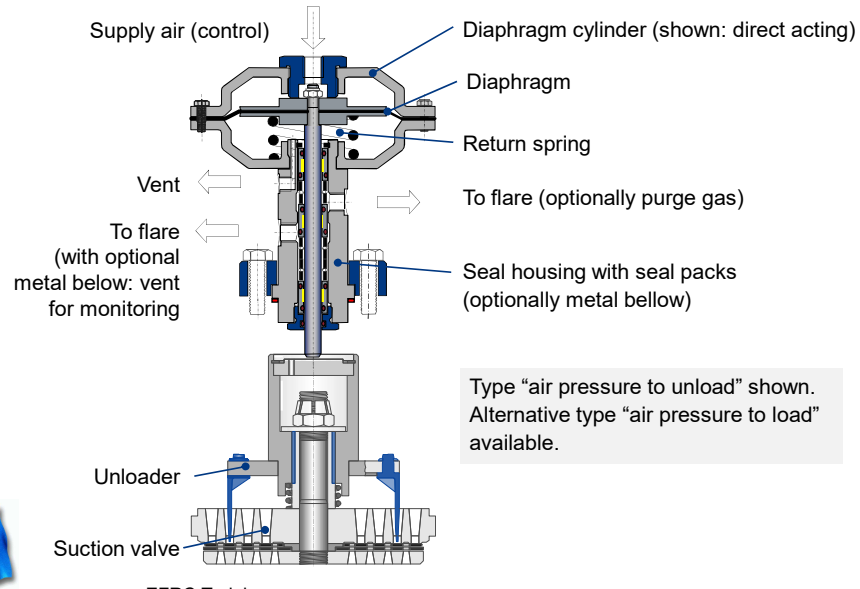
Example: Plug unloader shown.

Devices used for suction valve unloading and fixed volume clearance pockets:

- Fork type unloaders (valve depressors) with diaphragm or piston actuators
- Plug unloaders with piston actuators only (due to high stroke)

EFRC Training

Diaphragm actuator for fork type unloaders

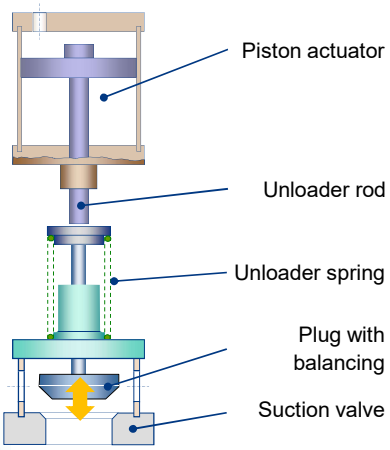


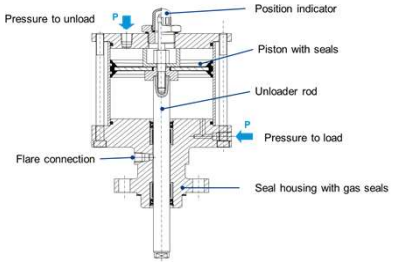
Type “air pressure to unload” shown. Alternative type “air pressure to load” available.

EFRC Training

Piston actuator with plug unloader

Schematic working principle

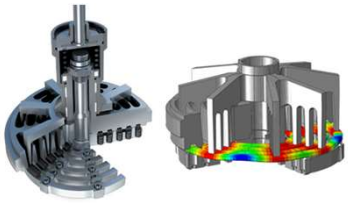




EFRC Training

Valve Unloading / Design criteria and variables

Fork unloaders



Unloading force
>
Max. drag force acting on valve sealing elements
+
Valve spring load
+
Unloader return spring load
+
Suction pressure acting on unloader rod

Design criteria

- Stresses in valve plates / ring elements
- Stresses unloader / components
- Max. force (diaphragm, piston actuator)

Design variables

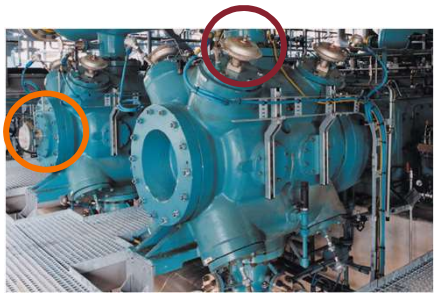
- Diaphragm diameter / control air pressure
- Material valve plate / rings (strength)
- Unloader configuration (unloading diameter, no. of arms / prongs)
- Valve flow efficiency (to influence drag force)

Note: valve lift and flow efficiency are considered in pulsation study

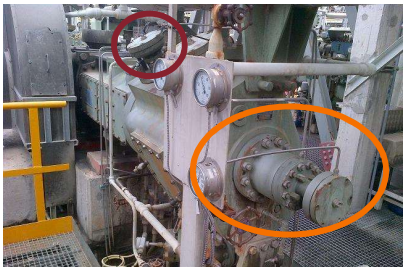
EFRC Training

Stepwise / Combination of valve unloading / FVCP

Diaphragm actuator



Plug actuator



- Fixed volume clearance pockets
- Valve unloading

EFRC Training

Stepwise options – Comparison of features

Feature	Valve unloading	Fixed volume clearance pockets
Control range / operational flexibility	Used for large step changes. Number of unloaded cylinder ends per stage define possible load steps. Can reduce capacity to 0%.	Used for fine load adjustment. Ideally in combination with valve unloaders. Limited turndown
Start-unloading	Yes	Add. on/off system for start-unloading required
Maintenance access	Actuators mounted on valve cover. No interference with maintenance on piston, piston and piston rings	No interference with maintenance on compressor valves
Energy efficiency	Parasitic losses of unloaded suction valve	More energy efficient than valve unloading
Impact on discharge gas temperature at part load	yes	no
Compressor footprint	Need a place for solenoid valves. Cylinders must have clearance between them	Additional room required at cylinder in axial direction. Need a place for solenoid valves.

EFRC Training

Benefits of stepless capacity systems

Refining, Chemical, Technical gases

- Reduce power costs by eliminating recycling
- Improve process control
- Enable efficient multi-service compressor arrangements
- Cost efficient layouts of the compression trains (CAPEX and OPEX) e.g. 2x70%

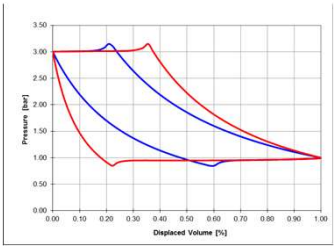
Natural gas

- Increase operational flexibility (natural gas storage)
- Automate capacity control (remote)
- Improve safety for operators and the asset
- Maximize equipment utilization (run driver at max. torque)

EFRC Training

Stepless methods

Stepless clearance pocket

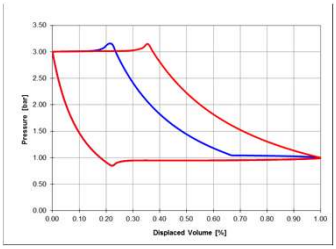


- Stepless adjustment of clearance volume on head end side
- Manually, hydraulically or electrically driven pockets

Speed control

- VFD drive adjusts compressor speed according to capacity needs
- Gas engines (natural gas) (70 - 100%)

Stepless valve unloading



- Suction valves are partly held open during the compression stroke. Controlled reverse flow of gas into suction chamber. Volume of gas reduced in the cylinder before compression starts
- Electronically controlled actuators
  A) Hydraulically driven
  B) Fully electric

Recycle valve

EFRC Training

Stepless variable volume clearance pockets

Manual

- Widely spread in natural gas industry
- Load adjustment difficult machine is running (safety reasons, high forces, corrosion)
- Trained operators required to prevent improper adjustment of the settings.

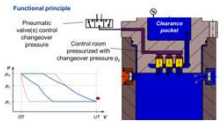
Electric

- Motor rotates a spindle via a high reduction gearbox. The spindle threads mesh with the hybrid nut threads to extend or retract the piston.
- Capacity change when compressor is running
- Remote, automated operation
- No power consumption required when piston is not moving

Hydraulic

- Piston of clearance pocket attached to hydraulic actuator
- External hydraulic unit provides hydraulic pressure to adjust piston.

Pneumatic



- The idea: Fixed clearance pocket combined with cyclic opening and closing control valve
- Clearance volume is adjusted during compressor / re-expansion stroke
- Capacity variation achieved by adjustment of change over pressure

EFRC Training

Stepless valve unloading systems

Hydraulic

- Electronically controlled and hydraulically driven actuators control start of compression stroke (suction valve closure)
- System synchronisation with crank shaft positon
- Fast switching solenoid valve controls the oil pressure acting on the actuator piston to drive unload rod
- Similar to diesel injection systems.

Electric

- Hybrid actuator combines two electric drive technologies (electromagnet and stepper motor)
- Unloading force and position controlled by electronics
- Automatic clearance and wear compensation while the compressor is running
- Internal electric energy recovery

EFRC Training

Stepless– Comparison of features

Feature	Stepless valve unloading	Variable volume clearance pocket
Control range and operational flexibility of compressor	large	medium
Precise process / interstage pressure control	highly dynamic control	moderate load change speed
Pulsations and vibrations	shift towards higher frequencies may require larger suction dampers	Less impact than stepless unloading
Compressor efficiency	Higher thanks to larger control range	reduced parasitic losses of valves
Impact on discharge gas temperature	discharge gas temperature increases at low loads	(only small amount of heating due to recirculation)

EFRC Training

Stepless– Comparison of features

Feature	Stepless Unloading	Variable volume clearance pockets
Technical limitations	Suction pressure Unloading force Stresses in valve sealing elements / actuators / unloaders Minimum valve diameter Compressor speed	Dynamic load on clearance pocket piston / piston rod Minimum cylinder bore diameter
Start-unloading	yes	No separate on/off system for start-unloading required; Higher motor starting currents
Maintenance access	No interference with maintenance on piston, piston and piston rings.	No interference with maintenance on compressor valves
Compressor footprint	Place needed for the installation of hydraulic unit or electronics	Additional room required at cylinder in axial direction

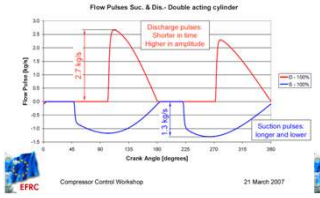
EFRC Training

Compressor engineering

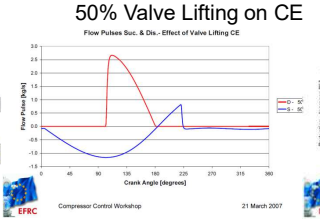
- Each capacity control system has its specific effect on the rod-load, rod-load reversal, torsional excitation and the excitation of suction and discharge pulsations.
- Amplitude and harmonic content of flow / resulting pressure pulsations and torsional excitation depend on the selected capacity control systems. Capacity control systems influence design of pulsation damper, piping and support

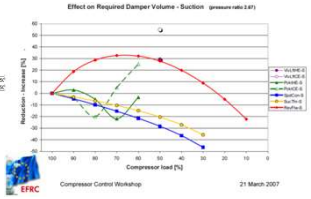
Examples:

Flow pulses at 100%



50% Valve Lifting on CE





Compressor engineering / Summary

- Various capacity control systems exist, each with stronger and weaker points
- Ultimate selection / combination depends on the specific application
- Capacity control affects various engineering/design aspects of the compressor and its system
  - Rod-load, rod-load reversal, lubrication
  - Pulsation and vibration control
  - Torsional vibrations
- Careful analysis required, adequate engineering tools are available

Thank you!

Klaus Stachel
HOERBIGER Compressor Solutions

klaus.stachel@hoerbiger.com