Gas Machinery Conference 2009 Short Course

Performance Control of Reciprocating Compressors: Devices for Managing Load and Flow

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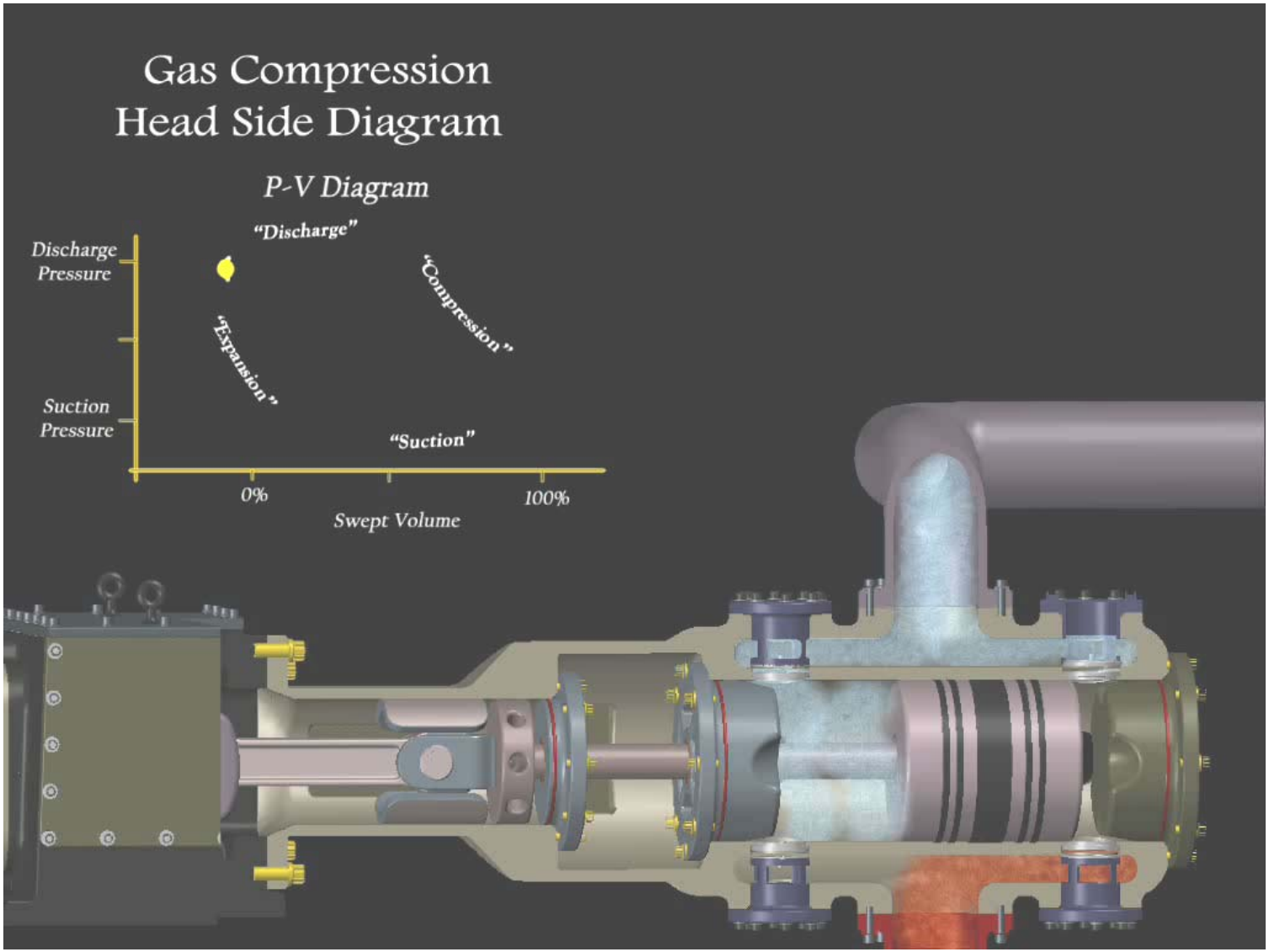
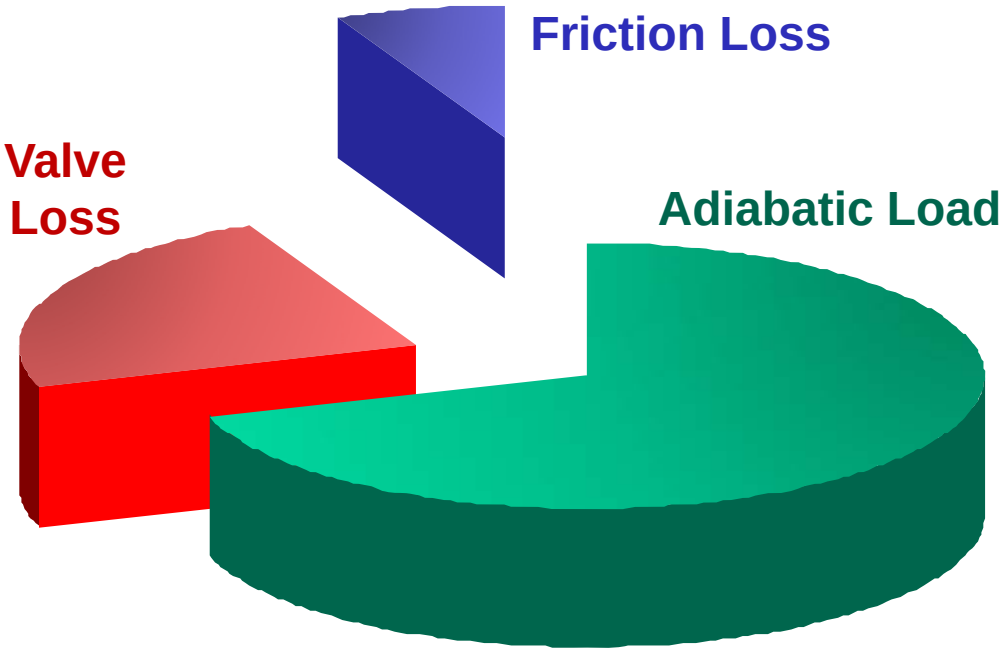
Provide course attendees with:

- A fundamental review and understanding of the many types of reciprocating compressor unloading and capacity control devices,
- Useful knowledge for evaluating and comparing individual unloading and control devices,
- Tools for identifying the best approach and devices for optimizing current, reapplied and new compressor performance relative to unique needs and budgets,
- An objective method for selecting and economically justifying optimum control devices.

- Quick-reference charts
- Pressure-Volume diagrams
- Diagrams, schematics and pictures
- Relative advantages and disadvantages
- Practical applicability
- Performance considerations across full operating maps
- Installation considerations
- Maintenance issues
- Operational limitations
- Automation possibilities
- Economic considerations and justification


Gas Compression
Head Side Diagram
P-V Diagram
"Discharge"
"Compression"
"Expansion"
"Suction"
Discharge Pressure
Suction Pressure
0%
100%
Swept Volume

Compressor Load
(Power Requirement)



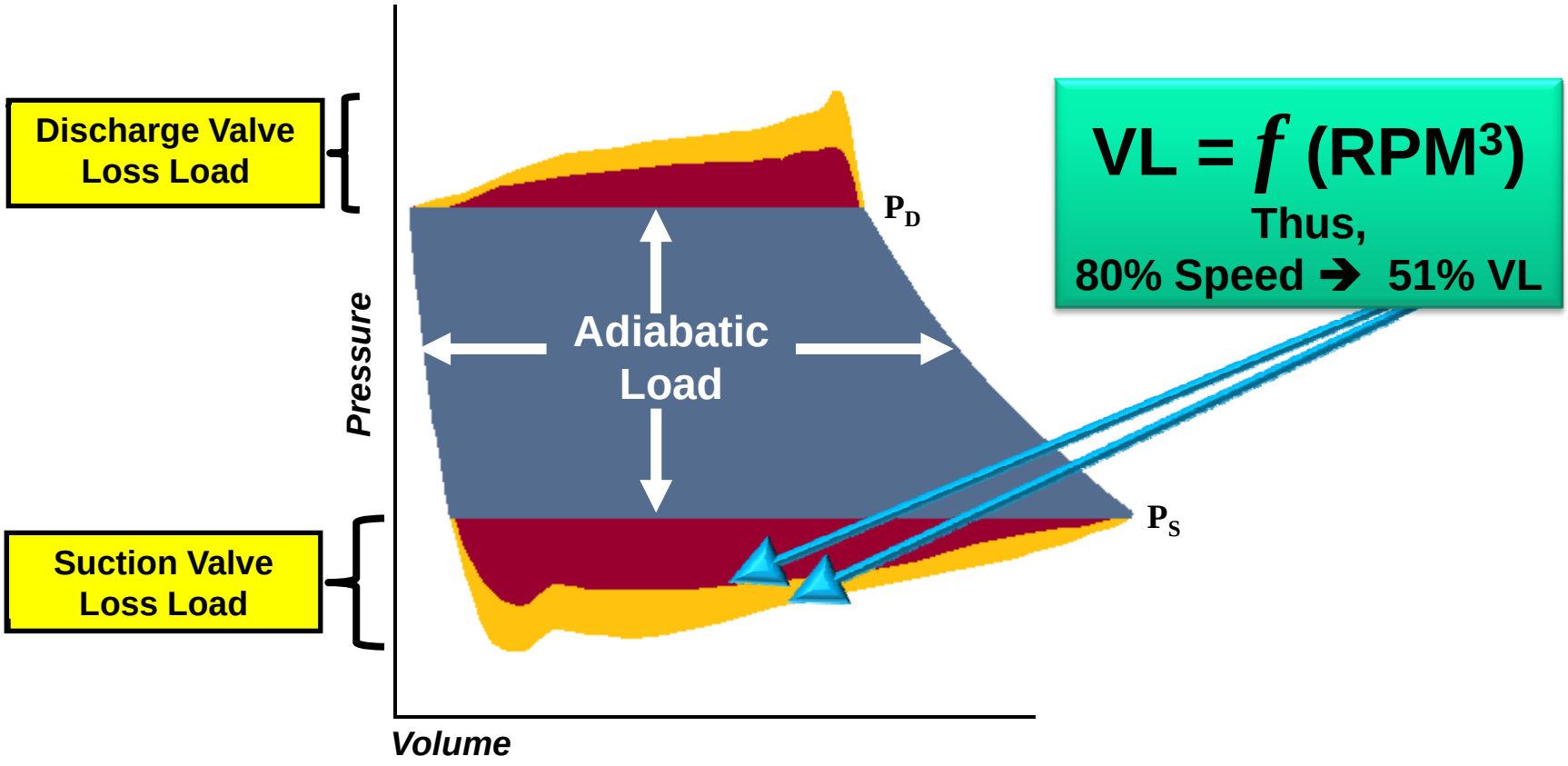
Indicated Load = **Adiabatic Load** + **Valve Loss**

(As Measured via Analyzer)

Total Cylinder Load = ***Indicated Load*** + **Friction Loss**

Indicated Load per End =

Adiabatic + ValveLoss$_{Suction}$ + ValveLoss$_{Discharge}$



Flow Rate or Capacity

$$\text{Flow} = f\left(VE_S \times P_S \times A_P \times S \times RPM \right)$$

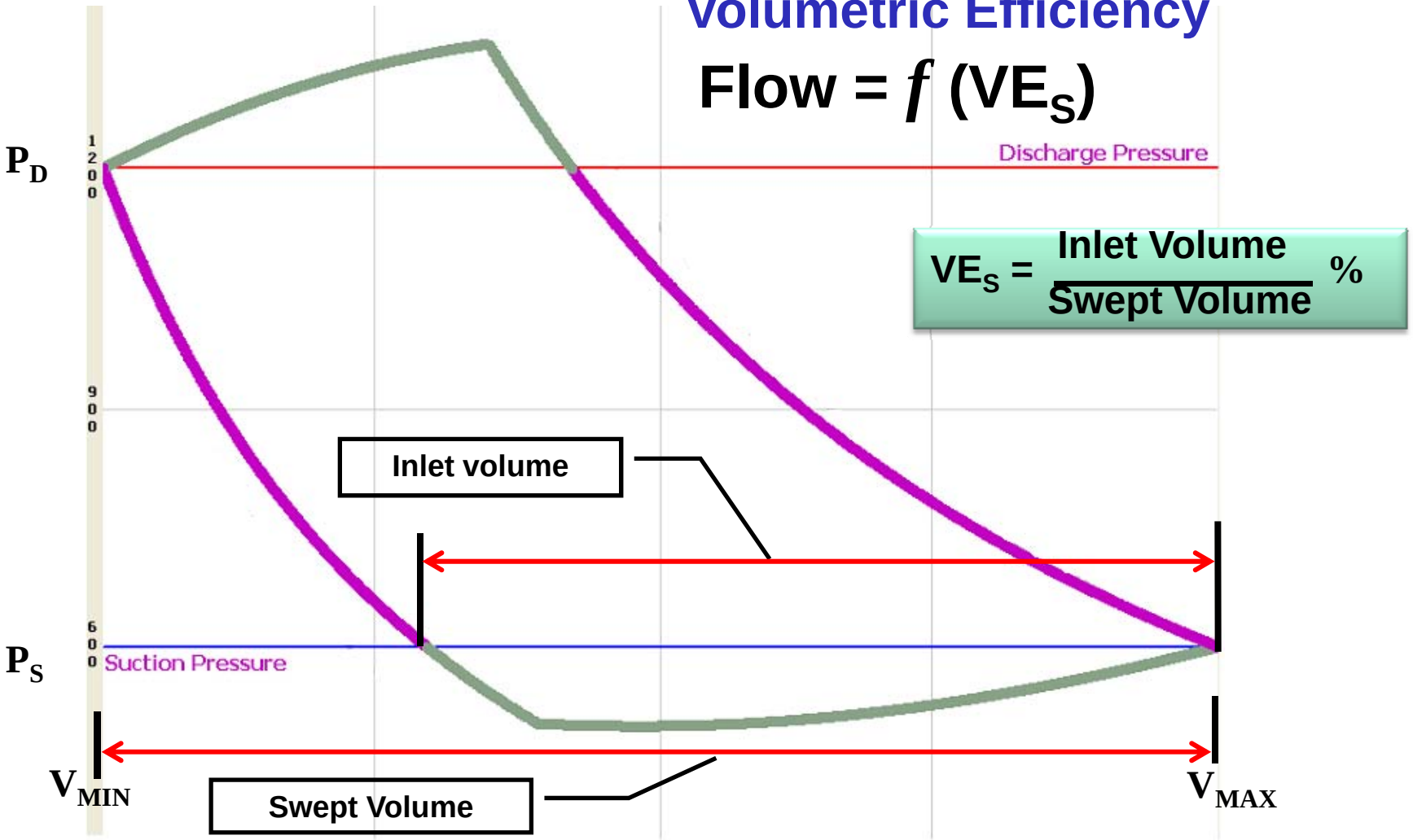
Suction Volumetric Efficiency

Suction Pressure

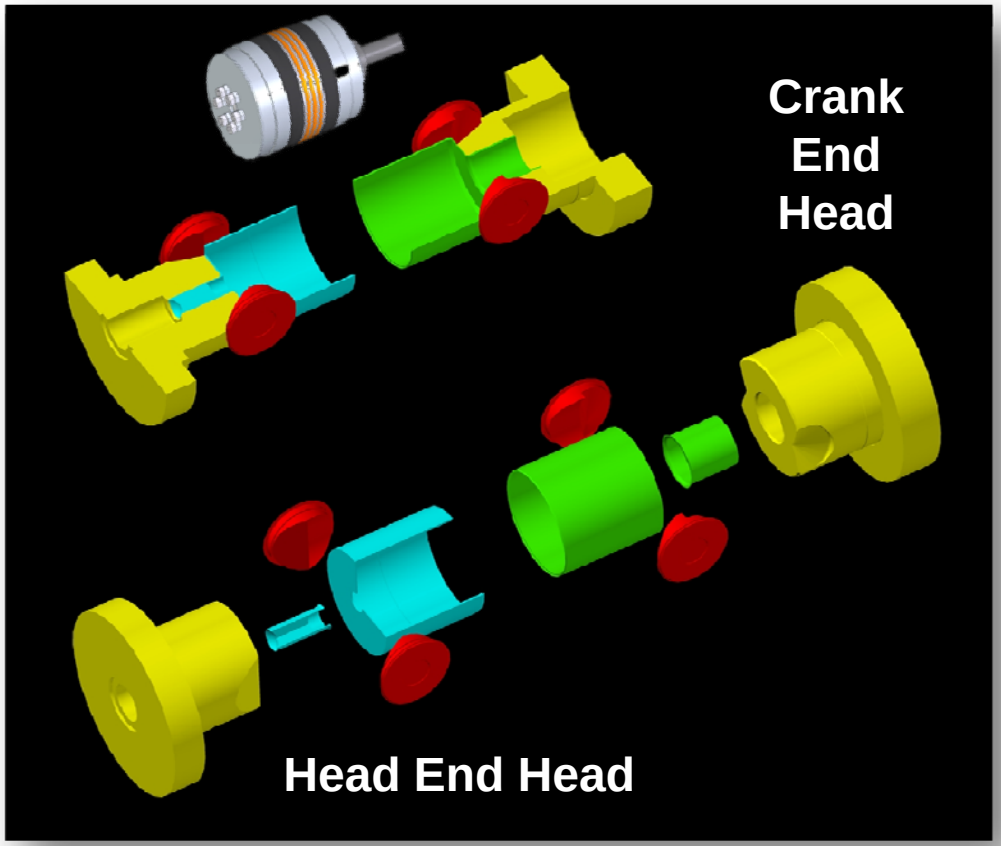
Piston Displacement
A_P = Piston Area
S = Piston Stroke
RPM = Speed

Volumetric Efficiency

Flow = f (VE_S)



$$VE_S = \frac{\text{Inlet Volume}}{\text{Swept Volume}} \%$$



Fixed Clearance Volume

$$\text{Flow} = f(VE_S)$$

$$VE_S\% \approx 100\% - Clr\% \left(R^{1/K} - 1\right)$$

$$Clr\% = \frac{Fixed\ Volume}{Swept\ Volume} * 100\%$$

R is *Pressure Ratio*

K is a Gas Property

Reasons for Control of Load and Flow

- Reduce Load for Easier Startup
- Gradual Loading After Startup
- Avoid Driver Overload as Conditions Change
- Deliver Required Flow Rate
- Maximize Driver Load Utilization and Flow
- Reduce the Number of Shut Downs and Start Ups
- Automate Unit Control
- Handle System Upsets without Shut Downs
- Accommodate Wide Range of Conditions (e.g. Storage/Withdrawal)
- System Optimization

Parameters Affecting Load and Flow

- Suction Pressure
- Suction Temperature
- Discharge Pressure
- Gas Properties
- Piston Stroke
- Speed
- Piston Area (bore size)
- Cylinder Fixed Clearance Percent
- Valve Size (effective area and resistance to flow)
- Number of Cylinder Active Ends (front and rear ends)

- ☑ **Physical Hardware Changes**
- ☐ Manual Control with Manual Actuation
- ☐ Manual Control with Automated Actuation
- ☐ Automated Control with Automated Actuation

Examples:

Valve spacers.

Relining cylinders to change bore diameters.

- ❑ Physical Hardware Changes
- ☑ **Manual Control with Manual Actuation**
- ❑ Manual Control with Automated Actuation
- ❑ Automated Control with Automated Actuation

Example:

Manual front head variable volume clearance pocket (VVCP).

- ❑ Physical Hardware Changes
- ❑ Manual Control with Manual Actuation
- ☑ **Manual Control with Automated Actuation**
- ❑ Automated Control with Automated Actuation

Examples:

Pneumatic, hydraulic and electric actuation devices that are activated with manual valves or switches.

- ❑ Physical Hardware Changes
- ❑ Manual Control with Manual Actuation
- ❑ Manual Control with Automated Actuation
- ☑ **Automated Control with Automated Actuation**

Examples:

Pneumatic, hydraulic and electric actuation devices that are controlled and activated by a Control Panel.

- ☑ **Variable Speed Control**
  - ❑ Engine Speed Governor
  - ❑ Variable Frequency Motor Drive
  - ❑ Torque Controller
- ❑ External Bypass
  - ❑ Startup Bypass
  - ❑ Capacity Control Bypass
- ❑ Suction Pressure Control
  - ❑ Pressure Reducing Valve
- ❑ Deactivate Cylinder End
  - ❑ Suction Valve Removal
  - ❑ Valve Unloaders (Plug-Type, Finger-Type, or Radial-Type)
  - ❑ Suction Valve Lifting
  - ❑ Internal Cylinder Body Bypass
  - ❑ Head End Bypass

- Variable Speed Control
  - Engine Speed Governor
  - Variable Frequency Motor Drive
  - Torque Controller
- ☑ **External Bypass**
  - **Start Up Bypass**
  - **Capacity Control Bypass**
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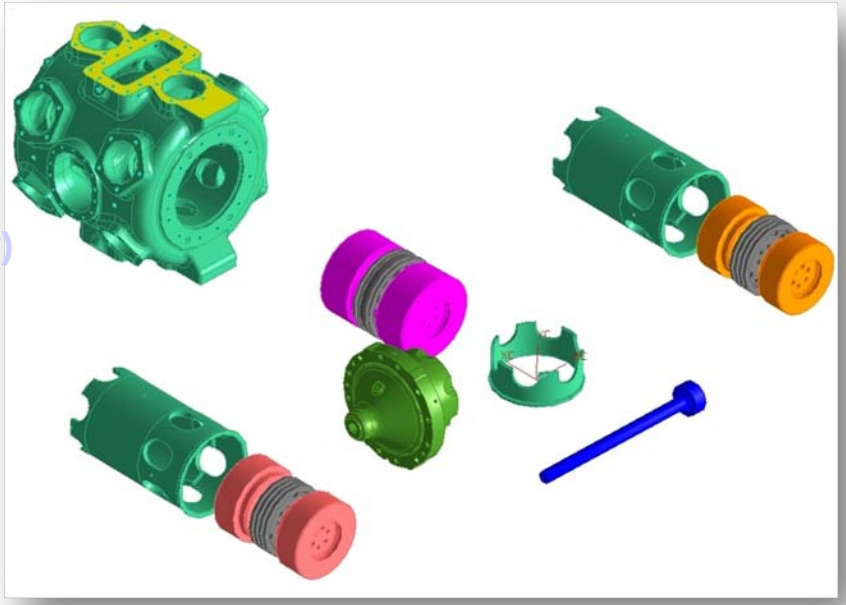
  - **Suction Valve Lifting**
  - **Internal Cylinder Body Bypass**
  - **Front Head Bypass**

- ☑ **Displacement Changes**
  - ❑ **Changing Bore Diameter or Stroke**
- ❑ Fixed Clearance Changes
  - ❑ Removable Clearance Plugs (Head or Body)
  - ❑ Clearance Bottles
  - ❑ Internal Body Pockets
  - ❑ Valve Spacers
  - ❑ Front Head Spacers
  - ❑ Piston Changes
  - ❑ Head End Fixed Volume Clearance Pockets
  - ❑ Valve Cap Fixed Volume Clearance Pockets
  - ❑ Variable Volume Clearance Pockets
  - ❑ Adjustable Suction Valves
- ❑ Timed Valve Closing
  - ❑ Infinite Step Unloaders (e.g. HydroCOM)
- ❑ Combinations of the Above



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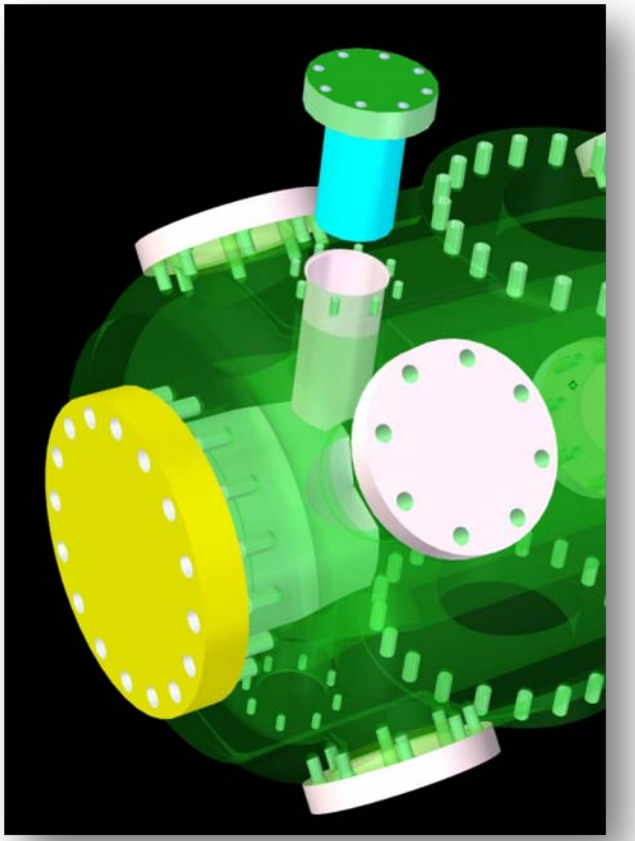

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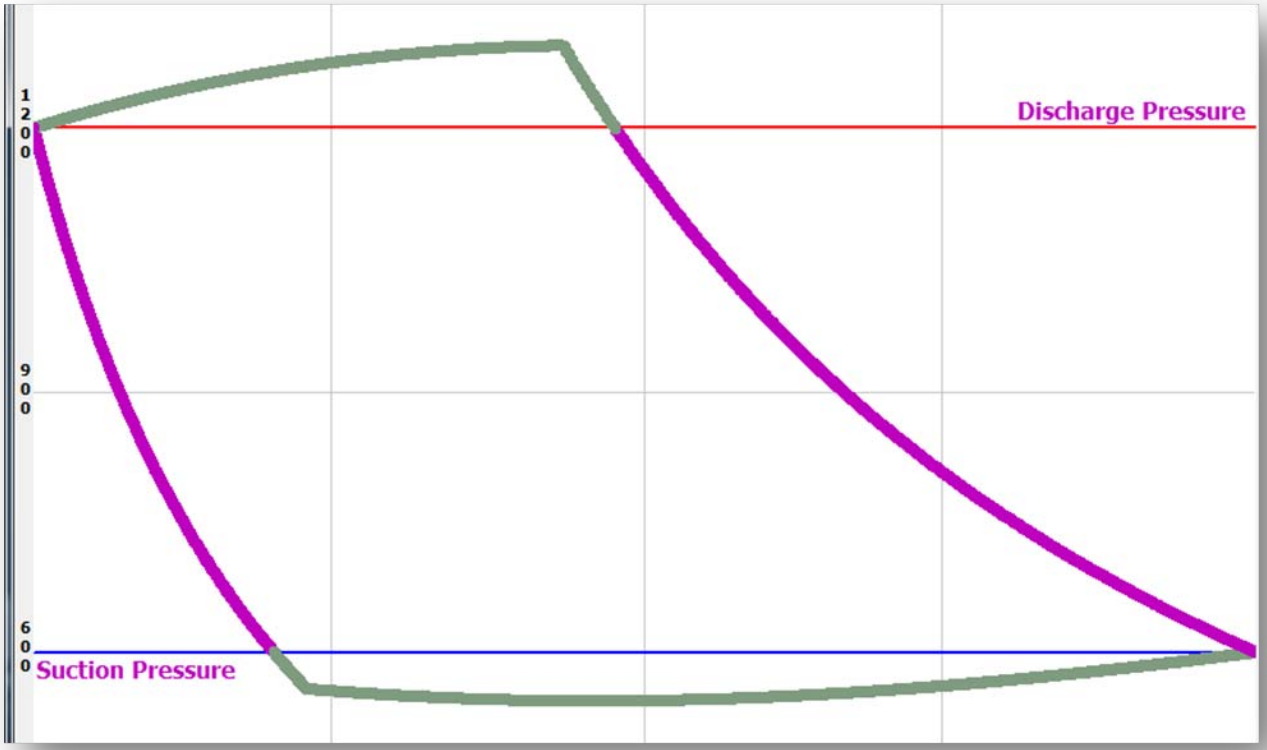
- ☑ **Combinations of the Above**

The Pressure-Volume Diagram



Items to Watch

- ❑ Efficiency
- ❑ Load Changes
- ❑ Flow Changes
- ❑ Load/Flow Unit

❑ INSTALLED COST

What is the relative initial capital investment cost of the device?

Low Initial Cost 

Moderately Low Initial Cost 

Medium Initial Cost 

Moderately High Initial Cost 

High Initial Cost 

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE

❑ EFFICIENCY

What is the relative effect of the device on isentropic efficiency during use?

Greatly improves	●●●●●
Moderately improves	●●●●○
Little or no effect	●●●○○
Moderately reduces	●●○○○
Greatly reduces	●○○○○

INSTALLED COST	**EFFICIENCY**	ADAPTABILITY	SIMPLICITY	AUTOMATABLE

❑ ADAPTABILITY

How easily is the device applied to, and installed on, existing equipment?

Easy	
Moderately Easy	
Neither Easy or Difficult	
Moderately Difficult	
Difficult	

INSTALLED COST	EFFICIENCY	**ADAPTABILITY**	SIMPLICITY	AUTOMATABLE

❑ SIMPLICITY

How easy is the device to use?

Easy	
Moderately Easy	
Neither Easy or Difficult	
Moderately Difficult	
Difficult	

INSTALLED COST	EFFICIENCY	ADAPTABILITY	**SIMPLICITY**	AUTOMATABLE

❑ AUTOMATABLE

How easily can the device be automated?

Easy	
Moderately Easy	
Neither Easy or Difficult	
Moderately Difficult	
Difficult	
Not Possible	

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	**AUTOMATABLE**

☑ Variable Speed Control

- ❑ Unit / Stage Bypass
- ❑ Throttling of Operating Pressures
- ❑ End Deactivation
- ❑ Displacement Changes
- ❑ Added Fixed Clearance
- ❑ Adjustable Head End Suction Valve
- ❑ Added Variable Volume Clearance
- ❑ Added Fixed Volume Clearance Devices
- ❑ Timed Valve Closing

❑ Defined

- ❑ Adjustment of the prime mover operating speed
- ❑ Control system evaluates a process variable and adjusts speed
- ❑ Affects the suction and discharge events
- ❑ Same adiabatic load per revolution, just a change in RPM

❑ Devices

- ❑ Governor
- ❑ Fuel Control Valve
- ❑ Variable Frequency Drives
- ❑ Torque Controllers

Image courtesy of Waukesha Engine Division

❑ What is it?

- ❑ Fuel Control Valve; Mechanical Governor; Torque Controller; Variable Frequency Drive

❑ What does the device do?

- ❑ Decreases / Increases the prime mover operating speed

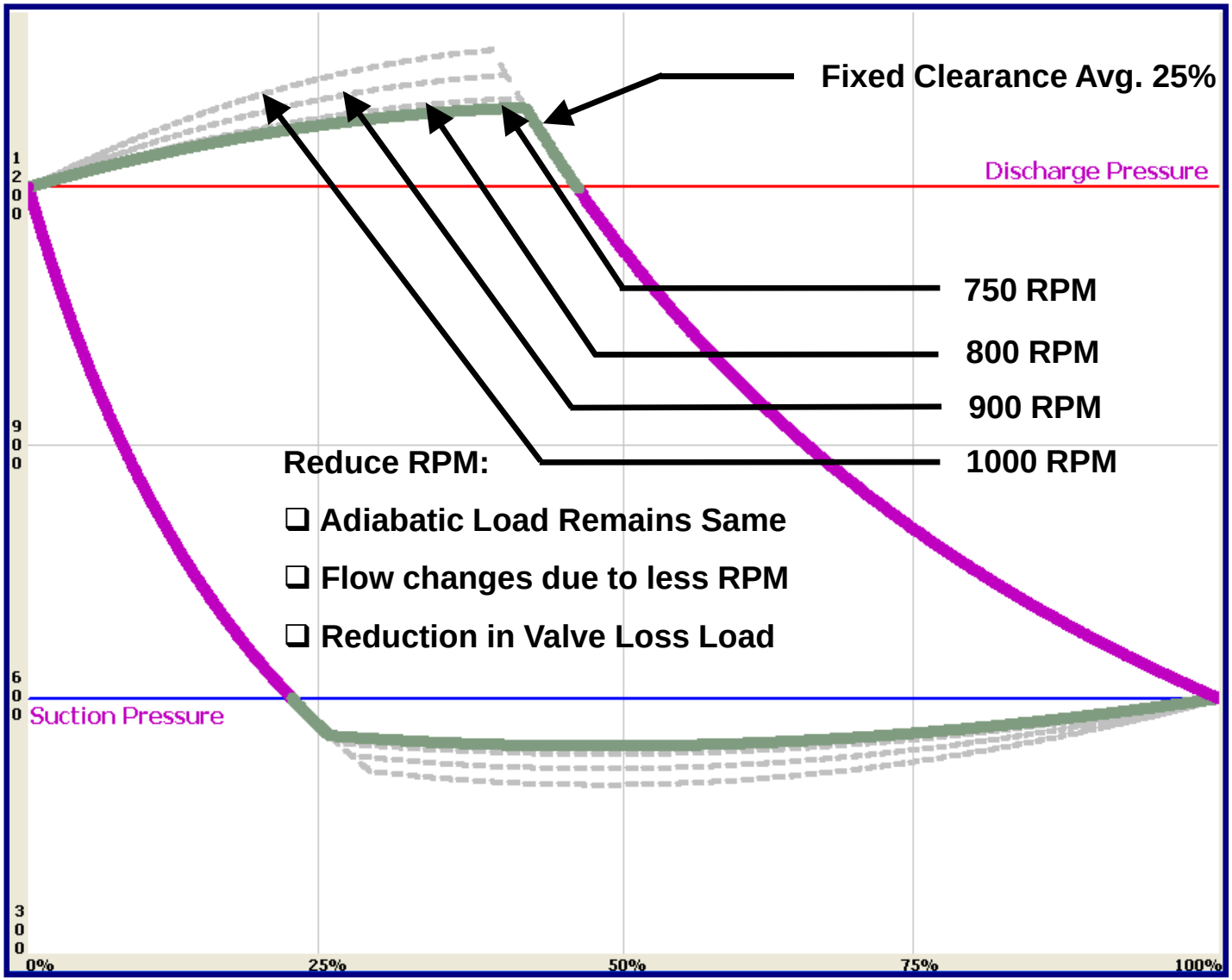
❑ How does it work?

- ❑ Input variable from the operator via the prime mover control system
- ❑ Appropriate signals are generated and the control device makes the necessary adjustments

❑ Where is it installed?

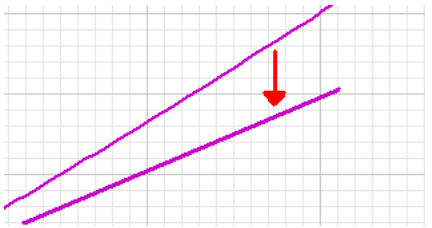
- ❑ Designed as part of the prime mover control system

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●○○○○	●●●●●	●○○○○	●●●●●	●●●●●



Load Changes

Flow Changes



- ❑ Variable Speed Control
- ☑ **Unit / Stage Bypass**
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- ❑ Displacement Changes
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- ❑ Added Variable Volume Clearance
- ❑ Added Fixed Volume Clearance Devices
- ❑ Timed Valve Closing

❑ **Defined**

- ❑ Start Up or Capacity Control
- ❑ Modulating Valves Commonly used for Control Purposes
- ❑ **Startup:** typically hot gas bypass (before cooler)
- ❑ **Capacity Control**: typically cooler gas bypass (after the cooler)
- ❑ Gas piped back to the suction scrubber

❑ **Devices**

- ❑ Piping system with appropriate plug-type throttling valves

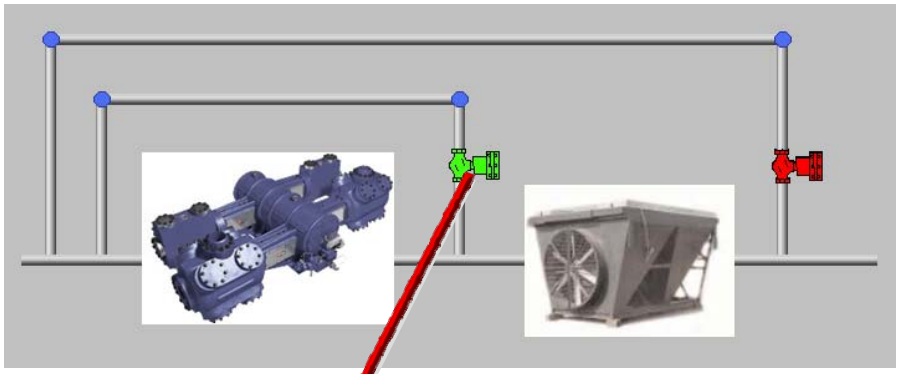


Image courtesy of Cameron Valves

Photos courtesy of El Paso Corp.

❑ What is it?

- ❑ Bypass Valve (Plug-type valve)
- ❑ External piping from discharge piping to suction piping (4 to 8 inch piping)

❑ What does the device do?

- ❑ Recycles gas - Allows compressed discharge gas to expand and flow back to the suction side of the compressor

❑ How does it work?

- ❑ Control overall output of the unit/station
- ❑ Open the control valve to allow gas to pass from the discharge to suction piping
- ❑ Open suction valve – signal to bypass valve to close (up to 20 seconds)

❑ Where is it installed?

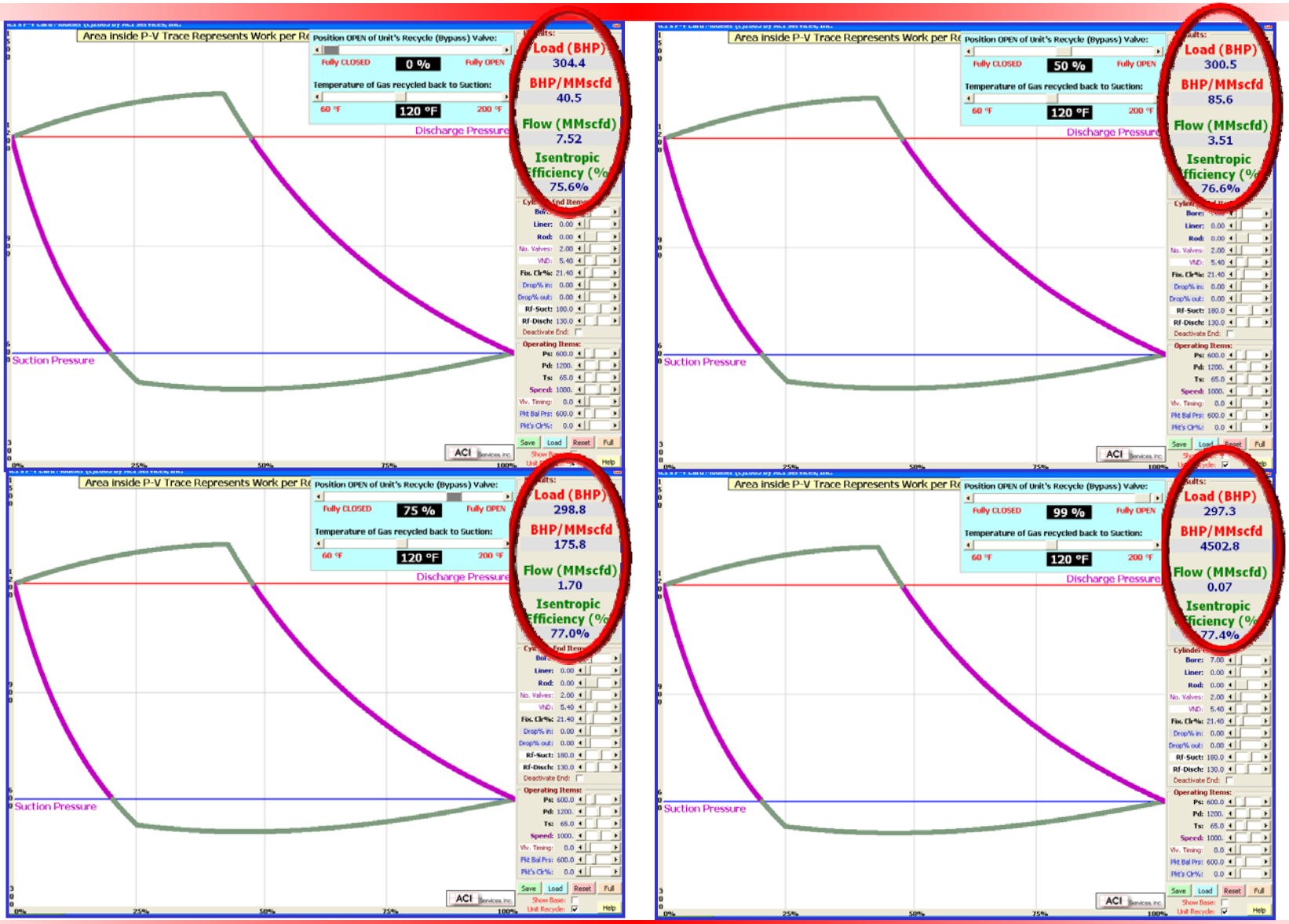
- ❑ Within the confines of the station piping; between discharge and suction

** Station's overall efficiency affected, not unit's isentropic efficiency.*

INSTALLED COST	EFFICIENCY*	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●●●○○	●○○○○	●●●○○	●●●●●	●●●●●

Unit / Stage Bypass

P-V Diagram



Throttling of Operating Conditions

- ❑ Variable Speed Control
- ❑ Unit / Stage Bypass
- ☑ **Throttling of Operating Pressures**
- ❑ End Deactivation
- ❑ Displacement Changes
- ❑ Added Fixed Clearance
- ❑ Adjustable Head End Suction Valve
- ❑ Added Variable Volume Clearance
- ❑ Added Fixed Volume Clearance Devices
- ❑ Timed Valve Closing

❑ Defined

- ❑ Adjustment of the operating pressures to a set value
- ❑ Typically suction pressure control
- ❑ Control system evaluates a process variable and adjusts the suction pressure
- ❑ Accomplished through a suction control valve
- ❑ Affects the suction and compression events
- ❑ Changes adiabatic load

❑ Devices

- ❑ Suction Pressure Reducing Valve

Suction Pressure Control Valves

Image Courtesy of Kimray

❑ What is it?

- ❑ Plug-type Control Valve – (manual, pneumatic or electric)

❑ What does the device do?

- ❑ Pinch back the suction pressure

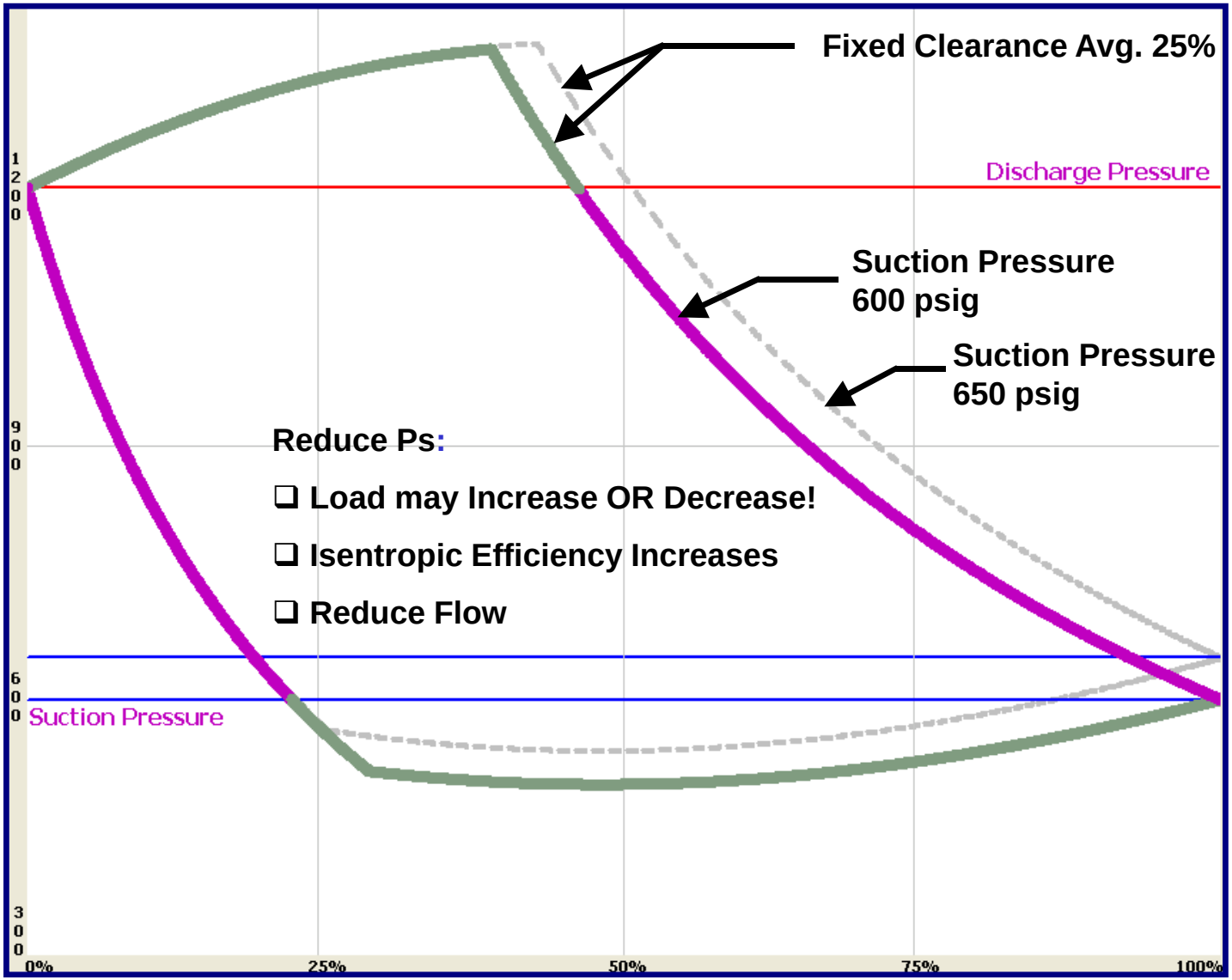
❑ How does it work?

- ❑ Intake line is throttled towards off
- ❑ No supply (or reduced) supply of gas to compressor
- ❑ The suction pressure will decline
- ❑ Ultimate result is a reduction in capacity

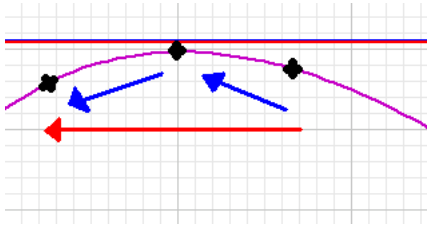
❑ Where is it installed?

- ❑ Within the suction piping prior to the scrubber / pulsation bottle

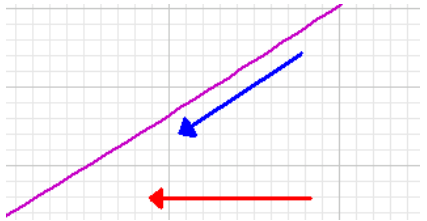
INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●●●●○	●●○○○	●●●●○	●●●●●	●●●●●



Load Changes



Flow Changes



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- ❑ Unit / Stage Bypass
- ❑ Throttling of Operating Pressures
- ☑ **End Deactivation**
- ❑ Displacement Changes
- ❑ Added Fixed Clearance
- ❑ Adjustable Head End Suction Valve
- ❑ Added Variable Volume Clearance
- ❑ Added Fixed Volume Clearance Devices
- ❑ Timed Valve Closing

❑ **Defined**

- ❑ Means to allow gas to flow out of the cylinder end during the compression stroke

❑ **Devices**

- ❑ Internal Body Ports
- ❑ Suction Valve Unloaders (Finger and Plug-type)
- ❑ Radial Valve Unloaders
- ❑ Valve Assembly Lifter
- ❑ Front Head Plug-type Bypass

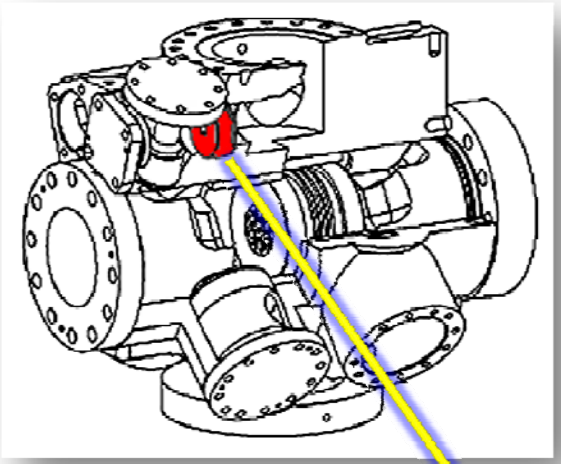
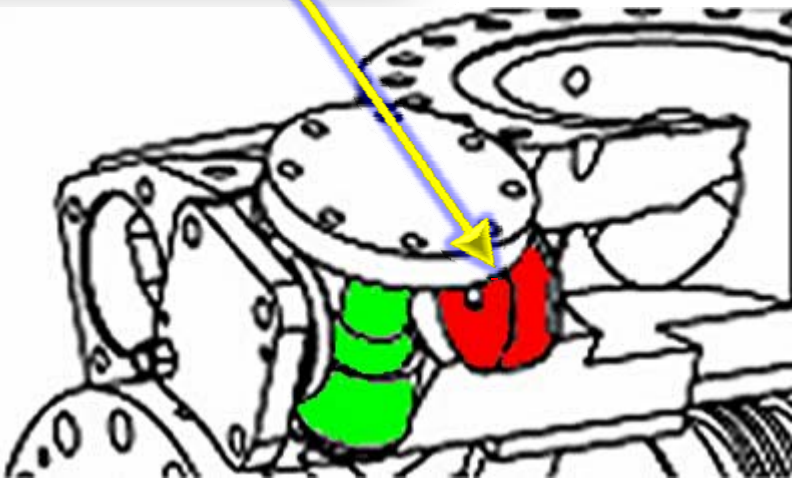


Image Courtesy of Cameron Compression Systems



❑ What is it?

- ❑ Removable plug (manually removed)
- ❑ Plug type actuator assembly

❑ What does the device do?

- ❑ Allows gas to flow back to inlet passage

❑ How does it work?

- ❑ Actuation medium supplied to actuation cylinder
- ❑ Actuation Pressure to load the cylinder
- ❑ Vent actuation pressure – gas pressure moves plug to open the volume allowing gas to flow

❑ Where is it installed?

- ❑ Cavity cast into the cylinder
- ❑ Head end or crank end

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●○○○○	●●○○○	●○○○○	●●●●○	●●●●●

Finger-type Valve Unloaders

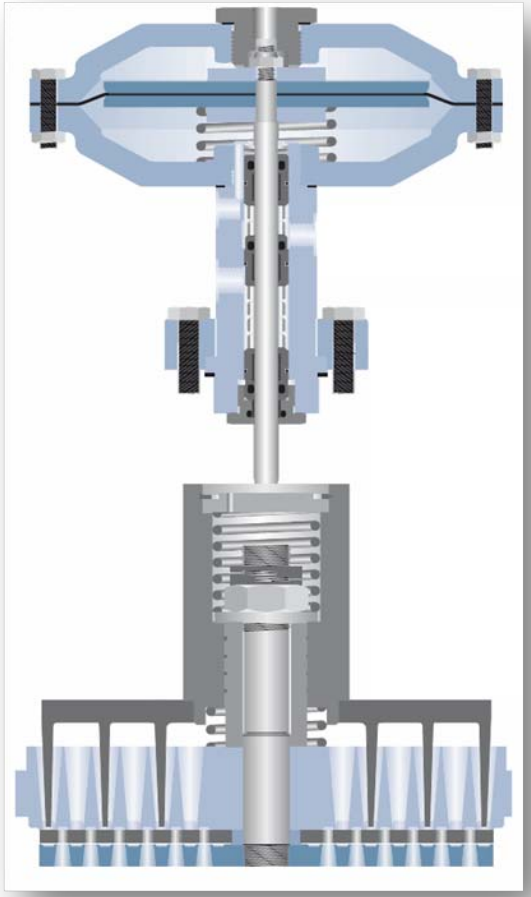


Image Courtesy of Hoerbiger Corp.

❑ What is it?

- ❑ Plunger with fingers attached
- ❑ Fits into the seat of the valve

❑ What does the device do?

- ❑ Depresses the valve plates (deactivating the cylinder end)
- ❑ Allows gas to pass through the valves during the compression event
- ❑ Gas passes back onto the inlet passage

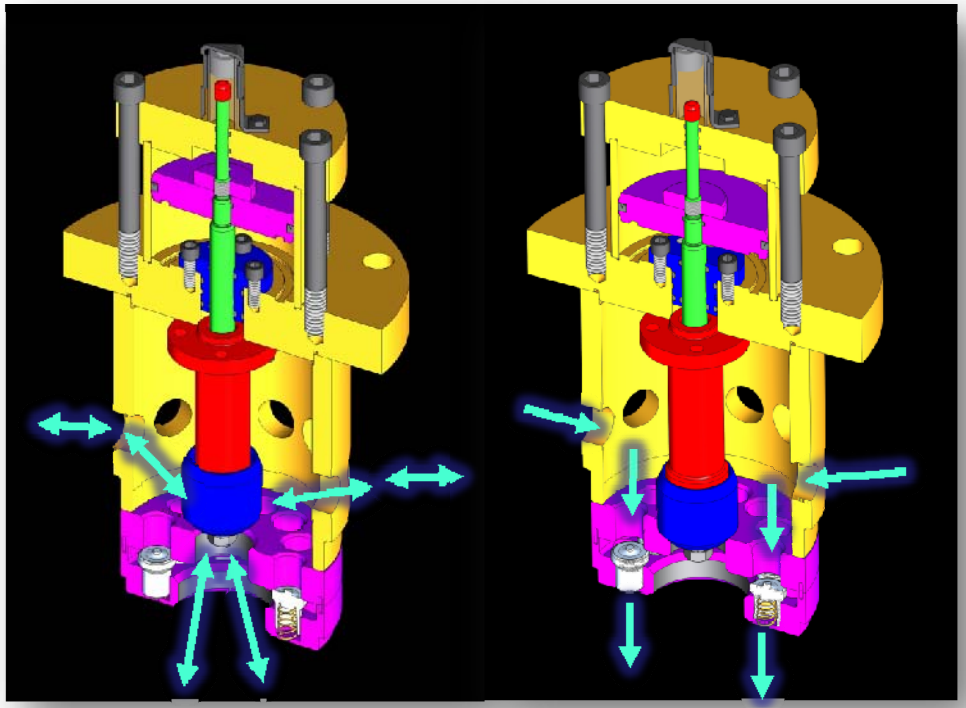
❑ How does it work?

- ❑ Fingers push and hold open the moving element in the suction valve
- ❑ Air pressure to unload

❑ Where is it installed?

- ❑ Over suction valves (head or crank end)

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●●●○○	●●○○○	●●●○○	●●●●○	●●●●●



Gas flows around valves

Gas flows through valves

❑ What is it?

- ❑ Shaft with a plug attached
- ❑ Partial valve with a hole in the center

❑ What does the device do?

- ❑ Deactivates the cylinder end
- ❑ Allows gas to pass through the hole in the valve during the compression event
- ❑ Gas passes back into the inlet passage

❑ How does it work?

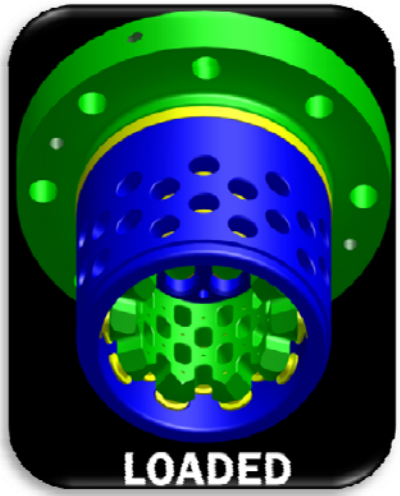
- ❑ Plug seals the hole during normal operation - Air pressure to load
- ❑ Remove Air pressure – gas pressure pushes the plug to the open position

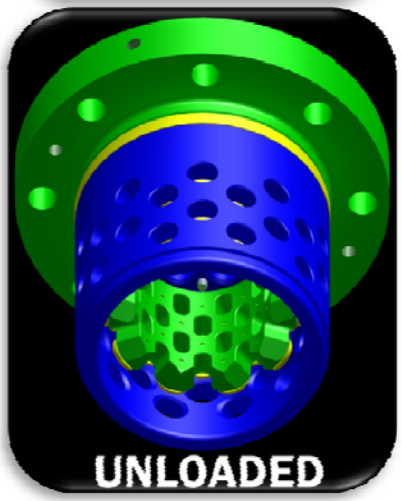
❑ Where is it installed?

- ❑ Over suction valves (head or crank end)

Images Courtesy of ACI Services, Inc.

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●●●○○	●●○○○	●●●○○	●●●●○	●●●●●





Images Courtesy of ACI Services, Inc.

❑ What is it?

- ❑ Poppet valve assembly
- ❑ Guard which holds the poppets connected to an actuator assembly
- ❑ Cylindrical seat for poppets

❑ What does the device do?

- ❑ Deactivates the cylinder end
- ❑ Allows gas to flow through seat
- ❑ Gas flows back into inlet passage

❑ How does it work?

- ❑ Air pressure to load
- ❑ Guard moves linearly up/down
- ❑ Poppets move with guard

❑ Where is it installed?

- ❑ Suction valves (head end or crank end)

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●●●○○	●●●●○	●●●○○	●●●●○	●●●●●

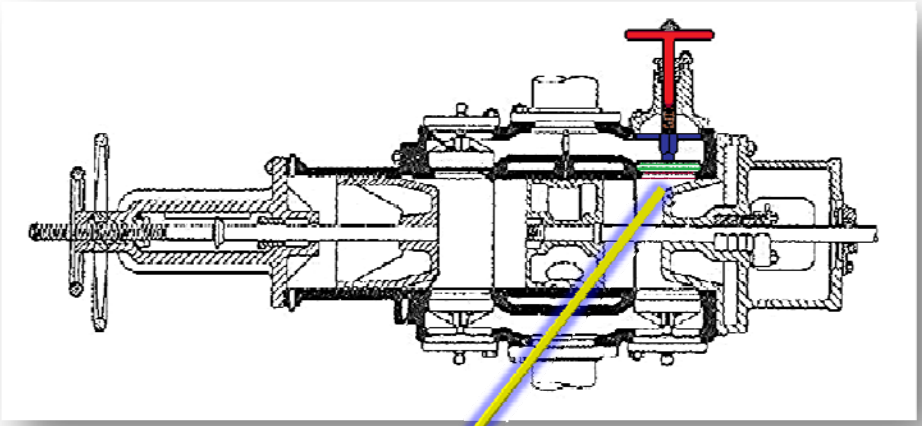
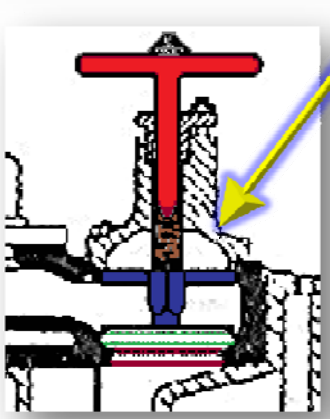
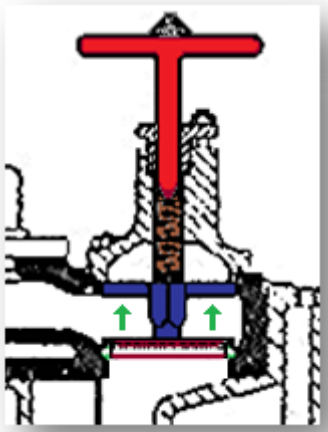


Image Courtesy of GPSA





❑ What is it?

- ❑ Valve attached to a lead screw
- ❑ Lead screw is mounted in a yoke assembly (valve cap)

❑ What does the device do?

- ❑ Deactivates the cylinder end
- ❑ Lifts the suction valve from their seat

❑ How does it work?

- ❑ Turn the lead screw (and valve assembly)
- ❑ Moves the valve away from its seat
- ❑ Allows gas to flow into the inlet passage

❑ Where is it installed?

- ❑ Over suction valves (head or crank end)

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●●●○○	●●○○○	●●●○○	●●●○○	●●○○○

Front Head Plug-type Bypass

Images Courtesy of ACI Services, Inc.

❑ What is it?

- ❑ Front end head with a bypass plug and actuator assembly
- ❑ External piping to inlet passageways

❑ What does the device do?

- ❑ Deactivates the cylinder end
- ❑ Allows gas to flow through the bypass plug to the bottle or suction valve

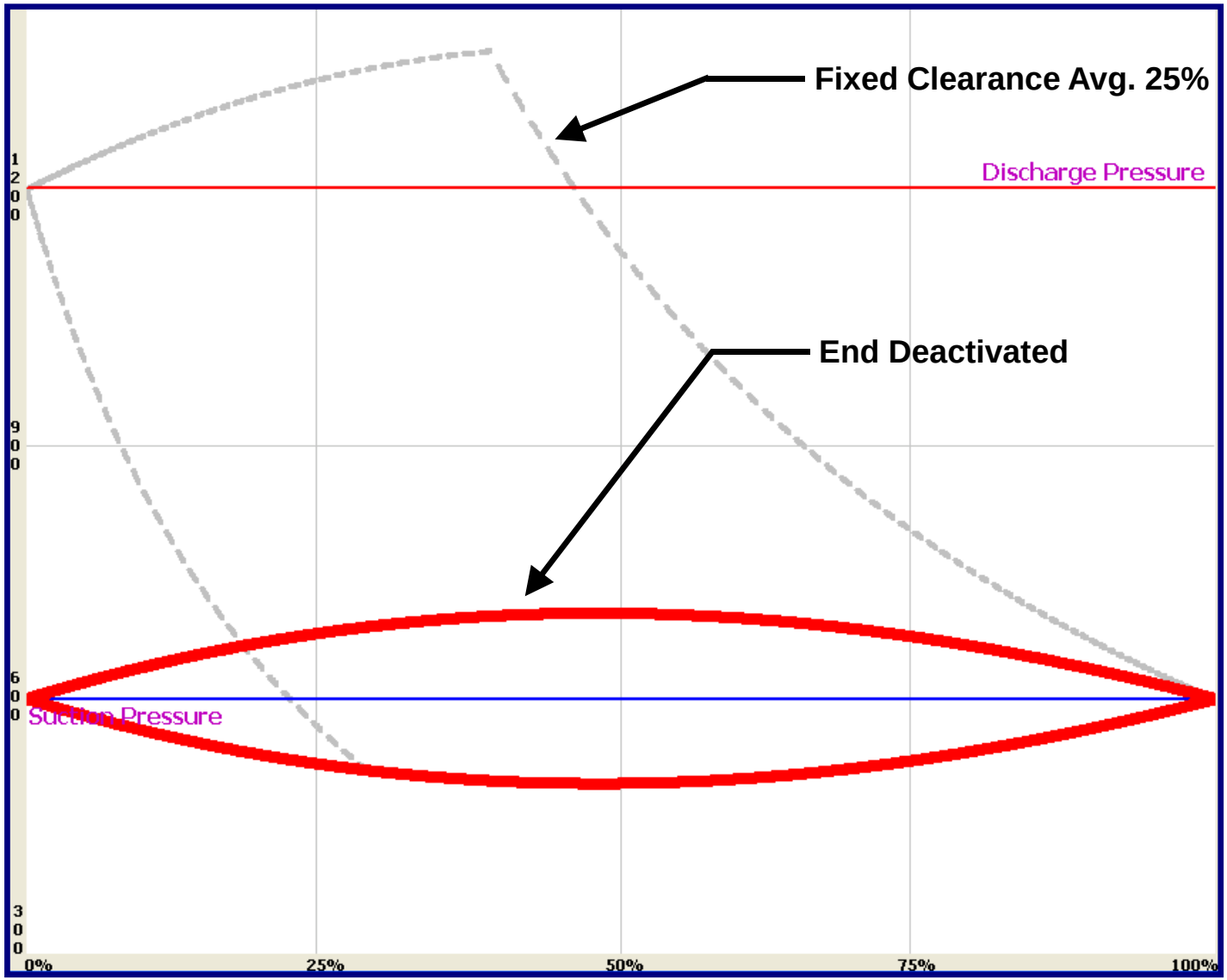
❑ How does it work?

- ❑ Air pressure to seat the bypass plug
- ❑ Remove pressure, cylinder pressure will push the plug away from the seat
- ❑ Gas flows around plug – deactivating end

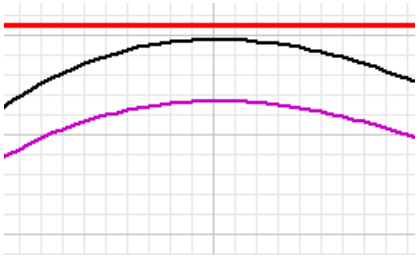
❑ Where is it installed?

- ❑ Cylinder Head End Head

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●●●○○	●●●○○	●●●○○	●●●●○	●●●●●



Load Changes



Displacement Changes

- ❑ Variable Speed Control
- ❑ Unit / Stage Bypass
- ❑ Throttling of Operating Pressures
- ❑ End Deactivation
- ☑ **Displacement Changes**
- ❑ Added Fixed Clearance
- ❑ Adjustable Head End Suction Valve
- ❑ Added Variable Volume Clearance
- ❑ Added Fixed Volume Clearance Devices
- ❑ Timed Valve Closing

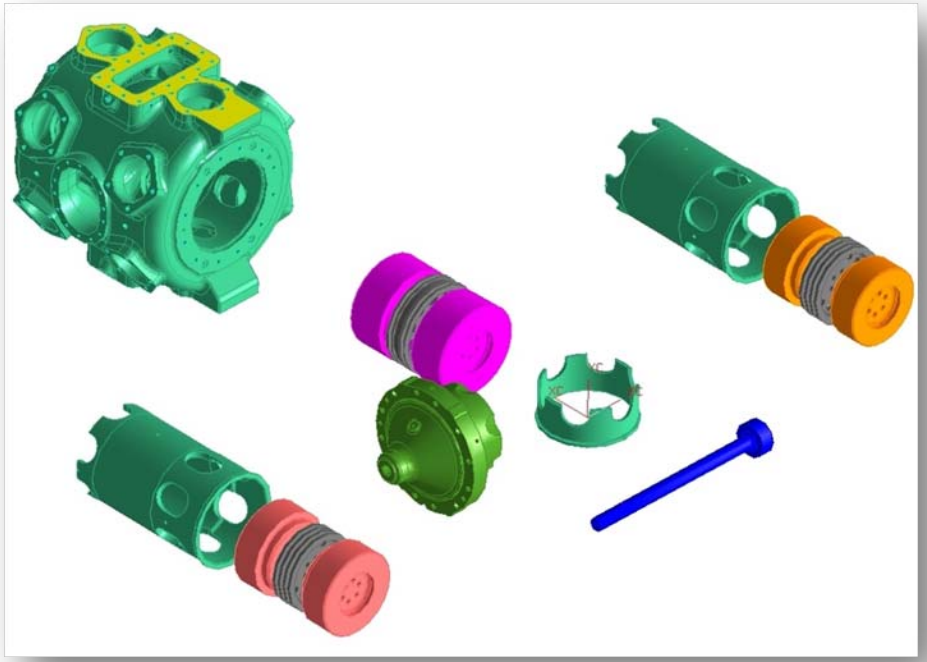
❑ **Defined**

- ❑ Change of the cylinder bore diameter
- ❑ Change of the stroke of the compressor throw

❑ **Devices**

- ❑ Piston and Liner Changes
- ❑ Crankshaft Changes

Liner Insertion (Cylinder Bore Change)



Images Courtesy of Cameron Compression Systems

What is it?

- Physical change to the cylinder bore size
- Utilization of cylinder slip fit liners

What does the device do?

- Reduces/increases the piston displacement
- Affects the cylinder fixed clearance

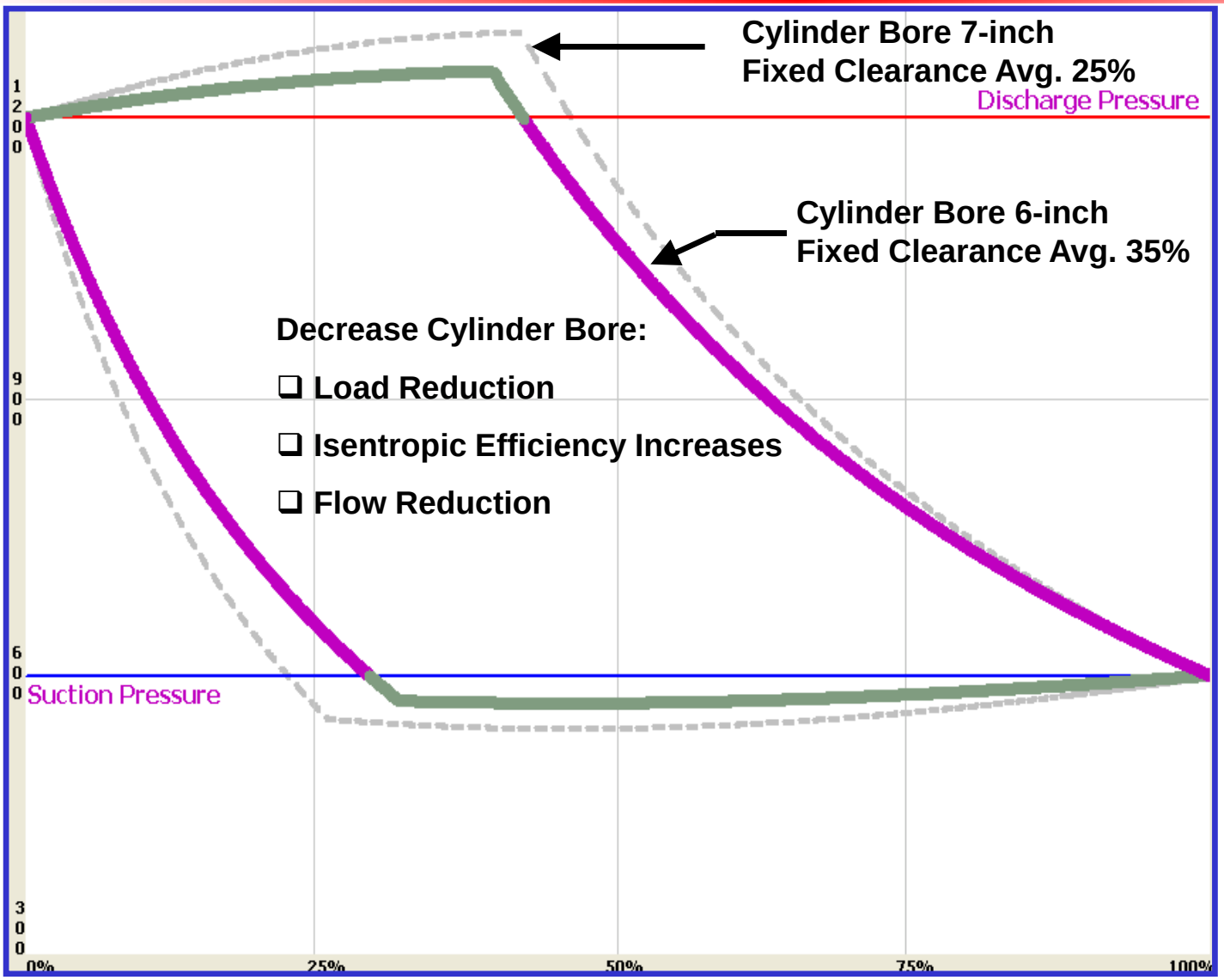
How does it work?

- Change the piston diameter
- Install the appropriate liner

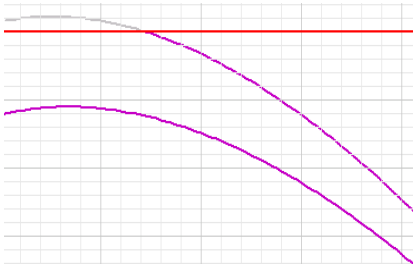
Where is it installed?

- Cylinder bore area

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●●●○○	●●●○○	●●●○○	●○○○○	○○○○○



Load Changes



Added Fixed Clearance

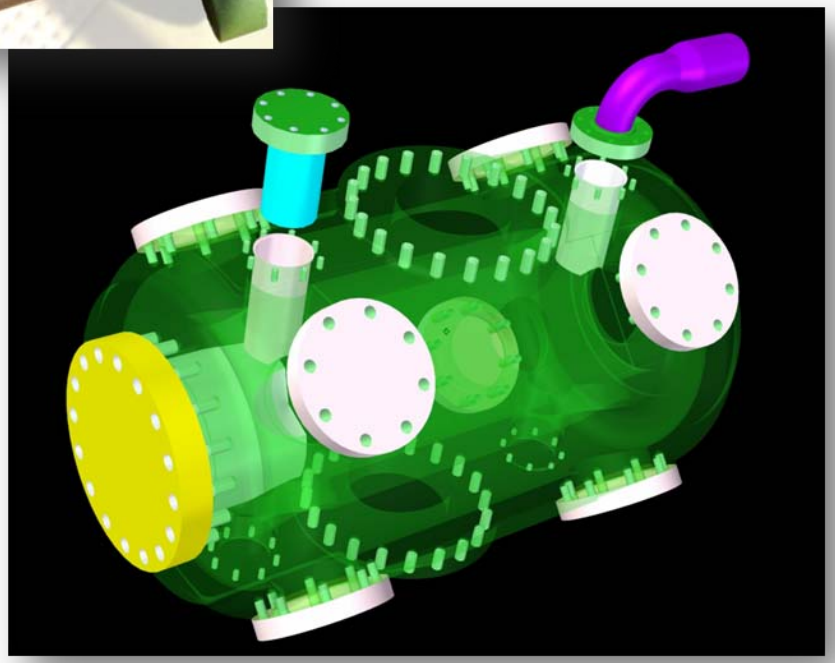
- ❑ Variable Speed Control
- ❑ Unit / Stage Bypass
- ❑ Throttling of Operating Pressures
- ❑ End Deactivation
- ❑ Displacement Changes
- ☑ **Added Fixed Clearance**
- ❑ Adjustable Head End Suction Valve
- ❑ Added Variable Volume Clearance
- ❑ Added Fixed Volume Clearance Devices
- ❑ Timed Valve Closing

❑ Defined

- ❑ Increase of the cylinder fixed clearance volume
- ❑ Once added, clearance is always present
- ❑ Physical change to the compressor cylinder
- ❑ Affects the compression and expansion events

❑ Devices

- ❑ Clearance Plugs/Bottles
- ❑ Valve Spacers
- ❑ Piston Modifications
- ❑ Cylinder Head Modifications
- ❑ Liner Changes



Images Courtesy of ACI Services, Inc.

❑ What is it?

- ❑ Cylinder designed with plug ports

❑ What does the device do?

- ❑ Plug/Partial Plug – Fills a volume
- ❑ Cap – Exposes designed volume
- ❑ Bottle – Adds additional volume

❑ How does it work?

- ❑ Remove the plug for added clearance
- ❑ Install a cap or bottle in place of the plug

❑ Where is it installed?

- ❑ In/over a cylinder body port

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
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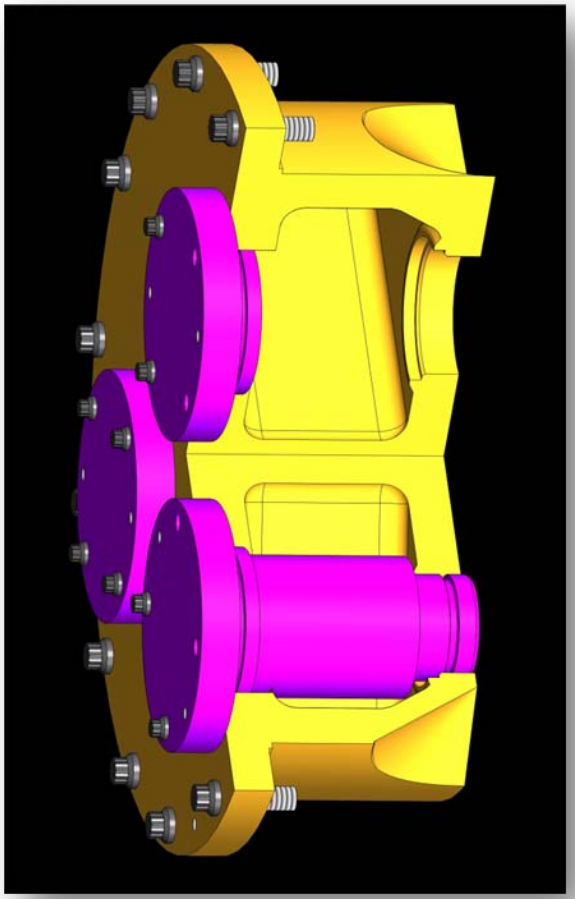

Image Courtesy of ACI Services, Inc.

❑ What is it?

- ❑ Retrofit of added port plugs

❑ What does the device do?

- ❑ Plug/Partial Plug – Fills a volume
- ❑ Cap – Exposes designed volume
- ❑ Bottle – Adds additional volume

❑ How does it work?

- ❑ Remove the plug for added clearance
- ❑ Install a cap or bottle in place of the plug

❑ Where is it installed?

- ❑ Front Head End of Cylinder
- ❑ Over a Valve (rare)

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
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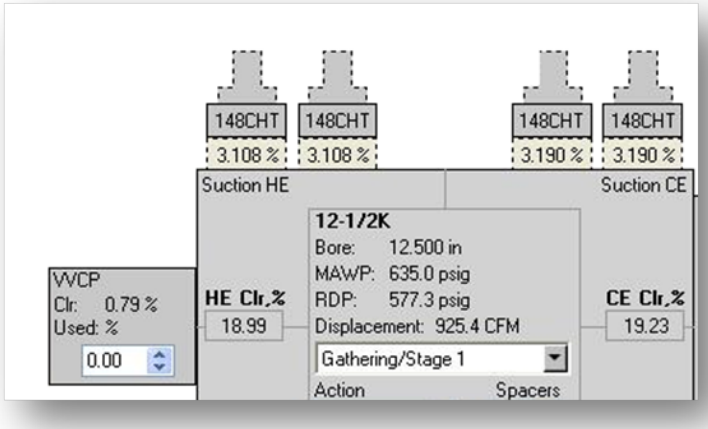

Images Courtesy of Ariel Corporation

❑ What is it?

- ❑ Ring manufactured from bar stock or tubing
- ❑ Thickness ranges from 0.375” to 1.50”

❑ What does the device do?

- ❑ Moves the valves away from cylinder bore
- ❑ Adds fixed clearance to the cylinder end

❑ How does it work?

- ❑ Valve seats on the spacer instead of the cylinder port
- ❑ Space under the valve - fixed clearance

❑ Where is it installed?

- ❑ Under the suction and/or discharge valves
- ❑ On one, or both ends of the cylinder

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●●●●●	●●●○○	●●●●●	●●○○○	○○○○○

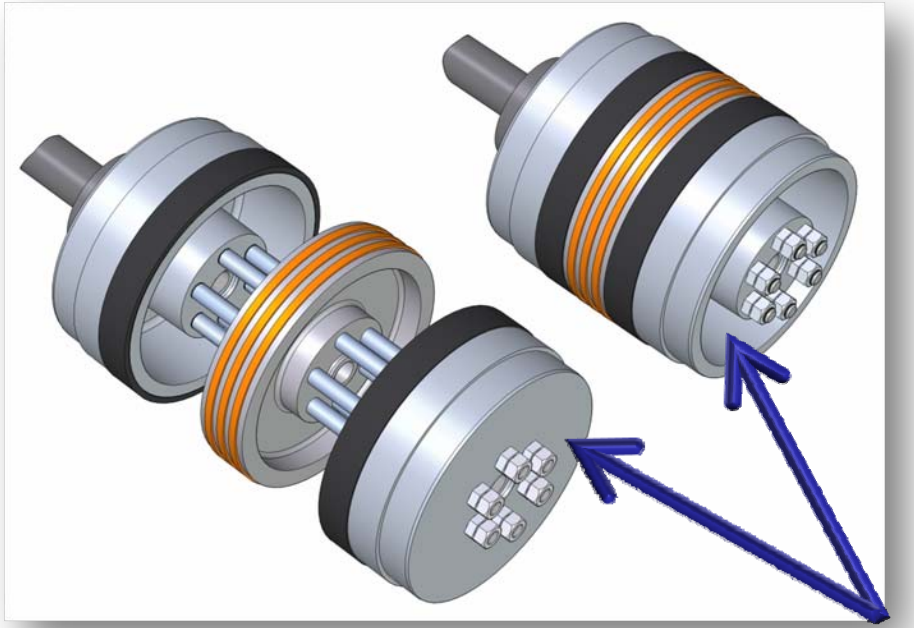

Image Courtesy of ACI Services, Inc.

❑ What is it?

- ❑ Piston design that is reversible
- ❑ Physical modification to existing piston

❑ What does the device do?

- ❑ Adds fixed clearance to the cylinder end

❑ How does it work?

- ❑ Minimum Clearance – installed one way
- ❑ Added Clearance – Reverse the piston end
- ❑ Permanently add clearance – Machine (shorten) the piston length

❑ Where is it installed?

- ❑ Piston assembly of the cylinder

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
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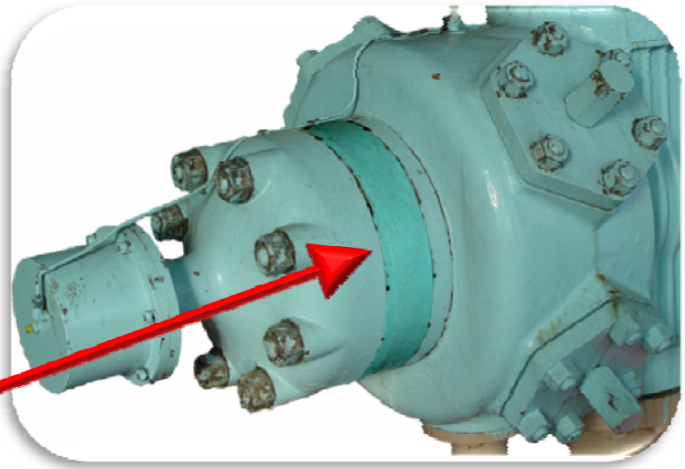
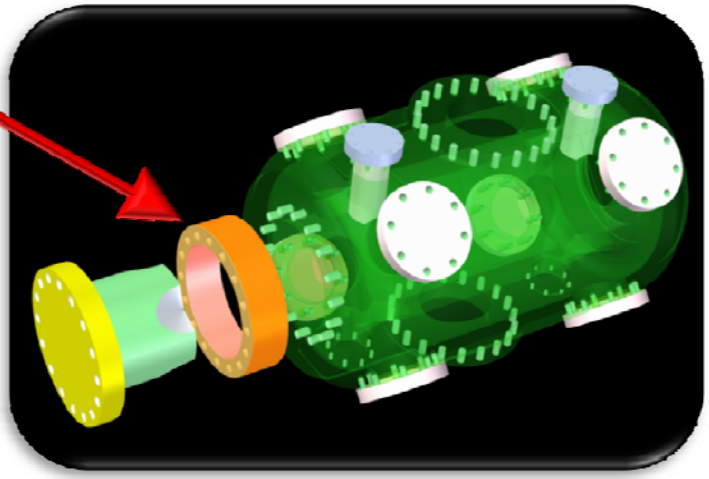
Front Head Spacers



Front Head Spacer Ring

Images Courtesy of ACI Services, Inc.



❑ What is it?

- ❑ Ring manufactured from bar stock
- ❑ Thickness varies with desired effect

❑ What does the device do?

- ❑ Moves the head away from cylinder bore
- ❑ Adds fixed clearance to the cylinder end

❑ How does it work?

- ❑ Remove cylinder front end head
- ❑ Install a spacer ring
- ❑ Install front end head with longer bolts

❑ Where is it installed?

- ❑ Cylinder front end head

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
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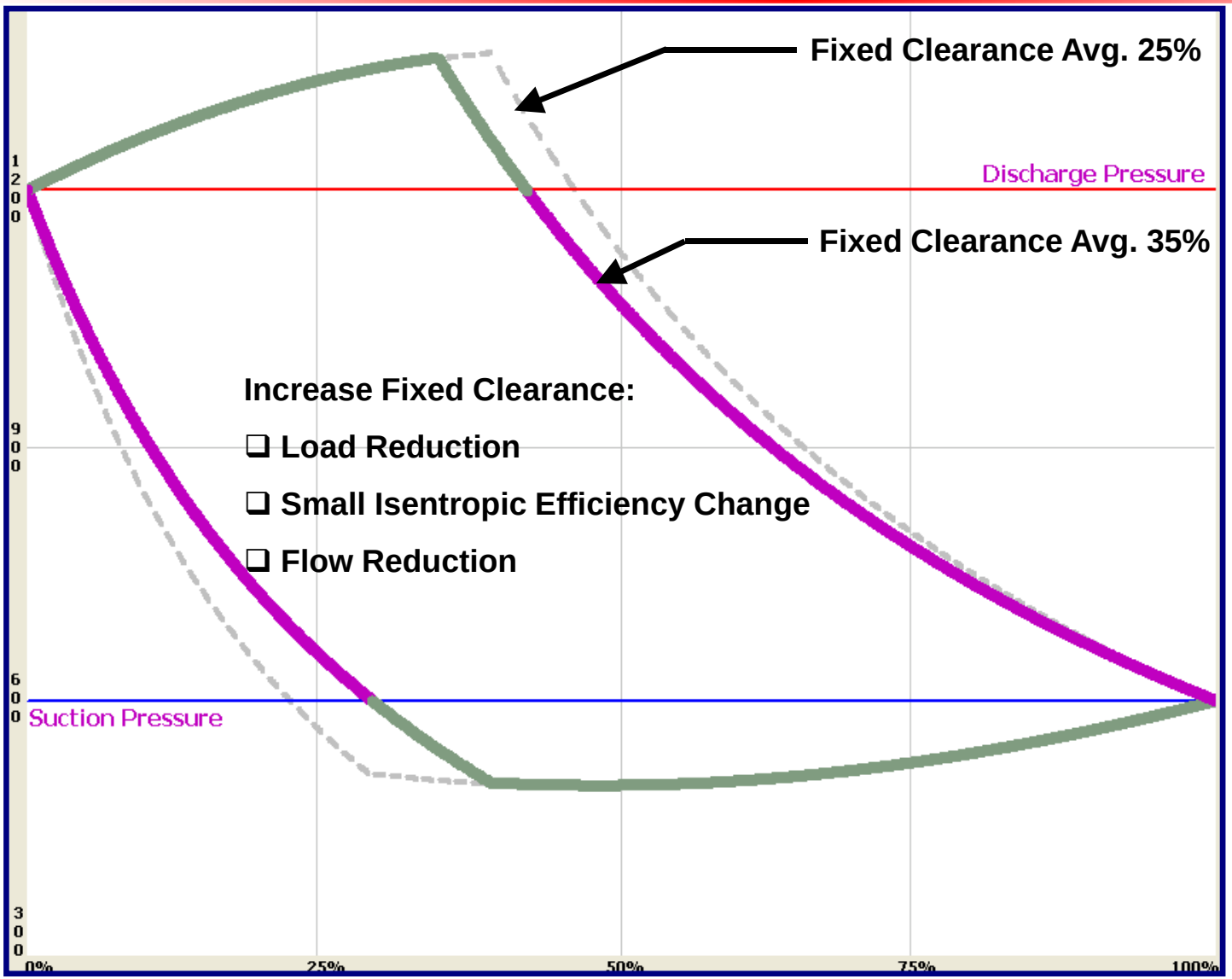
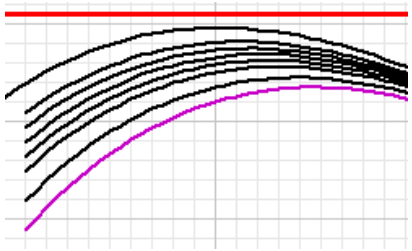


Load Changes



Adjustable Head End Suction Valve

- ❑ Variable Speed Control
- ❑ Unit / Stage Bypass
- ❑ Throttling of Operating Pressures
- ❑ End Deactivation
- ❑ Displacement Changes
- ❑ Added Fixed Clearance
- ☑ **Adjustable Head End Suction Valve**
- ❑ Added Variable Volume Clearance
- ❑ Added Fixed Volume Clearance Devices
- ❑ Timed Valve Closing

❑ Defined

- ❑ The suction valve's position is adjustable
- ❑ Valve can be screwed in and out, changing fixed clearance
- ❑ Adjusted to fully deactivate the cylinder end
- ❑ Affects the compression and expansion events

❑ Devices

- ❑ Valve-In-Piston Compressor Cylinder

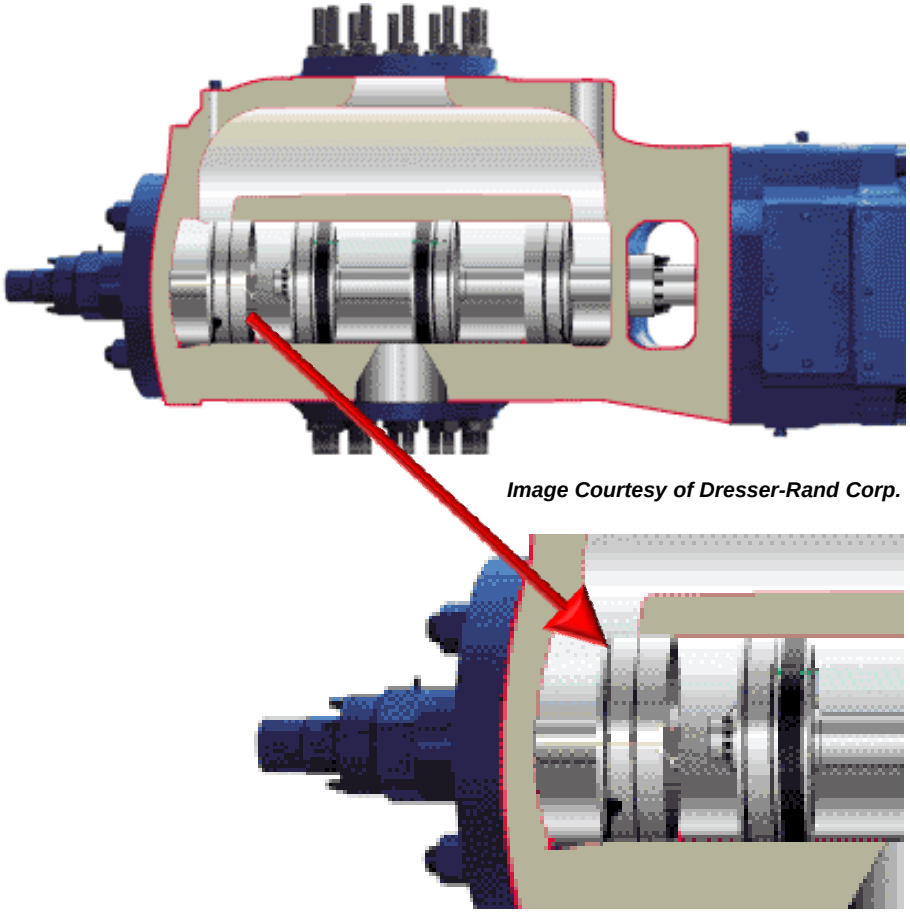


Image Courtesy of Dresser-Rand Corp.

❑ What is it?

- ❑ Suction valve installed on each end
- ❑ Threaded lead screw attached to the H.E. suction valve

❑ What does the device do?

- ❑ Moves the suction valve away from cylinder bore
- ❑ Adds fixed clearance to the cylinder end
- ❑ Deactivates the Head End

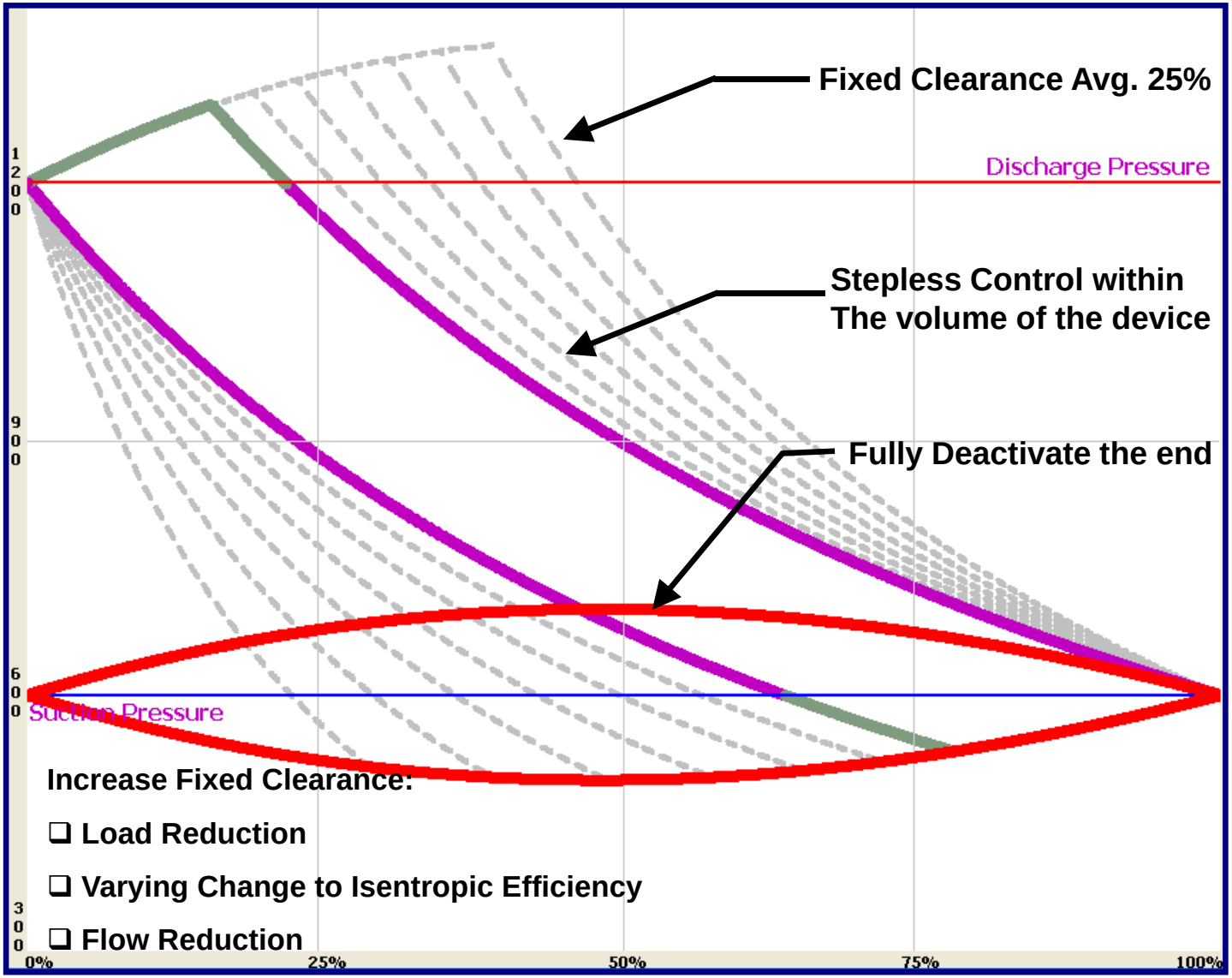
❑ How does it work?

- ❑ As lead screw is screwed out, the suction valve will move away from the piston

❑ Where is it installed?

- ❑ Cylinder head end head

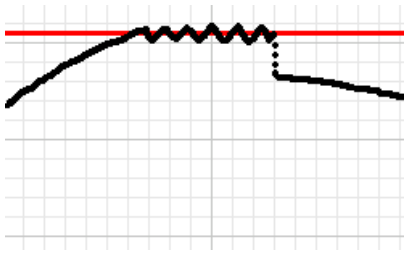
INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●○○○○	●●●○○	●○○○○	●●○○○	●●○○○



Increase Fixed Clearance:

- ❑ Load Reduction
- ❑ Varying Change to Isentropic Efficiency
- ❑ Flow Reduction

Load Changes



Added Variable Volume Clearance

- ❑ Variable Speed Control
- ❑ Unit / Stage Bypass
- ❑ Throttling of Operating Pressures
- ❑ End Deactivation
- ❑ Displacement Changes
- ❑ Added Fixed Clearance
- ❑ Adjustable Head End Suction Valve
- ☑ **Added Variable Volume Clearance**
- ❑ Added Fixed Volume Clearance Devices
- ❑ Timed Valve Closing

❑ **Defined**

- ❑ Adjust clearance volumes within the design of the device
- ❑ Accomplished by Manual, Hydraulic, or Gas Forces

❑ **Devices**

- ❑ VVP – Manual Screw Type
- ❑ VVP – Power Screw Type
- ❑ VVP – Hydraulic Assisted
- ❑ VVP – Gas Pressure Controlled

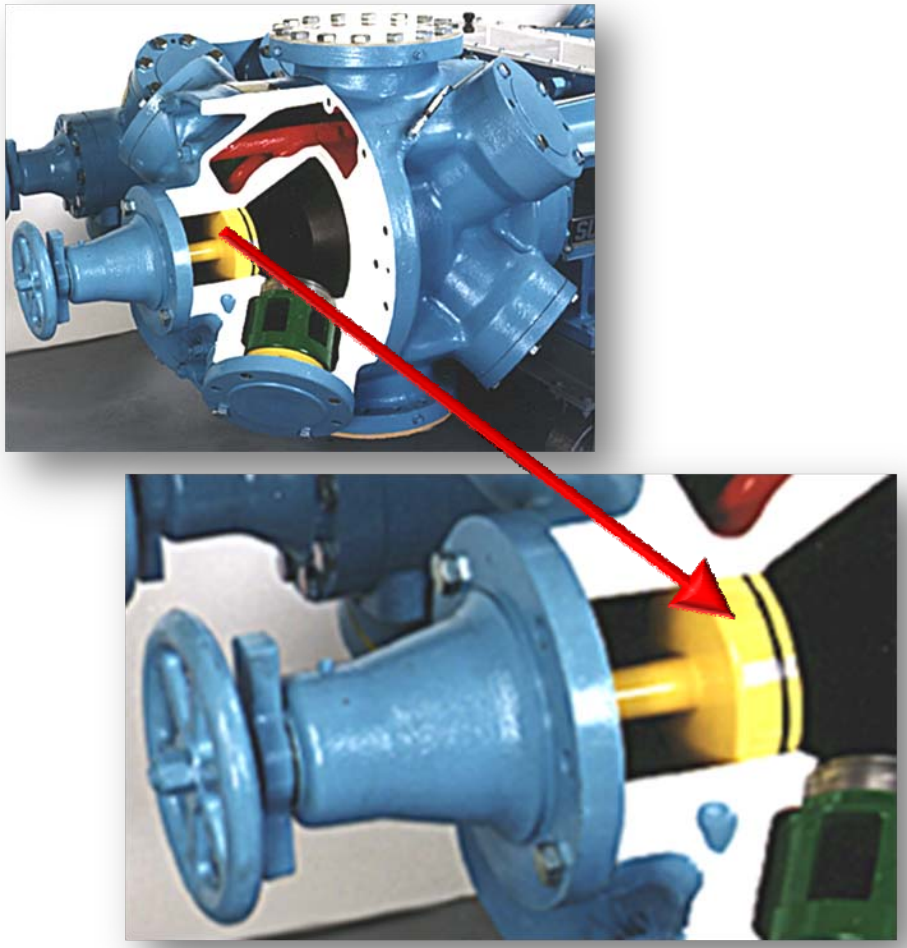


Image Courtesy of Cameron Corporation

❑ What is it?

- ❑ Variable clearance device
- ❑ Design as the head end head
- ❑ Piston installed on a lead screw

❑ What does the device do?

- ❑ Moves the piston away from cylinder bore
- ❑ Adds fixed clearance to the cylinder end
- ❑ Fixed clearance is changed in increments

❑ How does it work?

- ❑ As lead screw is screwed out (manually), the piston will move away from the piston

❑ Where is it installed?

- ❑ Cylinder head end head

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●●●●○	●●●○○	●○○○○	●●○○○	○○○○○

Image Courtesy of ACI Services, Inc.

Image Courtesy of Dresser-Rand Corp.

❑ What is it?

- ❑ Variable clearance device
- ❑ Designed for the front head

❑ What does the device do?

- ❑ Moves the piston away from cylinder bore
- ❑ Adds fixed clearance to the cylinder end
- ❑ Fixed clearance is changed in smooth increments

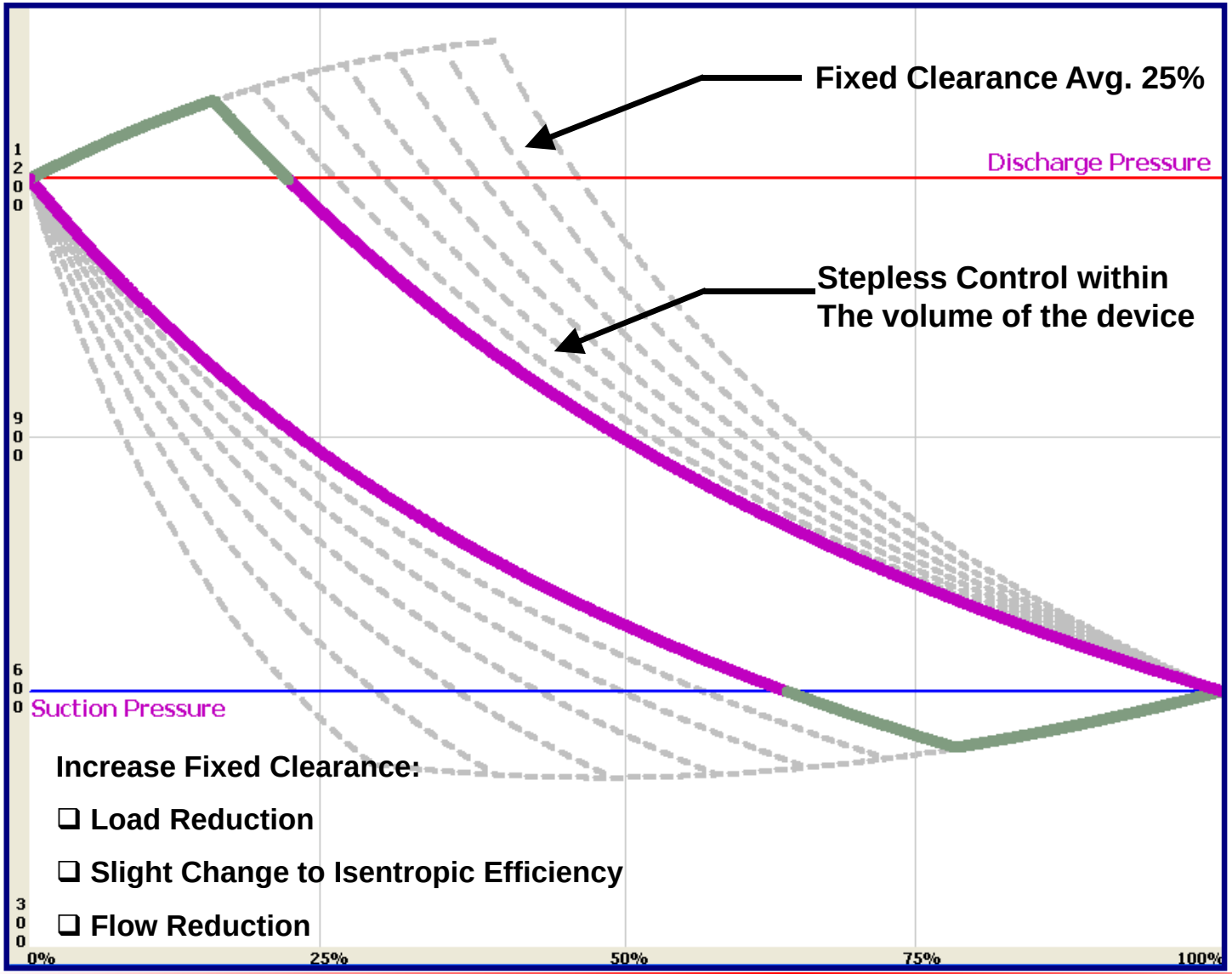
❑ How does it work?

- ❑ Suction/discharge pressure is a driving force to allow hydraulic fluid to flow in/out of the actuation cylinder allowing the piston to move back and forth

❑ Where is it installed?

- ❑ Cylinder's front head

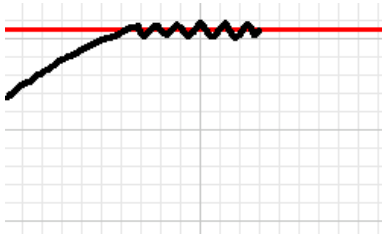
INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●●○○○	●●●○○	●●○○○	●●●●○	●●●●○



Increase Fixed Clearance:

- ❑ Load Reduction
- ❑ Slight Change to Isentropic Efficiency
- ❑ Flow Reduction

Load Changes



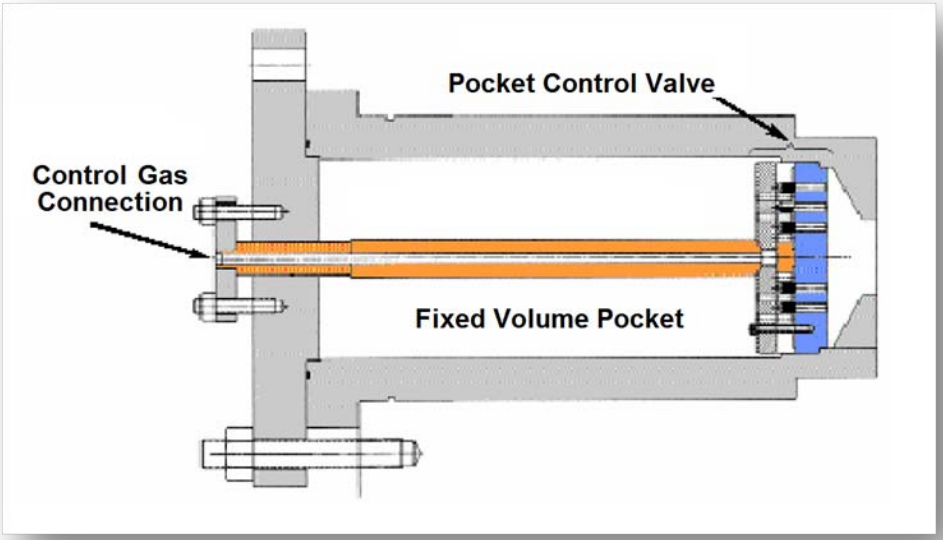


Image Courtesy of Dresser-Rand Corp.

❑ What is it?

- ❑ Fixed Volume Pocket
- ❑ Specially designed compressor valve

❑ What does the device do?

- ❑ Allows a fixed clearance to be added
- ❑ Varies the effective clearance based on the control pressure

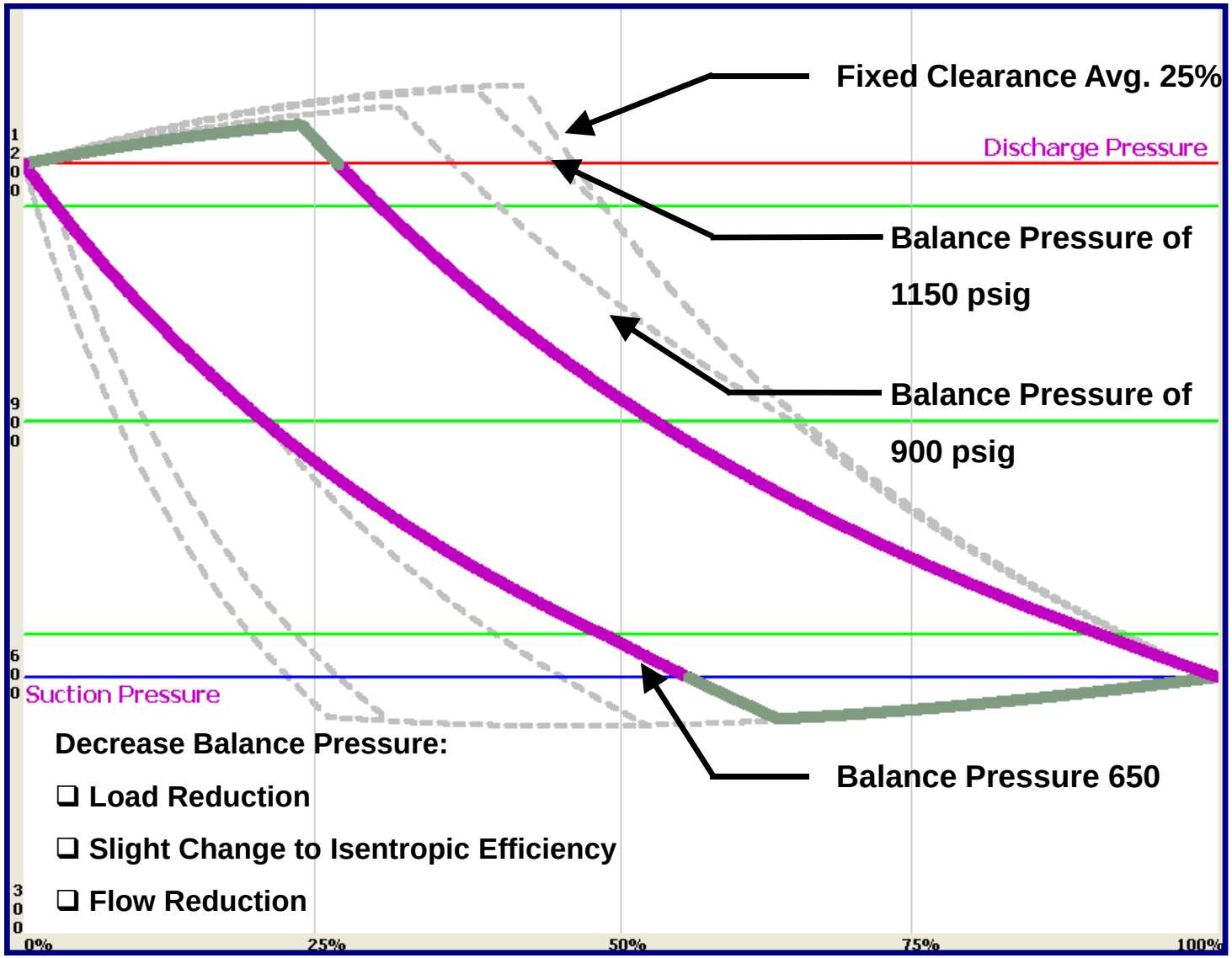
❑ How does it work?

- ❑ Valve guard designed to use control gas pressure on guard side of the elements
- ❑ Opens when the cylinder pressure is greater than the control pressure
- ❑ Closes when the cylinder pressure is less than the control pressure

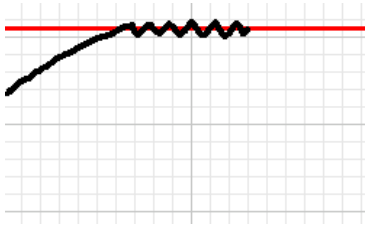
❑ Where is it installed?

- ❑ Compressor cylinder head or crank end

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●●●○○	●●●○○	●●○○○	●●●○○	●●●●○



Load Changes



Added Fixed Volume Clearance

- ❑ Variable Speed Control
- ❑ Unit / Stage Bypass
- ❑ Throttling of Operating Pressures
- ❑ End Deactivation
- ❑ Displacement Changes
- ❑ Added Fixed Clearance
- ❑ Adjustable Head End Suction Valve
- ❑ Added Variable Volume Clearance
- ☑ **Added Fixed Volume Clearance Devices**
- ❑ Timed Valve Closing

❑ **Defined**

- ❑ Adjust clearance volumes within the design of the device
- ❑ Accomplished by Manual, Hydraulic, or Pneumatic Forces

❑ **Devices**

- ❑ Front Head Volume Pocket
- ❑ Valve Cap Volume Pocket
- ❑ Internal Body Volume Pocket

Front Head Volume Pockets

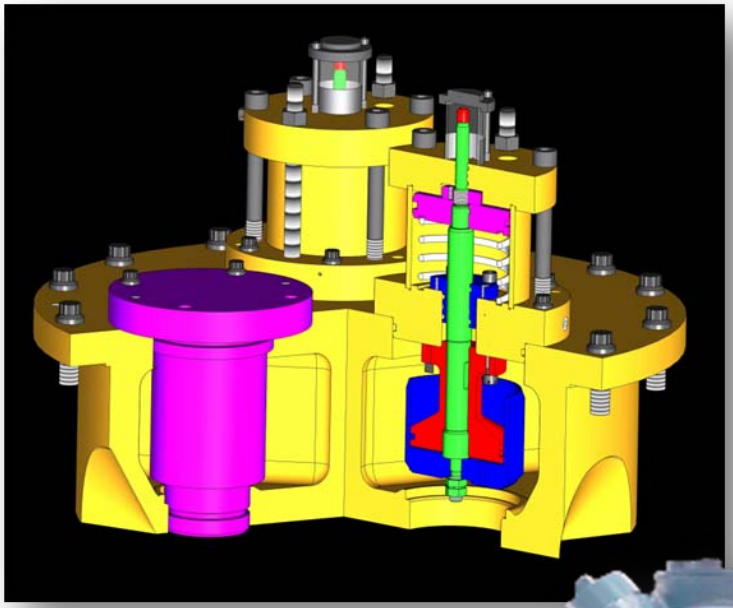


Photo Courtesy of ACI Services, Inc.

Photo Courtesy of Ariel Corporation

❑ What is it?

- ❑ Fixed clearance device
- ❑ Designed for the front head
- ❑ Actuator assembly

❑ What does the device do?

- ❑ Adds a predetermined amount of fixed clearance to the cylinder end

❑ How does it work?

- ❑ Actuation medium supplied to actuation cylinder
- ❑ Actuation Pressure to close off volume
- ❑ Vent actuation pressure – gas pressure moves plug to open the volume

❑ Where is it installed?

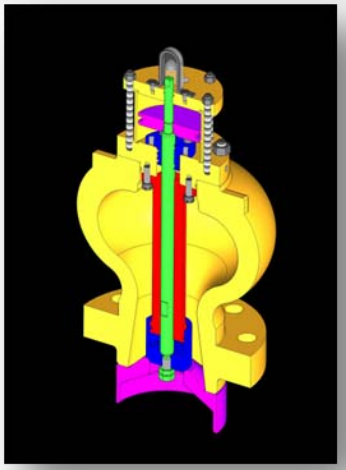
- ❑ Cylinder head end head

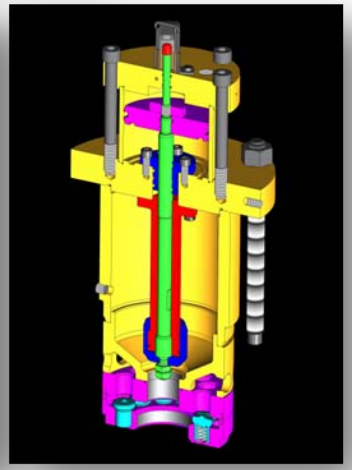
INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●●●○○	●●●○○	●●●○○	●●●●○	●●●●●

Valve Cap Volume Pocket

Photo Courtesy of Dominion Resources

Images Courtesy of ACI Services, Inc.





❑ What is it?

- ❑ Fixed clearance device
- ❑ Designed as part of the valve cap
- ❑ Actuator assembly

❑ What does the device do?

- ❑ Adds a predetermined amount of fixed clearance to the cylinder end

❑ How does it work?

- ❑ Air, gas, or manual power actuates device
- ❑ **Closed**: Actuation pressure engaged
- ❑ **Open**: Vent actuation pressure
- ❑ Requires a special valve retainer

❑ Where is it installed?

- ❑ Over a suction or discharge valve on the head or crank end of the cylinder

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●●●○○	●●●○○	●●●○○	●●●●○	●●●●●

Internal Body Volume Pockets

Photo Courtesy of Cameron Corporation

What is it?

- Fixed clearance device
- Actuator assembly

What does the device do?

- Adds a predetermined amount of fixed clearance to the cylinder end

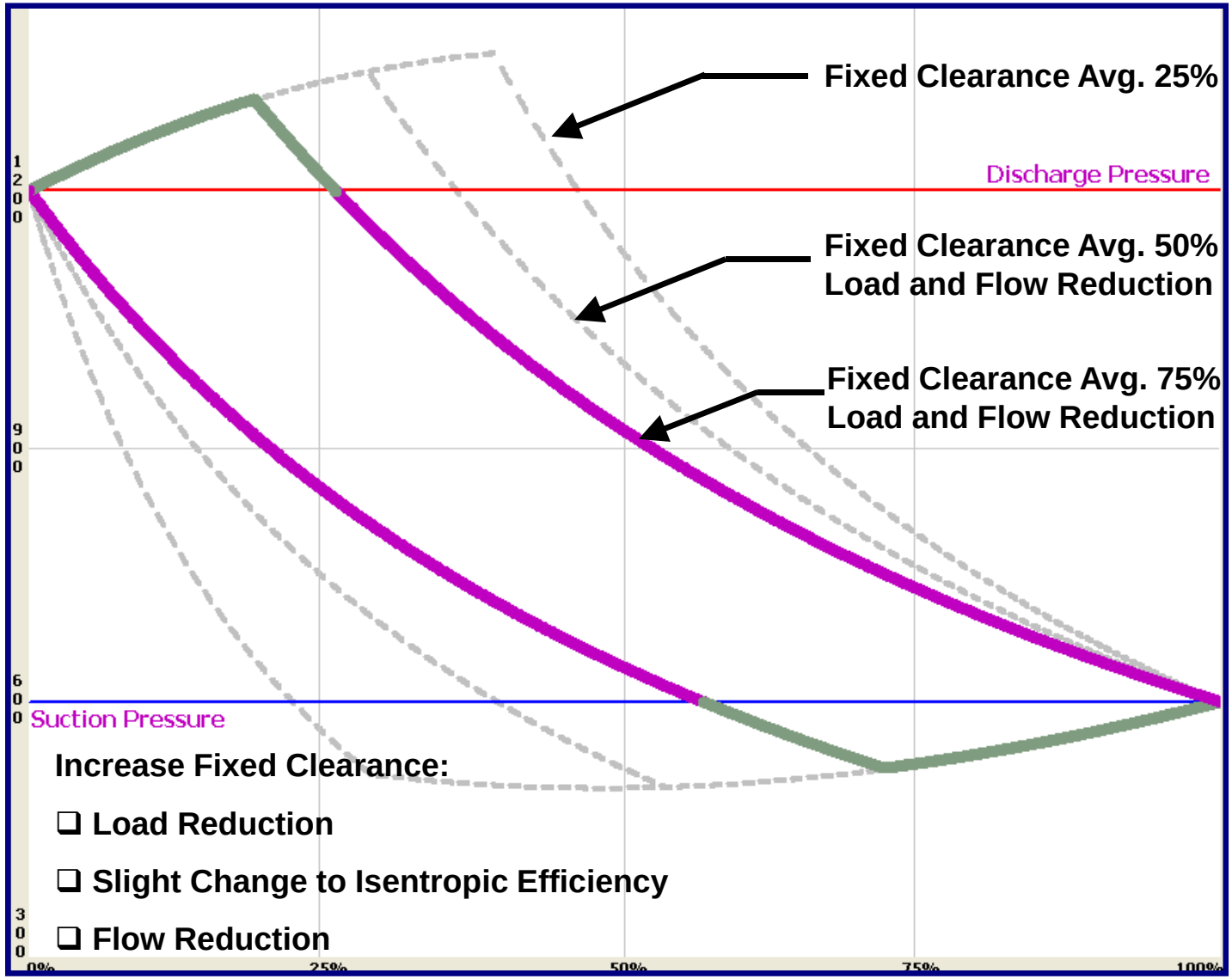
How does it work?

- Actuation medium supplied to actuation cylinder
- Actuation Pressure to close of volume
- Vent actuation pressure – gas pressure moves plug to open the volume

Where is it installed?

- Cavity casted into the cylinder
- Head end or crank end

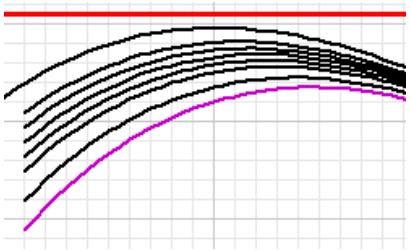
INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●○○○○	●●●○○	●○○○○	●●●●○	●●●●●



Increase Fixed Clearance:

- ❑ Load Reduction
- ❑ Slight Change to Isentropic Efficiency
- ❑ Flow Reduction

Load Changes



Timed Valve Closing

- ❑ Variable Speed Control
- ❑ Unit / Stage Bypass
- ❑ Throttling of Operating Pressures
- ❑ End Deactivation
- ❑ Displacement Changes
- ❑ Added Fixed Clearance
- ❑ Adjustable Head End Suction Valve
- ❑ Added Variable Volume Clearance
- ❑ Added Fixed Volume Clearance Devices
- ☑ **Timed Valve Closing**
- ❑ Changes to Valve Flow Area

❑ **Defined**

- ❑ Delay of the closing point of the suction valves
- ❑ Electronic, hydraulic, pneumatic or mechanical means
- ❑ Delay reduces the net piston displacement
- ❑ Delay increases the effective fixed clearance
- ❑ The net effect is a reduction in capacity
- ❑ Accomplished during the compression event

❑ **Devices**

- ❑ Hydraulic / Electronic controlled finger type devices

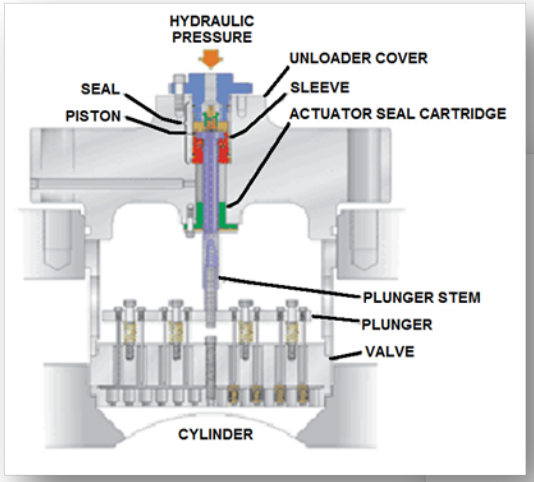


Image Courtesy of Dresser Rand Corp.

Image Courtesy of Hoerbiger Corporation

❑ What is it?

- ❑ Computer controlled, hydraulically activated, finger unloader system

❑ What does the device do?

- ❑ Forces the suction valve to remain open during the compression event

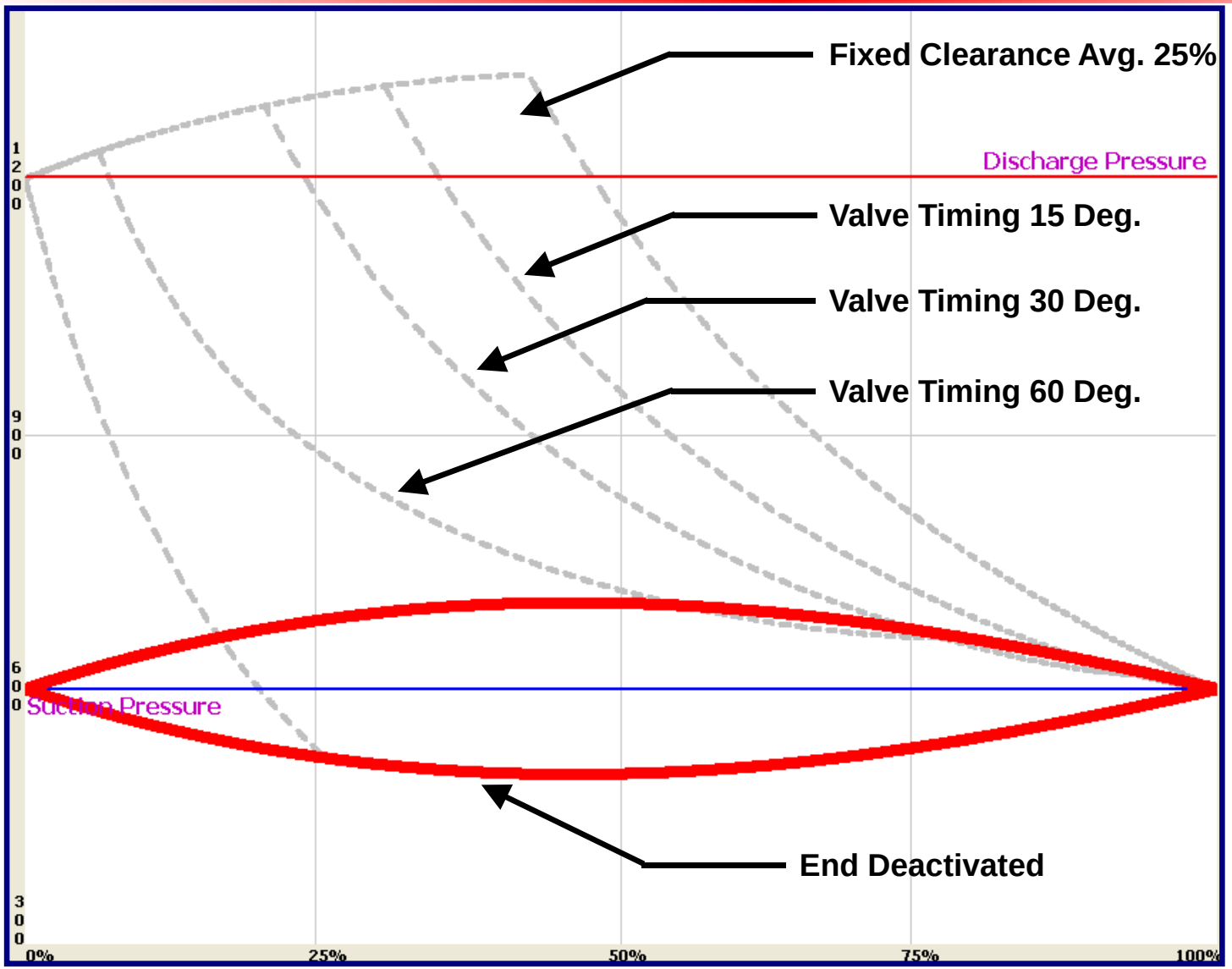
❑ How does it work?

- ❑ Re-expansion - the suction valve is closed (due to differential pressure)
- ❑ Suction - the unloader forces the valve open
- ❑ Compression - the unloader forces the valve open (gas flows into suction plenum)
- ❑ Compression - Suction valve is allowed to close at a selected crank angle

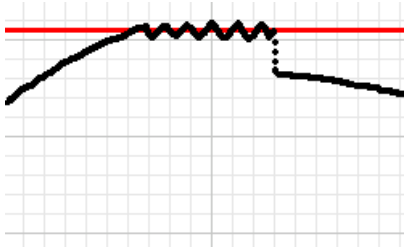
❑ Where is it installed?

- ❑ Head end / Crank End Suction Valves

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●○○○○	●●○○○	●●○○○	●●●●●	●●●●○



Load Changes



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- ❑ Added Variable Volume Clearance
- ❑ Added Fixed Volume Clearance Devices
- ❑ Timed Valve Closing
- ☑ **Changes to Valve Flow Area**

❑ **Defined**

- ❑ Provide More Flow Area
- ❑ May Increase Fixed Clearance
- ❑ Manual Shut Down Required
- ❑ Application may Limit Range of Valve Types to Consider

❑ **Devices**

- ❑ Suction and/or Discharge Valves

Adjustments to Valve Flow Areas

Images Courtesy of ACI, Cook Manley, Dresser-Rand Corp., and Hoerbiger

❑ What is it?

- ❑ Efficient Compressor Valves

❑ What does the device do?

- ❑ Reduces Valve Losses
- ❑ **May** Include Added Fixed Clearance

❑ How does it work?

- ❑ Increases Effective Flow Area
- ❑ Minimizes Effort to Open/Close Valve

❑ Where is it installed?

- ❑ Compressor Valve Ports

INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●●●●○	●●●●○	●●●●○	●●●●○	○○○○○

Valve-In-Piston Type Cylinder

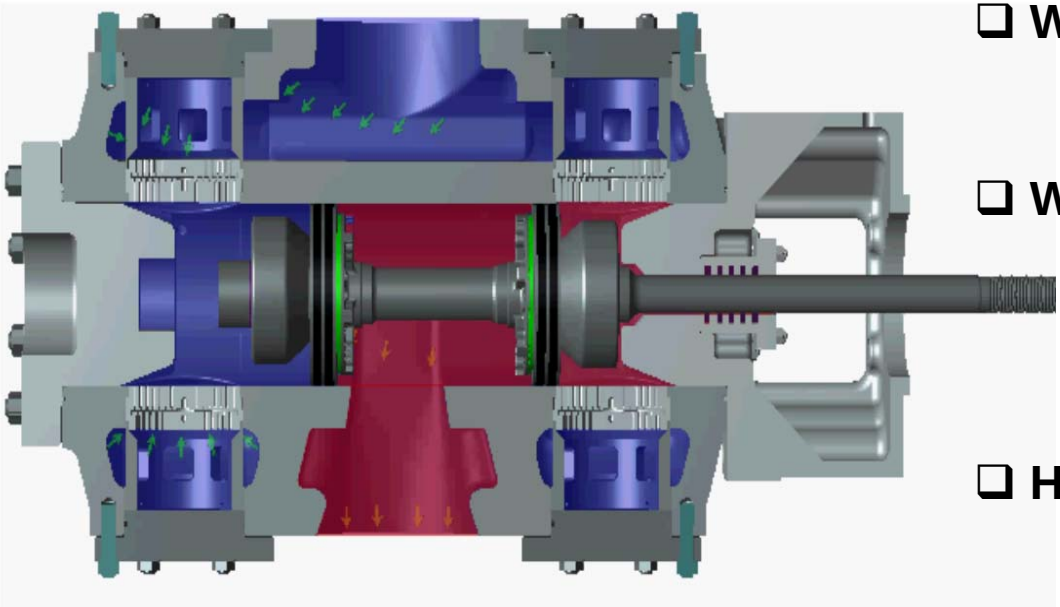


Image Courtesy of Dresser-Rand Corp.

❑ What is it?

- ❑ New Cylinder Design

❑ What does the device do?

- ❑ Moves Discharge Valves to Piston
- ❑ Adds Fixed Clearance to Cylinder Ends
- ❑ **Doubles** number of Suction Valves

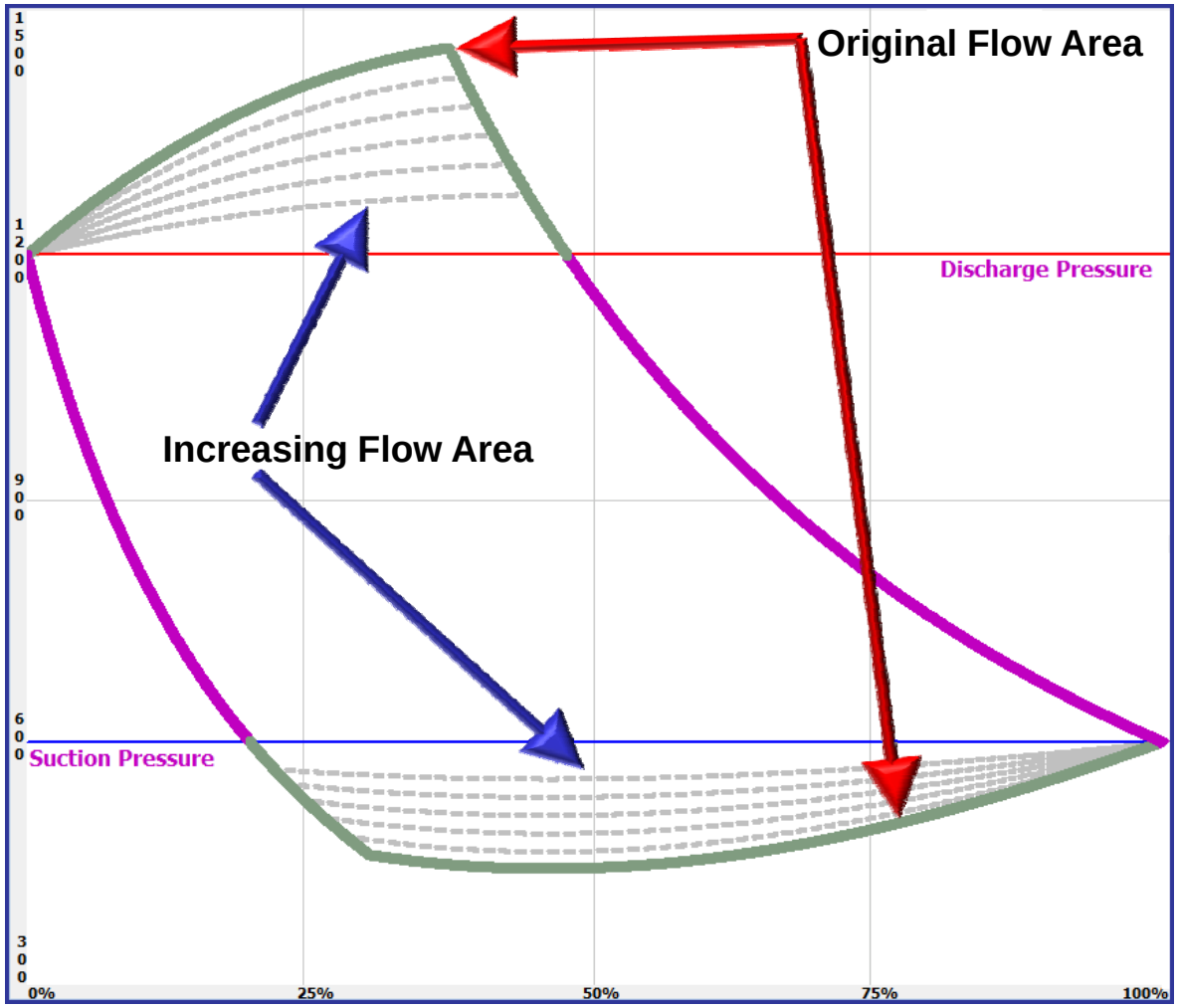
❑ How does it work?

- ❑ Doubling of suction valves tends to reduce suction valve losses by 75%

❑ Where is it installed?

- ❑ Completely New Cylinder

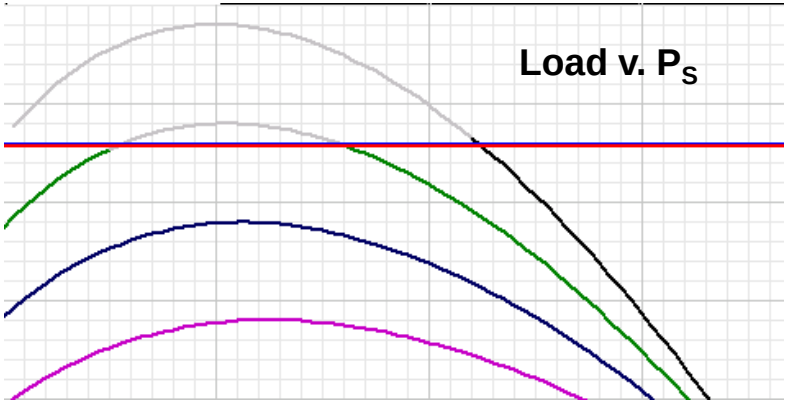
INSTALLED COST	EFFICIENCY	ADAPTABILITY	SIMPLICITY	AUTOMATABLE
●●●●○	●●●●○	●○○○○	●●○○○	○○○○○



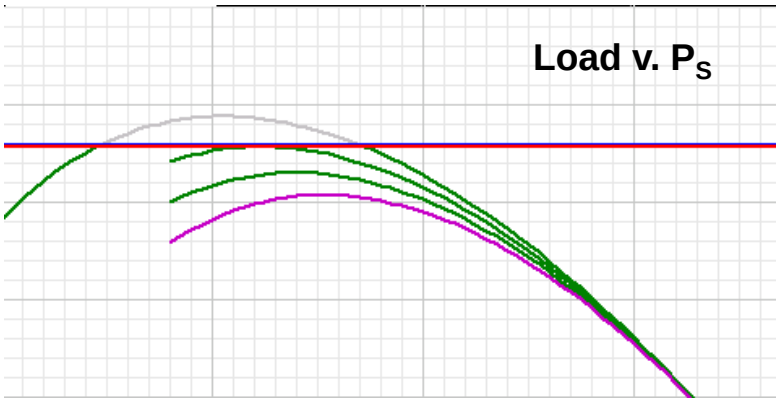
- Load Reduction
- Increase in Isentropic Efficiency
- Potential Flow Increases only if Power Savings can be Utilized

Selecting the Appropriate Devices for a Specific Application

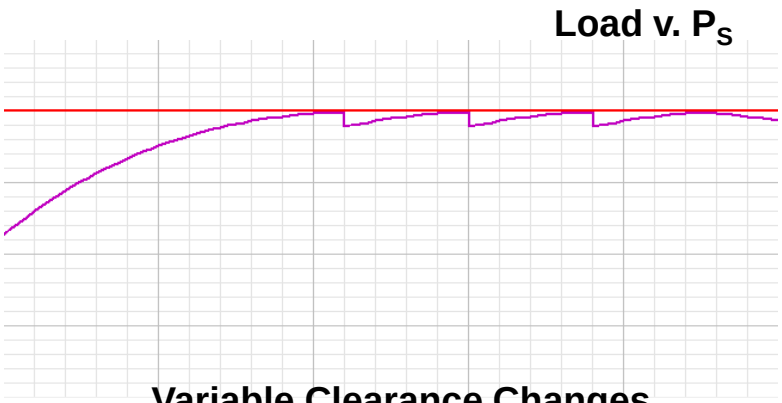
Selecting the Appropriate Device(s) for a Specific Application



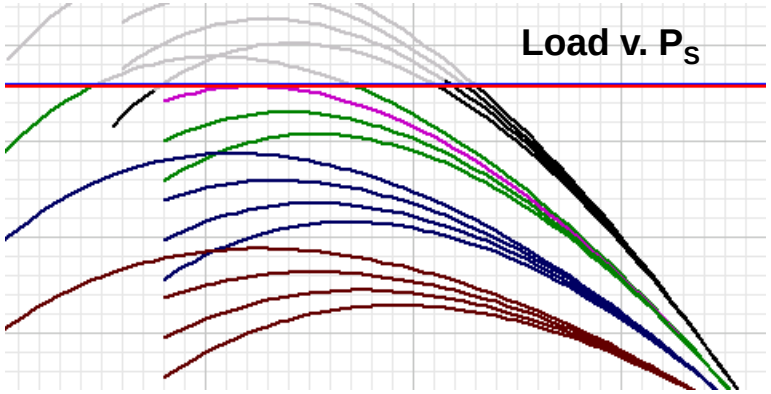
End Deactivation
Typically large load/flow changes



Fixed Clearance Changes
Typically smaller load/flow changes



Variable Clearance Changes
Typically very smooth changes to load/flow



Combinations - Best of each
Gives maximum coverage of operating ranges

- ☑ **Determine the required range of operating conditions**
  - ❑ **Gas composition**
  - ❑ **Pressure and temperature ranges**
  - ❑ **Flows**
  - ❑ **Important operating points**
- ❑ **Determine the timing of operating condition changes**
  - ❑ **Fluctuating, gradual, seasonal, random**
- ❑ **Determine the physical properties of the compressor and driver**
  - ❑ **Driver load and speed ratings and ranges**
  - ❑ **Compressor frame and cylinder sizes and ratings**
  - ❑ **Include any existing load and flow devices**
  - ❑ **System cooling capacities, temperatures and pressure drops**

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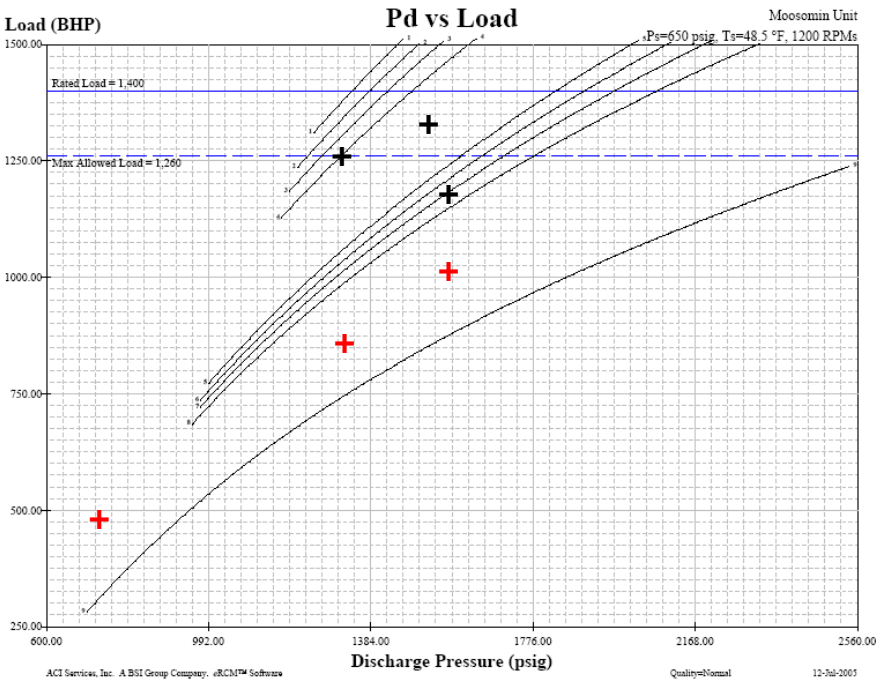
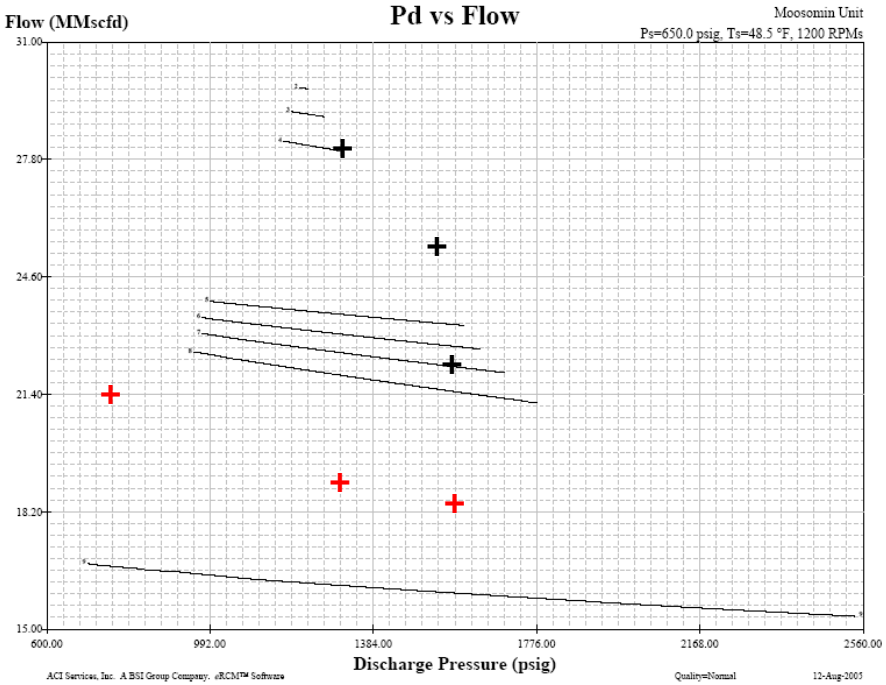
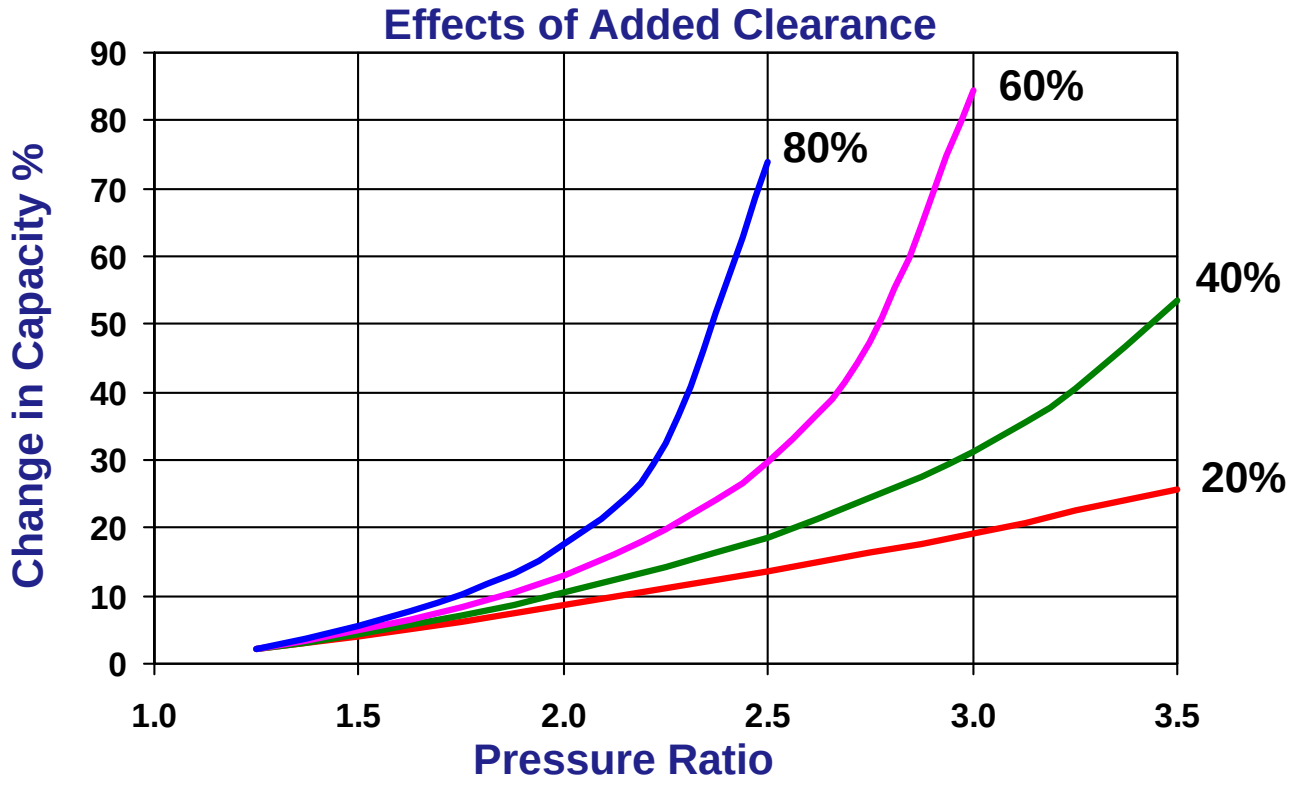
  - ❑ **Include any existing load and flow devices**
  - ❑ **System cooling capacities, temperatures and pressure drops**

- Model the compressor performance
  - Need a robust performance modeling approach
  - Determine how well the existing unit handles the range of conditions
  - Safe operating limits – Load, MAWP, Rod Load, PNR, Low VE, temperatures...
  - Identify gaps in unit capability





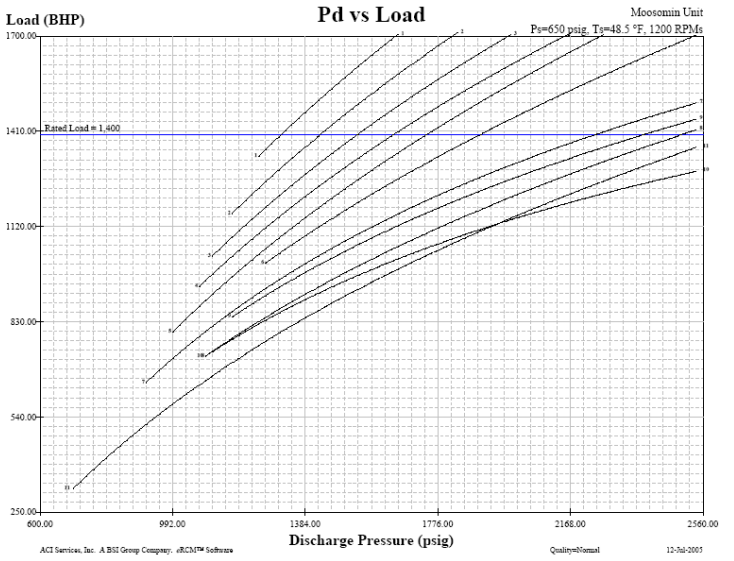
- Investigate alternatives for changing the unit performance
  - Review types of devices
  - Compare relative characteristics of devices with application requirements
  - Select tentative devices to be investigated



- Change the compressor performance model
  - Change performance model to add tentative changes

    (cylinder bore size, fixed clearances, deactivation, or combinations)
  - Evaluate the changes vs. the desired performance and flexibility
  - Tune the parameters to optimize the performance
  - Review Limits – Load, MAWP, Rod Load, PNR, Low VE, Temperatures...
  - Iterate as necessary until tentative hardware selection is complete

Finding an optimum solution can be a challenging process!



- Justification – Types of Projects
  - Mandatory Projects
    - Contracted Flow Requirements
    - Equipment Replacement / Maintenance Requirements
    - HSE (Health-Safety-Environment) Related
  - Discretionary Projects
    - Maximize Capacity
    - Efficiency Improvements
    - Maintenance Savings
    - Automation
    - Equipment Protection

- Justification – Economic Considerations
  - Costs
    - Capital costs – hardware devices, control system, software
    - Installation cost, freight, taxes, misc.
    - Long term operating and maintenance costs
  - Potential Areas of Savings
    - Increased flow capacity (throughput)
    - Operation and maintenance labor savings
    - Operating efficiency improvement / energy savings
    - Increased reliability - maintenance savings, and downtime reduction
    - Favorable environmental impact
    - Maximize asset utilization – capital avoidance
    - Tax savings / incentives
    - Extend equipment useful life
    - Other
  - Typical Financial Hurdles
    - Percent Rate of Return on Investment
    - Months/Years to payback

Financial Modeling Tools

Project Financial Analysis (US$)				Sheet 1 of 2			Date	
Project Number			Product Line				Project Mgr.	
Project Name	Bypass elimination project							
Project Description								
Brief Year of Return (yr 1)	2006							
		Approvals						
	Comments		2006	2007	2008	2009	2010	2011	2012
A. Projected Fuel Usage Savings			$ 1,600,000	$ 1,600,000	$ 1,600,000	$ 1,600,000	$ 1,600,000	$ 1,600,000	$ 1,600,000
Confidence Level			100%	100%	100%	100%	100%	100%	100%
Original Fuel Consumption	BTU/BHP-Hr		7,000	7,000	7,000	7,000	7,000	7,000	7,000
New Fuel Consumption	BTU/BHP-Hr		6,800	6,800	6,800	6,800	6,800	6,800	6,800
Average Unit BHP	BHP		1,000	1,000	1,000	1,000	1,000	1,000	1,000
Hours of Operation Per Year			2,000	2,000	2,000	2,000	2,000	2,000	2,000
Fuel Cost per MMBTU	$/MMBTU		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
B. Increased Throughput			$ -	$ -	$ -	$ -	$ -	$ -	$ -
Increase in Flow Rate									
Value per Unit Flow									
C. Projected Maintenance Cost Savings			$ 17,500	$ 17,500	$ 17,500	$ 17,500	$ 17,500	$ 17,500	$ 17,500
Labor Hours Saved			300	300	300	300	300	300	300
Labor Rate (fully burdened)			45	45	45	45	45	45	45
Labor Cost Saved			13,500	13,500	13,500	13,500	13,500	13,500	13,500
Repair Parts Saved			3,500	3,500	3,500	3,500	3,500	3,500	3,500
Lubricants & Other Fluids Saved			500	500	500	500	500	500	500
Other Costs Saved			400	400	400	400	400	400	400
D. Other Savings (list):			$ 3,000	$ 3,000	$ 3,000	$ 3,000	$ 3,000	$ 3,000	$ 3,000
			$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000
			$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000
			$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000
E. Incremental Operational Costs (list):			$ 500	$ 500	$ 500	$ 3,500	$ 500	$ 500	$ 500
Air Compressor Power & Maint.			$ 500	$ 500	$ 500	$ 500	$ 500	$ 500	$ 500
Air Compressor Replacement						$ 3,000			
Net Savings Savings (= A+ B+ C+ D- E)			$ 1,620,400	$ 1,620,400	$ 1,620,400	$ 1,617,400	$ 1,620,400	$ 1,620,400	$ 1,620,400
EBITDA			$ 1,620,400	$ 1,620,400	$ 1,620,400	$ 1,617,400	$ 1,620,400	$ 1,620,400	$ 1,620,400
Terminal Value									$ -
		Implementation Costs (Unit 2)				Years After Implementation			
Project Payback Life Cycle Year	2004	2005	2006	2007	2008	2009	2010	2011	2012
EBITDA	$ -	$ (253,000)	$ 1,620,400	$ 1,620,400	$ 1,620,400	$ 1,617,400	$ 1,620,400	$ 1,620,400	$ 1,620,400
Depreciation		$ (72,400)	$ (45,250)	$ (18,100)	$ (18,100)	$ (18,100)	$ (9,050)		
EBT	$ -	$ (325,400)	$ 1,575,150	$ 1,602,300	$ 1,602,300	$ 1,599,300	$ 1,611,350	$ 1,620,400	$ 1,620,400
- Cash Taxes (credit)	$ -	$ (126,506)	$ 614,309	$ 624,897	$ 624,897	$ 623,727	$ 628,427	$ 631,956	$ 631,956
- Working Capital Investment			$ 161,790	$ -	$ -	$ -	$ -	$ -	$ (161,790)
- Capital Investment	$ -	$ (181,000)							
+ Depreciation		$ 72,400	$ 45,250	$ 18,100	$ 18,100	$ 18,100	$ 9,050	$ -	$ -
After-tax Cash Flow	$ -	$ (307,094)	$ 844,302	$ 995,503	$ 995,503	$ 993,673	$ 991,574	$ 988,444	$ 1,150,234
Discount Rate	8.0%	Additional Description & Comments:							
Income Tax Rate	39%								
IRR	288%								
NPV	$ 4,451,064.9								
Payback Time (years)	0.4								
PI									

Financial Modeling Tools

Savings Spreadsheet

1. Fuel Savings

300	Number of days operating per year
24	Average number of hours operating per day
1200	Average Engine Load (BHP)
7600	Average Engine Fuel Consumption (BTU/BHP-hr)
950	Fuel Heating Value (BTU/CF)
$5.00	Fuel Gas Cost (US$/MCF)
5.0	Efficiency Gain (%)
$24,192	Savings Sub-total ($US/yr)

We have provided:

- ☑ **A fundamental review of the many types of reciprocating compressor unloading and capacity control devices,**
- ☑ **Useful knowledge for evaluating and comparing individual unloading and control devices,**
- ☑ **Tools for identifying the best approach and devices for optimizing current, reapplied and new compressor performance relative to unique needs and budgets,**
- ☑ **An objective method for selecting and economically justifying optimum control devices**

Questions ?