INDUSTRIAL REFRIGERATION CONTROL VALVES

Presented To:

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Today's Agenda

- The role of control valves in an industrial refrigeration sytem
- Types of control valves
  - Solenoids
  - Pressure regulators
  - Expansion Valves
- The fundamental components of various control valves
- How do control valves work?
  - Piloted Pressure Regulators
  - Gas Powered Valves
  - Motorized Valves
- The Basics – Installation, Set-up, Maintenance
- A look at the future of control valves

What is Control?

- According to Wikepedia, control is:

- *"that function of the system that adjusts operations as needed to achieve the plan, or to maintain variations from system objectives within allowable limits".*

The Role of Control Valves In An Industrial Refrigeration System

- The Primary Driver
- Change
  - With very few exceptions, something is always changing somewhere in an industrial refrigeration facility.
    - Loads
    - Defrost
    - Maintenance
    - Room Conversions
  - Control valves are needed to facilitate and manage change.

The Role of Control Valves In An Industrial Refrigeration System

- With respect to managing change:
- Much of the time, we need control valves to prevent change by:
  - Maintaining evaporator pressure/temperature
  - Maintaining superheat levels
  - Maintaining liquid levels
  - Maintaining oil temperature
  - Maintaining subcooling
  - Maintaining flow rates
- In the midst of external changes to the refrigeration environment.

The Role of Control Valves In An Industrial Refrigeration System

- Operationally, control valves control:
  - Start/stop of refrigerant flow
  - Pressure
  - Temperature
  - Modulation of refrigerant flow
- Functionally,
  - A change in the system (the stimulus) leads to
  - A reaction from the control valve (the response)

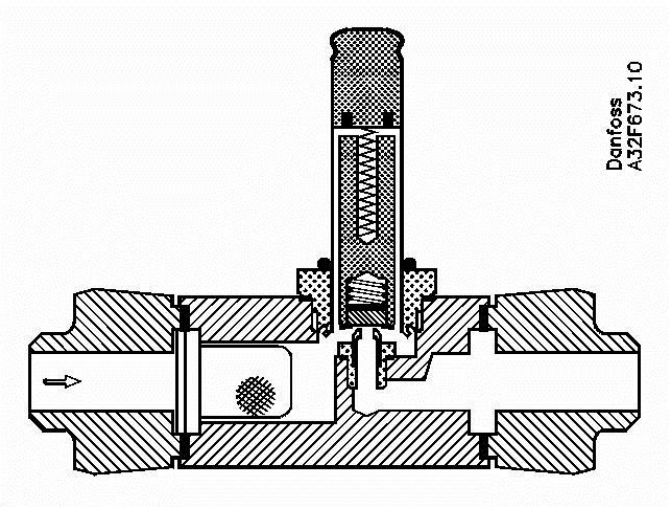
Types of Control Valves

- Solenoids
  - Direct Acting
  - Piloted
  - Gas Powered
  - Motorized
- Pressure Regulators
  - Direct Acting
  - Piloted
  - Motorized
- Expansion Valves
  - Pulse Width Modulating
  - Motorized

Types of Control Valves Solenoids

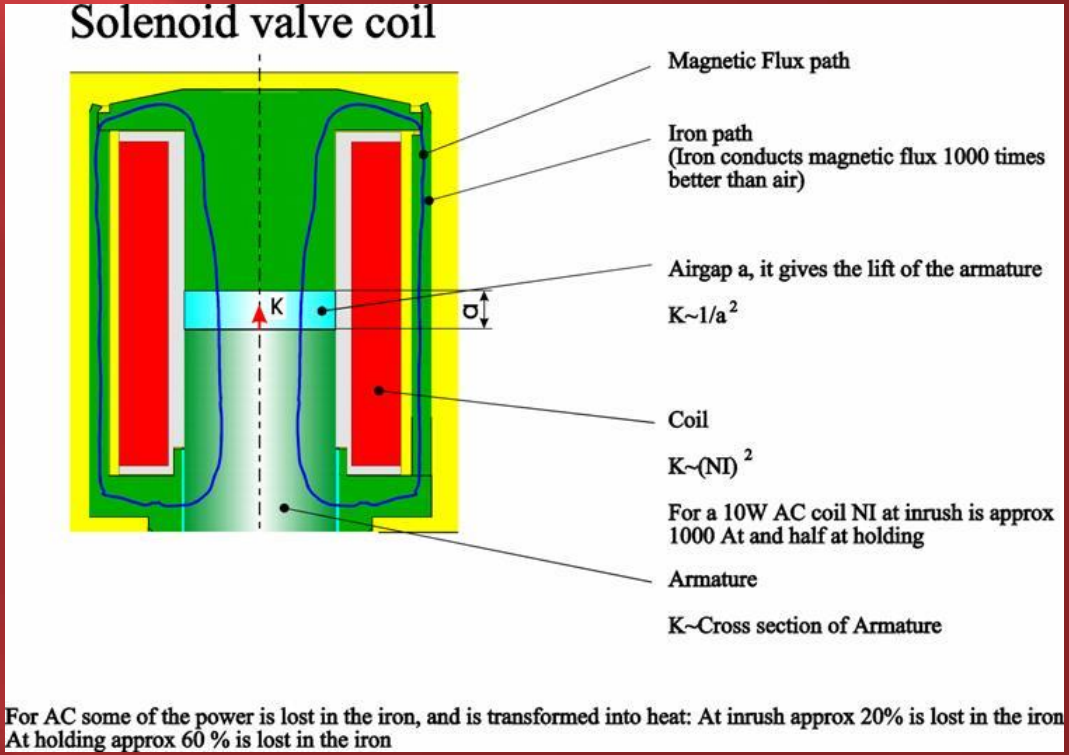
- Direct Acting
- Servo-driven
- Gas Powered
- Motorized
- Others

Direct Acting Solenoids

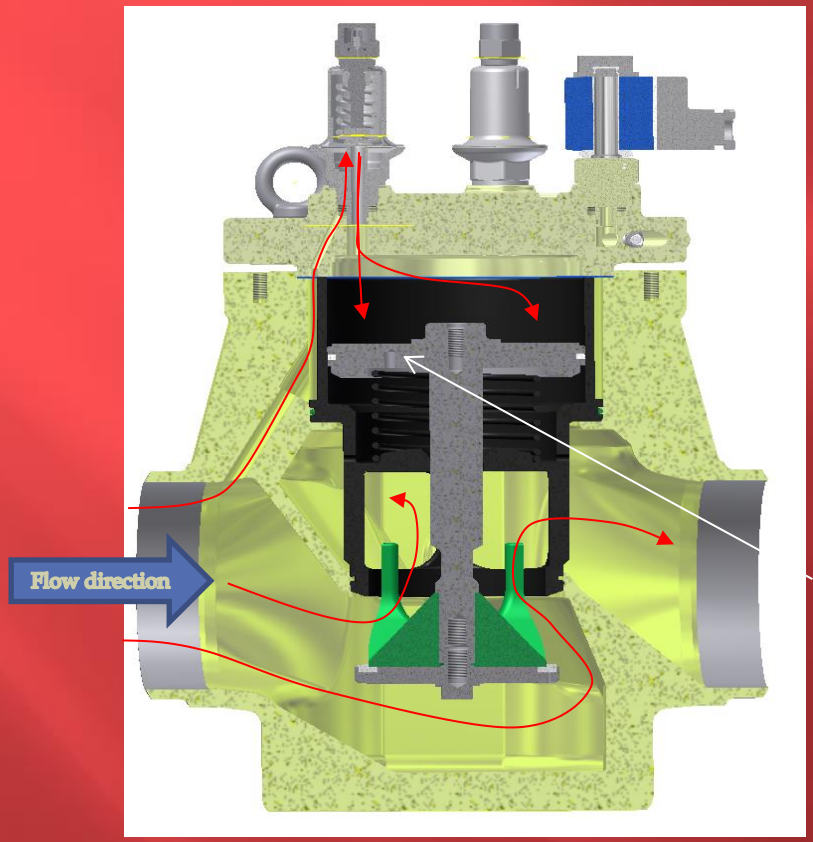


The valve is opened as a result of the magnetic field which is created when the solenoid coil is energized.

The ability of the magnetic field to open the valve is applicable to small valves only.



Servo-driven Solenoids



Valve opens as a result of a force imbalance. The basic principle is:

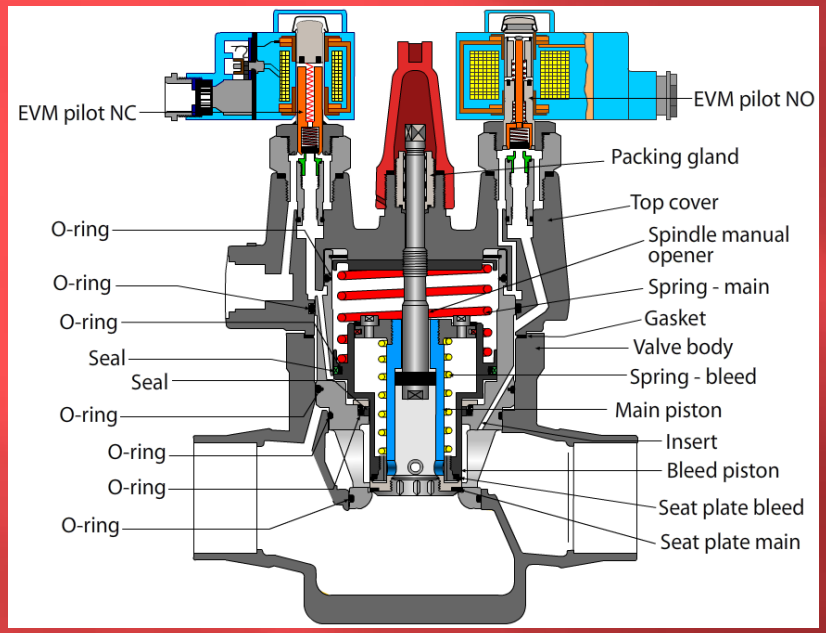
Force = Pressure x Area

When there is a pressure difference between the inlet side of the valve and the outlet side of the valve, we can create a force imbalance between the two by changing both the pressure and the area over which the pressure is acting.

Note that the opening force must also overcome the spring force which is used to close the valve.

As a result of the need for a force imbalance, there is an inherent need for a minimum amount of pressure differential across the valve. Failure to provide this differential can result in valve "chattering".

Gas Powered Solenoids



The valve in this picture is a Danfoss ICLX gas powered valve. It has a built in mechanical "soft start" and an internal drainage system to remove condensate from the chamber as the valve closes.

Unlike Servo-driven solenoids, gas powered solenoids use high pressure gas to open (or in some cases close) and do not require pressure differential to open or close the valve.

Gas powered valves are most typically used on the suction lines of low temperature systems. A primary objective of the design is to minimize pressure drop across the valve in order to maintain as high of a suction pressure as possible in order to achieve good energy efficiency.

Because these are typically used on freezer applications, the pressure differential between that used in defrost and the suction pressure is usually quite high.

For this reason, an initial "soft start" is typically recommended in order to avoid hydraulic hammer in the suction line.

Motorized Solenoid Valves

The motorized valve is getting far more use as a speed controlled solenoid valve than ever before.

The simplest form of a control valve is a solenoid valve. However, given the size and conditions within many industrial refrigeration systems, we don't always want a simple on/off control. We want to be able to control the speed at which the valve opens and/or closes.

The motorized valves in this picture are Danfoss ICM valves. They are located on the hot gas and suction lines of a spiral freezer. They are powered on or off with a simple relay contact. Speed of opening and closing are independent of each other.

The power to open and close the motorized solenoid is supplied by the motor. Therefore, there is no pressure differential required for a motorized solenoid to open or close.

Other Types of Solenoids

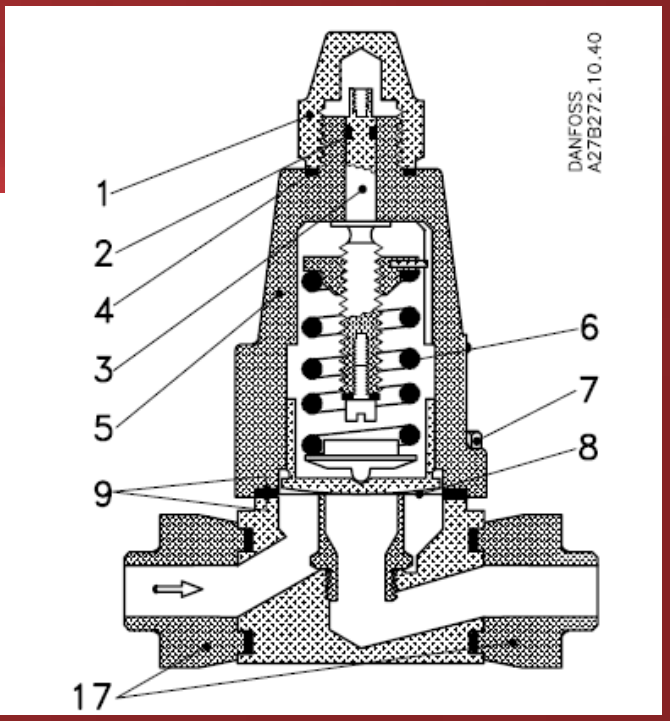
- Butterfly
- Pneumatic

Pressure Regulators Direct Acting

- Similar Principal to Direct Acting Solenoids
- No servo type system
  - Spring pressure set to desired opening pressure
  - Independent of downstream pressure
- Advantages
  - Simple
  - Low Cost
- Disadvantages
  - Low capacity range
  - Flanged, Pressure rating = 406 psi, Lower temperature rating = -58 ˚F

Pressure Regulators
Direct Acting

1. Protection cap
2. O-ring
3. Spindle
4. Gasket
5. Cover
6. Spring
7. Screw
8. Diaphragm
9. Gasket
17. Flanges



Pressure Regulators Pilot Driven

- Probably the most common kind of control valve
- Typical uses include suction lines, defrost relief lines, hot gas mains
- Functionality determined by pilot valves and configuration of pilots on the main control valve

Pilots

There is a wide variety of pilots used on pressure regulators. In a non-quantified order of usage, most of the pilots used fall into one of the following categories:

- Solenoid pilots – usually normally closed (NC) but also normally open (NO) are available
- Back pressure pilots – used to maintain a set pressure upstream of the pressure regulator
- Outlet pressure regulator – typically used to maintain a set pressure downstream of the pressure regulator
- Electronically operated pressure pilot
- Differential pressure pilot
- Other pilots – temperature operated, motorized pilots, etc.

Common Pressure Regulator Configurations

- One function inlet pressure regulator – known as STD (Danfoss), A4 (Parker), HA4 (Hansen)
- Defrost Relief – known as STD (Danfoss), K type for Parker and Hansen
- Inlet Pressure w/ electric forced closed – known as S for all manufacturers
- Inlet Pressure w/ electric forced open – known as B for all manufacturers
- Outlet Pressure Regulator – known as O for all manufacturers

Common Pressure Regulator Configurations - continued

- Outlet Pressure Regulator w/ Electric Forced Closing – known as OS for all manufacturers
- Differential Pressure Regulator – known as L for all manufacturers
- Differential Pressure Regulator w/ Electric Forced Opening – known as BL for all manufacturers
- Electronic Media Temperature Control – known as J for all manufacturers

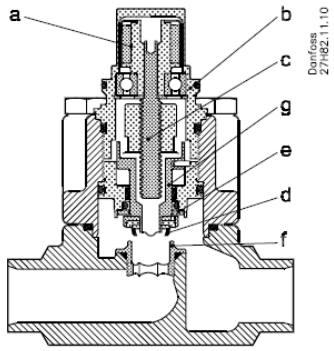
Common Pressure Regulator Configurations - continued

- Electronic Media Temperature Regulation w/ Set Inlet Pressure – known as JD for all manufacturers
- Back Pressure Regulator with 2 different pressure settings – known as D for all manufacturers
- Inlet pressure regulation w/ forced opening and forced closing – known as BS for all manufacturers

Pressure Regulators Motorized

- We call these pressure regulators, however:
  - Most of the time we are regulating temperature
  - Or, flow
- With the above in mind,
  - We can modulate pressure/temperature via an analog signal
  - Or, we can control the rate at which the pressure/flow changes simply by a relay input (the motorized solenoid)
- The key point here is that we can control the rate at which pressure and/or flow changes in small discrete steps.

Pressure Regulators Motorized



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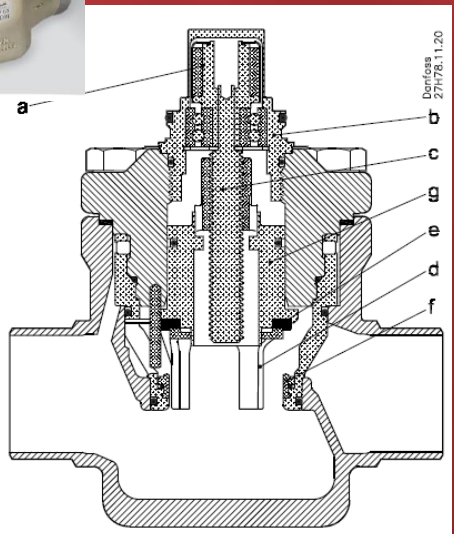

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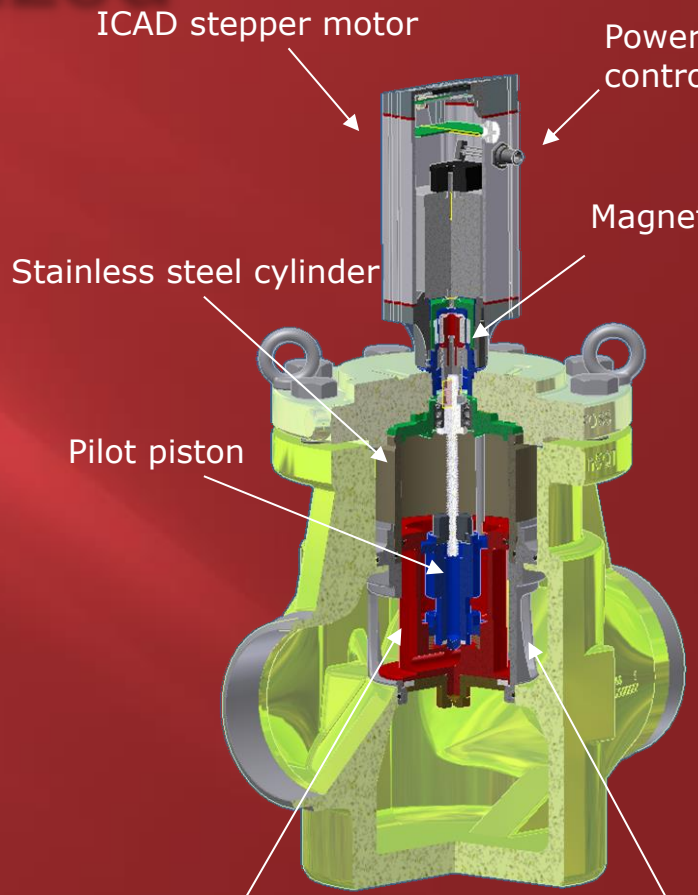


Electronic Expansion Valves

- Two Fundamental Types
  - Pulse Width Modulation Valves (PWM)
  - Motorized Expansion Valves (EEV)
- Two different means of controlling flow
  - PWM controls flow through start/stop
    - At start 100% flow
    - At stop 0% flow
    - Flow rate is determined by number of pulses in a given period of time
  - EEV controls flow by adjusting Cv of valve
    - Flow rate is determined by control signal
    - Sensitivity of flow control determined by number of discrete steps from 0% open to 100% open

The Fundamental Components

- A source of force to do work
  - Electric coils
  - Pressure differential
  - High pressure gas (similar to pressure differential)
  - Electric motor
  - Pneumatic
- A means of controlling that work
  - Springs
  - Hydraulics
  - Control signals

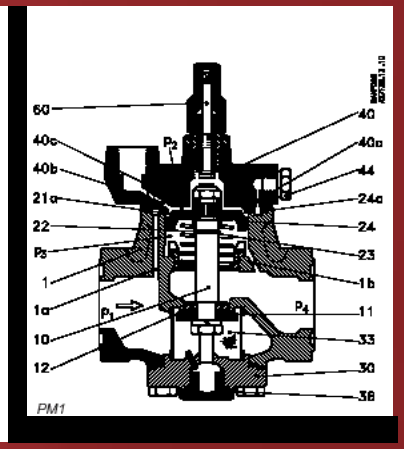
We call this regulation

The Fundamental Components

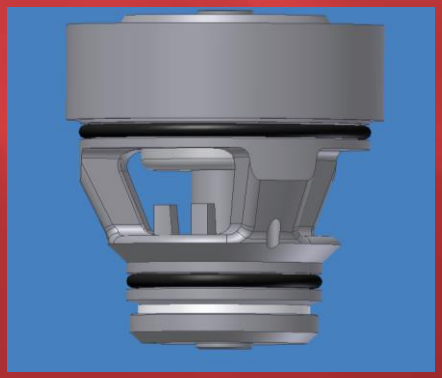
- A physical means to meter flow
  - A spring/piston/cylinder system

PM 1 and PM 3

1.	Valve body
1 a	Channels in valve body 1
1 b	Channels in valve body 1
10.	Valve spindle
11.	Teflon valve plate
12.	Throttle cone
21a.	Equalisation hole in servo piston 24
22.	Locking ring
24.	Servo piston
24a.	Gasket
30.	Bottom cover
33.	Strainer
36.	Plug
40.	Cover
40 a	Channels in cover 40
40 b	Channels in cover 40
40 c	Channels in cover 40
40 d	Channels in cover 40
44.	Pressure gauge connection
60.	Manual operating spindle
61.	External pilot connection
S I, S II	Pilot valve connections in series connection holes
P.	Pilot valve connection in parallel connection hole

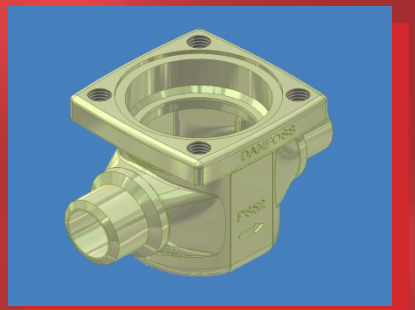


  - A module



The Fundamental Components

- A means of containing and directing the flow



How Do Control Valves Work? Piloted Pressure Regulators

There are several different types of piloted pressure regulators available in the marketplace. This presentation will focus only on Danfoss ICS Pressure Regulators although there are many similarities in function

Characteristics

- Modular construction – uses the same body as the Danfoss ICLX Gas Powered Valve and the Danfoss ICM motorized valve
- Weld-in construction – no potential for flange leakage
- No internal wear surfaces

How Do Control Valves Work? Piloted Pressure Regulators

- **Piloted Pressure Regulators – 3 types of pilot configurations:**
  - **Single pilot single function**
    - Solenoids
    - Back pressure regulators
    - Outlet pressure regulators
    - Others
  - **Control Logic**
    - A parameter is sensed – back pressure, outlet pressure, media temperature, etc.
    - When that parameter is "strong" enough, it overcomes the force keeping the valve closed
    - The valve opens to the necessary degree at which the forces balance
    - And closes when the parameter weakens

How Do Control Valves Work? Piloted Pressure Regulators

Three Pilot Pressure Regulators

- Allows for two or more functions to be controlled by regulator
- Typical multi-function regulators:
  - Dual Pressure Regulators (D)
  - Back Pressure Regulator with Forced Closing (S)
  - Back Pressure Regulator with Forced Opening (B)
  - Outlet pressure regulator with forced closing (OS)
  - Back pressure regulator with forced opening and forced closing (BS)
  - Media temperature regulator with pre-set back pressure regulator (JD)

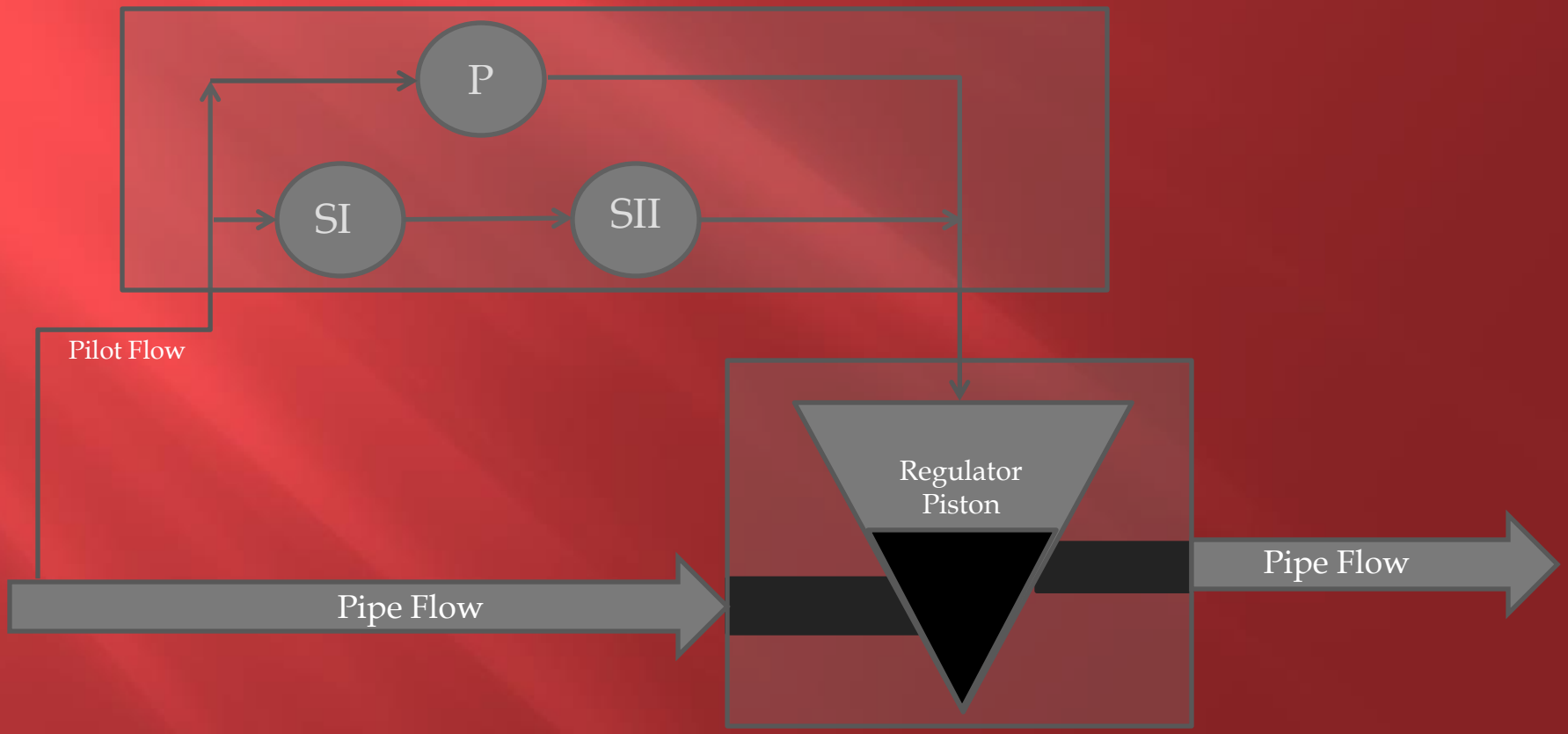
How Do Control Valves Work? Piloted Pressure Regulators

Three Pilot Regulators – continued

- Two Series Ports
  - SI
  - SII
- One Parallel Port
  - P
- In order for flow to pass through the series ports and open the valve, both pilots must be open
- Flow will always pass through the parallel port if it is open.

Piloted Pressure Regulators

3 Pilot Flow Pattern



Note: This example represents control by inlet pressure.
There are many other configurations available.

How Do Control Valves Work?
Gas Powered Valves

There are several different kinds of gas powered valves in the industry. This presentation will focus only on the Danfoss ICLX gas powered valve.

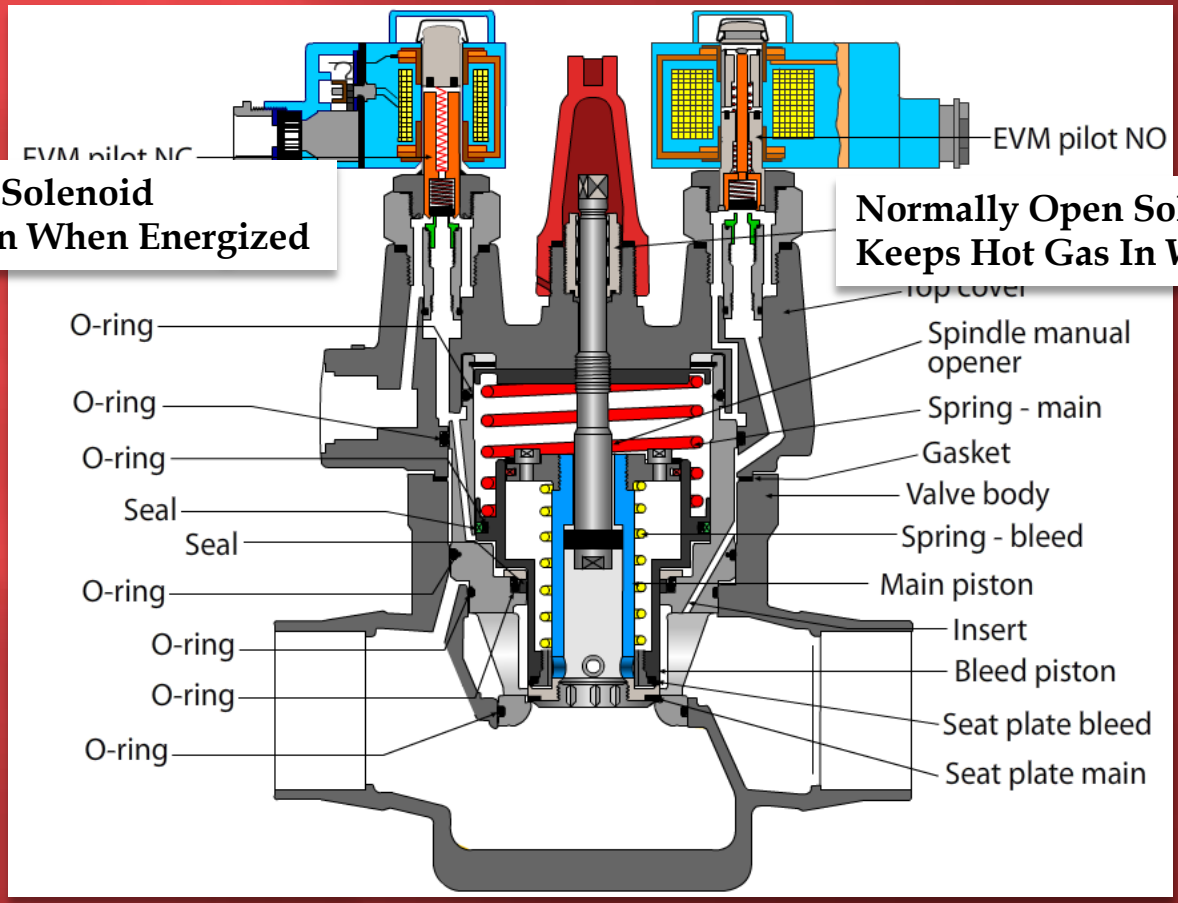
Characteristics

- Normally closed valve – solenoids are energized for normal operation
  - Mechanical two step opening valve
    - Will only open 10% as long as pressure differential across valve exceeds 22 psi
    - Fully opens when pressure differential drops below 22 psi
- Fully modular with no internal wear surfaces

Gas Powered Valves
Solenoid Action

Normally Closed Solenoid
Allows Hot Gas In When Energized

Normally Open Solenoid
Keeps Hot Gas In When Energized

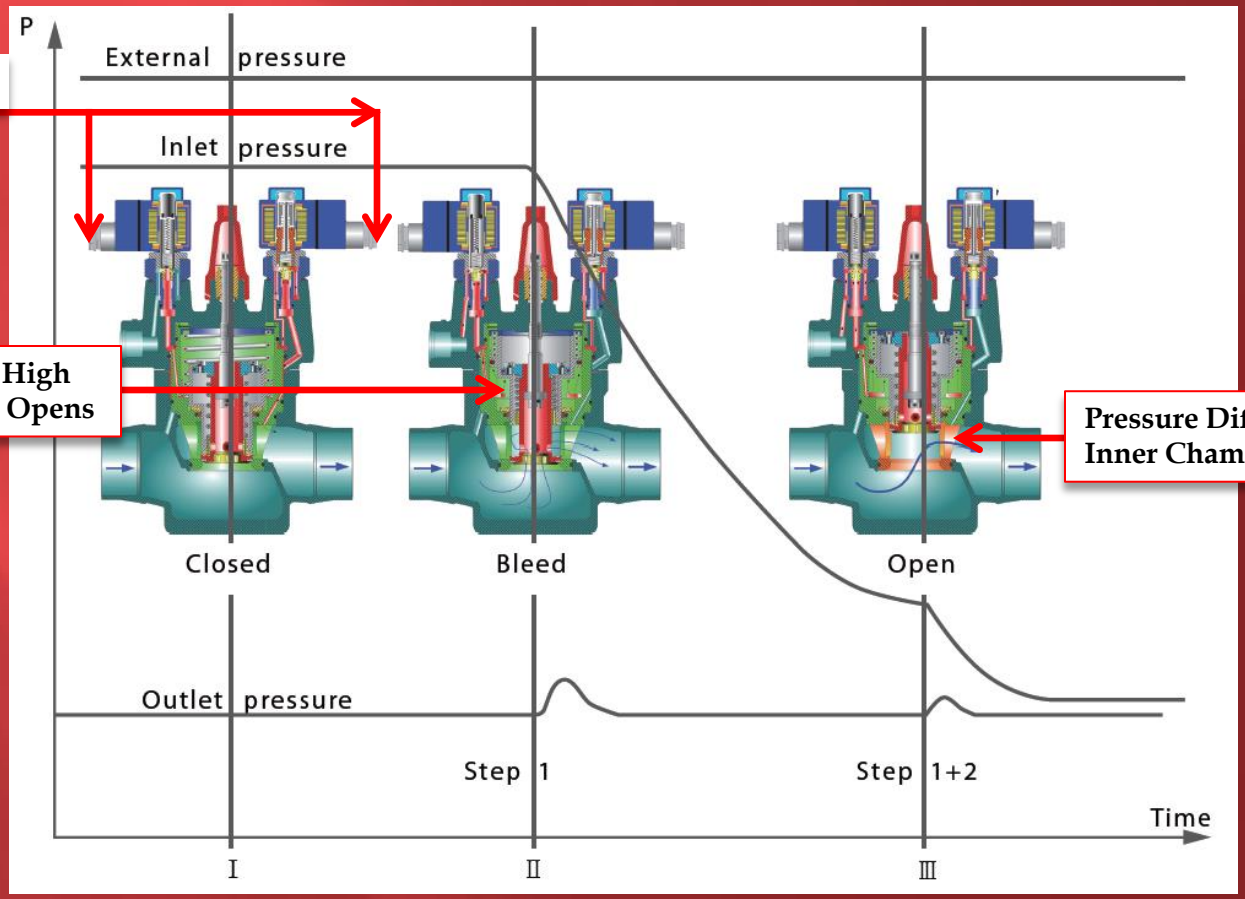


Gas Powered Valves
Opening Sequence of ICLX Valve

One Input Signal

Pressure Differential High
Only Outer Chamber Opens

Pressure Differential Low
Inner Chamber Opens



How Do Control Valves Work? Motorized Valves

- As with other control valves discussed in this presentation, there are other commercially available motorized valves. This presentation will focus only on the Danfoss ICM Motorized Valve.
- **Characteristics**
  - Powered by a digital stepper motor
  - Magnetically coupled drive
  - Can be operated in digital (solenoid) or analog mode
  - Adjustable opening and closing speeds
  - Optical encoder for precision position control
  - Expansion cones (¾″ to 2-½″) and Regulation cones (¾″ to 6″)
  - No internal wear surfaces

How Do Control Valves Work?
Motorized Valves

Sensor device reports information to control device

↳ Control device sends output signal to ICAD motor

↓ Analog Signal (mA or V)
To Modulate Valve OD

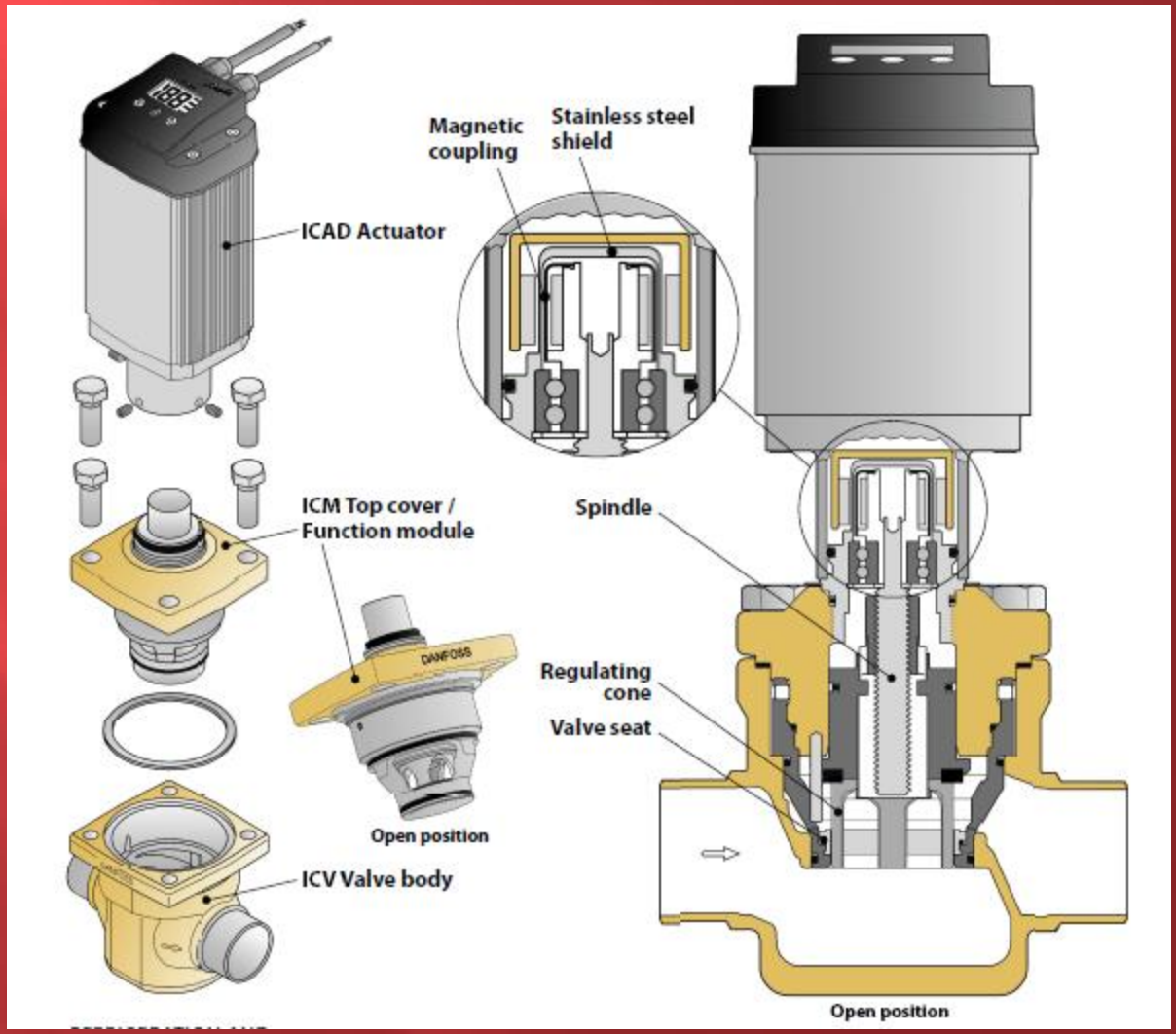
or

↓ Digital Output (relay contact)
To Open or Close Valve

↳ ICAD Motor drives internal screw drive to open or close valve
Through magnetic coupling

NOTE: Valve will respond as fast and as accurately as the control system requires. However, valve will only move as the control instructs it to move.

How Do Control Valves Work? Motorized Valves



The Basics Installation

- **Best Practices**
  - Pipe and valve body should be clean and dry prior to welding valve body into line
  - Weld body into line and paint weld region with a zinc-rich primer
  - Inspect module to ensure that piston moves smoothly and o-rings are in place
  - Lubricate o-rings with refrigerant grade oil
  - Insert module
  - Lubricate flat gasket and place in gasket containment groove on body
  - Immediately attach bonnet (with pilots installed) with bonnet bolts and torque to recommended specifications

The Basics
Installation

- **Best Practices - continued**
- If system will not be started up immediately, protect elements such as coil armatures and magnetic drive couplings
- Replace seal caps on manual stems
- Strainers are always recommended in order to prolong the life and performance of the control valve
- Painting the valve with an epoxy based paint will ensure long life; however, do not paint valve tags or other elements which provide information on the type, size, or function of the valve
- Confirm that valve size, type, and function match information on the P&ID

The Basics
Set-up

Set-up refers to the point at which the valve is installed, the system charged with refrigerant, and final adjustments need to be made. These adjustments could be:

- Pilot settings
- Motor programming
- Manual Overrides

The Basics
Set-up

Piloted Pressure Regulators – Setting up pilots

- Make sure that manual jacking stem is in "auto" mode.
- Perform a coarse adjustment of pilot once the system is charged.
- Install calibrated gauge valve in a location which will provide a true representation of the actual pressure.
- Adjust pilot per the manufacturers instructions until the desired pressure is reached. This will likely be an iterative process during start-up.

The Basics Maintenance

As a minimum, we want to follow IIAR Bulletin 110

Section 6.6.2 Control Valves

- Most automatic control valves have no external moving parts requiring maintenance; they shall be dismantled and overhauled when recommended by their manufacturer(s) or when found faulty in service or when tested
- Valves which are automatically controlled should be tested annually for correct function; this is often done by changing the setting of the controlling device and observing the response…
- Take precautionss to avoid hazard from pressure or residual ammonia when filters are opened or control valves dismantled. Liquid refrigerant may be trapped in assemblies which have become choked with dirt. Fastenings of covers shall only be loosened and not removed completely before unseating the seal or gasket to ensure that gas or liquid is not released in an uncontrolled manner.
- Leaking floats from defective float valves may contain a substantial quantity of liquid ammonia; there is a risk of bursting as temperature rises. Any floats found to contain liquid shall promptly be put in a safe place, for example by returning the float to its housing and continuing to vent the latter.

The Basics Maintenance

Why do we need to perform maintenance on control valves?

- Mechanical Integrity
- Process Integrity
- Energy Efficiency
- Functional Efficiency

Maintenance
Mechanical Integrity

The number one PSM citation issued under the Chemical National Emphasis Program is Mechanical Integrity (23.2%)

- There are many elements to Mechanical Integrity – all of which can lead to citations for failure to comply:

  MI Written Procedures
  MI Equipment Deficiencies
  MI Inspection and Testing
  MI Inspection and Testing Frequency
  MI Inspection and Testing Following RAGAGEP

- Do Control Valves fall under the scope of Mechanical Integrity? *

  To answer this we need to look at the consequences of loss of function:

  - If loss of function can lead to loss of ammonia, it belongs in the MI program
  - If loss of function = operational issue, it is a maintenance item but not part of the MI program

* Courtesy of the Industrial Refrigeration Consortium, University of Wisconsin

Maintenance
Mechanical Integrity

How can a failed control valve lead to potential ammonia releases?

- Failure of soft hot gas solenoid to open, can have catastrophic consequences when the main valve opens
- Failure of any control valve to open in order to drain liquid can lead to trapped liquid in the piping or the valve and result in excessively high pressures and, potentially, pipe rupture
- Failure of any control valve to open in order to transfer liquid from suction traps, or transfer drums can lead to dangerous conditions
- Failure of any packing gland in a manual jacking stem can lead to "nuisance" leaks which can, over time, lead to large losses of refrigerant

Maintenance
Mechanical Integrity

* Courtesy of the Industrial Refrigeration Consortium, University of Wisconsin

Maintenance Process Integrity

The purpose of the control valve is to - control!

- What do we want to control?
  - Room Temperature
  - Product Temperature
  - Room Humidity
- Poorly maintained control valves:
  - Do not function as designed, which can lead to loss of control over the critical characteristics of the product
  - Fail to maintain required room temperatures
  - When the control valve ceases to function properly, several results usually occur:
    - Process control is lost – usually leading to poor product quality or reduced production
    - The valve gets jacked open, suction pressure drops, and energy consumption goes up

Maintenance Energy Efficiency

A poorly maintained control valve will almost always have an impact on the energy consumption of the refrigeration system. Control valves which do not function properly usually lead to one of three actions:

- Ignore the consequences – i.e. take what you can get
  - Not typical as this leads to the aforementioned Process Integrity problems
- Bypass the control valve
  - Jack open the manual stem
  - Bypass around the control valve to a manual mode (e.g. hand expansion valve)
- Reset the control valve to a non-optimized setting
  - Drop the suction pressure to a level which ensures that room temperature will always be maintained
  - Feed higher liquid rates through electronic expansion valve and take more suction trap pump outs

Maintenance Functional Efficiency

There are numerous other consequences which can result from poorly maintained control valves:

- ❑ Valves which fail to activate or deactivate properly usually require manual intervention
- ❑ Valves which fail to hold or achieve desired set points will either lead to underperformance or will have to be adjusted manually
- ❑ System appearance which presents a lot of "red flags"

* Courtesy of the Industrial Refrigeration Consortium, University of Wisconsin

Maintenance Inspections

Types of Inspections

- **Routine Inspection** – Set by the organization based on some established, and defendable logic
- **Semi-annual Inspection** – typically covers critical isolation valves but should also be considered for control valves which fall under the MI Program
- **Annual Inspection** – A systematic inspection program conducted by internal staff or an outside resource
- **Five Year Maintenance and Inspection** – An independent inspection performed by someone other than the staff with direct responsibility for operations and maintenance

* Courtesy of the Industrial Refrigeration Consortium, University of Wisconsin

Maintenance
Visual Inspections

What are we going to look for with respect to control valves?

- ❑ Nuisance leaks
- ❑ Active Corrosion
- ❑ Ability to manually jack open valve
- ❑ Verify valve tag is present and correct
- ❑ Verify bolts and nuts are present and, at least, appear to be tightened fully
- ❑ Energize/De-energize solenoid to initiate state change and listen for audible indications of anything abnormal
- ❑ If equipped with a pilot light, verify that it is working
- ❑ Inspect electrical connections, cords, junction boxes for electrical integrity
- ❑ For piloted regulators, ensure that pilot can be adjusted for different pressure settings and check gauges for accuracy and calibration

* Courtesy of the Industrial Refrigeration Consortium, University of Wisconsin

Maintenance
Internal Inspections

Up to this point, we have focused on visual examinations and obvious performance issues

When is it necessary to open a control valve and inspect or rebuild the internals ?

- ❑ When the valve fails to function properly
  - Valve fails to maintain correct pressures
    - Pilot is plugged
    - Internal seals (o-rings) have failed
    - Piston is seized
- ❑ When the manufacturer recommends maintenance
  - This assumes that valve has been visually inspected routinely and no abnormalities have been observed
  - Are there any clues as to which valves are more likely to need rebuilding or replacement?

Maintenance
Internal Inspections

Control valves are designed and constructed with components which are expected move on a regular basis – moving components wear

- There are clues, however, which we can take advantage of in improving our ability to figure out which valves are more susceptible to wear
- The usual suspects:
  - Water
  - Solid Contaminants
- Scheduling service and inspection
  - 3 months following a new system start-up
  - Immediately prior to re-starting a system which has been idle for 6 months or more
  - Immediately prior to re-starting a system which has experienced a major component failure
  - Periodic inspection – adjusted according to plant conditions

Maintenance
Internal Inspections

Criteria – establish a point system

- Pulsations
- Plant pressures – above or below atmospheric pressure
- Strainers present and well maintained
- Single or Two-phase refrigerant?
- Idle times
- Water Content

Each criterion has a point value assigned to it

Add up the value of the first five criteria

The interval for recommended inspections will then be determined by the water level in the system

Overall, recommended inspection intervals will range from yearly in the most severe cases to once every 5 years

A Look At The Future

Where is the industry headed towards in the next decade?

Expect To See

- More packaged systems
- More use of CO_2
  - As a refrigerant
  - As a secondary (volatile) brine
- More DX Systems
- Much higher level of control in all phases
- Stainless Steel Piping
- Stainless Steel Valves
- Higher Design and Operating Pressures
- Lower Temperatures

Thank You

Questions?