ARC™ Technical Design Guide

Revision: 5/4/21

ARC™ Technical Design Guide

Table of Contents

Disclaimers:

1) Milwaukee Cylinder reserves the right to change the content of this document, including specs and information, without notice or prior obligation. We encourage users to go to the Milwaukee Cylinder website to get the latest version.

2) This information is presented as a guide only. It is important that you analyze all aspects of your application, including consequences of any failure. Due to the variety of operating conditions and applications, the user, through their own analysis and testing, is solely responsible for making the final selection of the products and systems and assuring that all safety, performance, and warning requirements of the application are met. Always test your system to validate performance. Manufacturing variances, hydraulic system differences, environment, etc. may cause differences with what is included in this document vs. your actual performance.

1. Discussion

The purpose of this document is to help explain how to use the ARC™ Technology in a customer's application.

ARC™ is applicable to our Series H family of hydraulic cylinders.

ARC™ Technology is a proprietary technology that recirculates oil through the piston when the cylinder reaches end-of-stroke. When not at the end-of-stroke, the recirculation flow path is closed, allowing the cylinder to achieve full power and speed.

ARC™ uses a cartridge that includes a set of opposing, near zero leak, poppet valves. One of the valves is always closed when at mid-stroke, activated by differential pressure. When end-of-stroke is reached on the selected side, the poppet valve is pushed open, allowing flow to bypass the piston, flushing the cylinder with clean, cool oil from the circuit's power unit.

ARC™ will generate heat, similar to heat generation over a relief valve. This document provides recommendations on how to use ARC™ effectively to achieve the desired benefit while managing heat generation.

2. Benefit Summary

See *Section 5.1: Removing Stagnant Oil from a Cylinder*
Removing stagnant oil from the cylinder can potentially extend cylinder life by 25% or more. ARC™ flushes the cylinder with clean, cool oil, every time the cylinder reaches the end-of-stroke, where ARC™ is installed, displacing stagnant oil with fresh oil from the power unit.

See *Section 5.2: Cooling Hot Running Cylinders*
Cooling for hot running cylinders can allow cylinders to operate successfully in higher temperature environments. ARC™ flushes the cylinder with cool oil, every time the cylinder reaches the end-of-stroke, where ARC™ is installed, displacing hot oil with cool oil from the power unit.

See *Section 5.3: Removing Air from the Cylinder and Circuit*
Removing air from the cylinder and circuit helps eliminate erratic cylinder performance. ARC™ provides a path for air trapped in the cylinder to be recirculated to the power unit where it can be safely removed.

3. Specifications

3.1. General Specifications

3.1.1. Activation Distance

ARC™ begins to activate when the piston is 3/16” from the end of stroke and fully activates once the piston reaches the end cap.

Note: ARC™ works on cushioned cylinders. However, if a stop tube is being used, ARC™ will not work on the side of the piston where the stop tube is being used (it will work on the side of the piston where there is no stop tube).

3.1.2. Mid Stroke Leakage

Though ARC™ is designed to limit leak-by when at mid-stroke, some leakage may occur. ARC™ uses a metal-to-metal sealing design to allow for long life with limited wear. ARC™ is designed to have an estimated mid-stroke leak rate 0.0009 GPM. Below is an example for reference.

Example: for a 4” bore cylinder, assuming a .0009 GPM leak rate equates to approximately 0.015” drift per minute.

3.2. Available Bore & Rod Combinations

ARC™ is available on the following bore and rod size combinations in the Series H family of hydraulic cylinders.

Bore ø (inches)	Rod ø (inches)
3.25	1.375
3.25	1.75
4	1.75
4	2
5	2
5	2.5
5	3
6	2.5
6	3

Bore ø (inches)	Rod ø (inches)
6	3.5
6	4
7	3
7	3.5
7	4
7	4.5
7	5
8	3.5
8	4

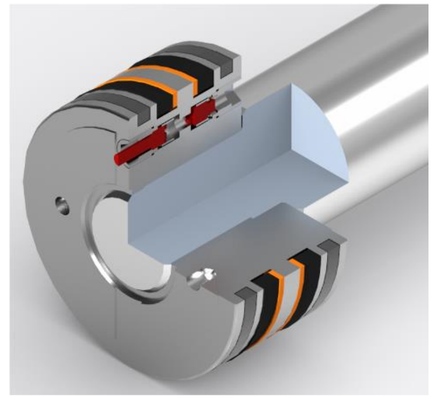
Bore ø (inches)	Rod ø (inches)
8	4.5
8	5
8	5.5
10	4.5
10	5
10	5.5
12	5.5
12	7

3.3. ARC™ Options

3.3.1. Flow Direction

ARC™ is available to allow flow through the blind (cap) end or rod (head) end.

On the end that is selected for recirculation, the poppet valve has a long stem that extends outside of the piston when the valve is seated. When the piston is 3/16” away from the end-of-stroke, the stem contacts the endcap, and the poppet valve begins pushing off its seat. This action allows oil to flow from the high-pressure side of the piston, through the ARC™ cartridge in the piston and out through the exit port of the end-cap. The opposing poppet valve has a shortened stem that does not extend outside of the piston. When end-of-stroke is reached on shortened stem side, the short stem does not contact the end cap at the end of stroke, and the poppet valve remains closed. This prevents recirculation on this side of the cylinder.



Blind End Shown

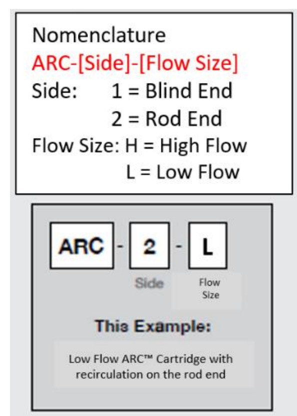
3.3.2. Flow Size

ARC™ is available in two standard flow sizes: High Flow and Low Flow

See *Section 4.1. Recirculation and Flow* for estimated flow rates. Other flow rates are available as custom. Flows will vary by environment and other application specific variables.

3.4. Ordering Part Number

When adding ARC™ Technology to a configured cylinder, include “S” for “special” in the configured cylinder model number (see page 32 of our catalog). Then, include the relevant “ARC-#-#” note in your inquiry using the chart shown.

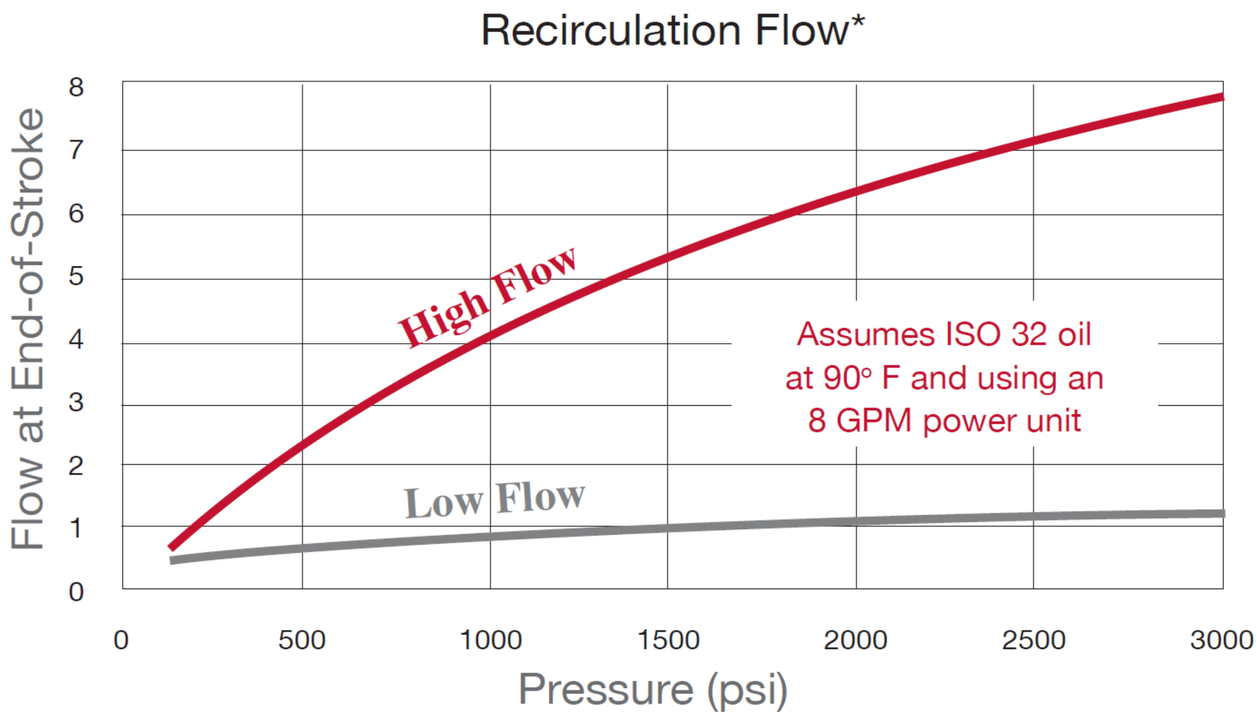


4. Design Considerations

4.1. Recirculation and Flow

4.1.1. Flow Chart

ARC™ Technology is offered in a high flow or low flow option. The below chart represents expected recirculation flow for each option based on operating pressure. Actual flow performance may vary, depending on application specific parameters (return line back pressure, fluid viscosity, temperature, power unit capacity, etc.). The below chart shows flow when no cushion is present.



*This chart is based on non-cushioned cylinders. Cushioned cylinders will have a reduced flow based on the cushion setting.

Example: Cylinder Recirculation Time

For this example, the customer has a cylinder in a warm environment and has determined the cylinder needs to recirculate once every 5 cycles. The cylinder being used includes a High Flow ARC™ option, has a 4" bore, with an 8" stroke, and operates at 2000 psi. How much time does ARC™ need to be activated per stroke to achieve recirculating the full volume in 5 cycles?

Variables and Assumptions:
Operating Pressure = 2000 psi
Flow Rate (F) [Estimated from Chart] = 6.4 GPM
Bore Diameter (D) = 4 in
Stroke Length (S) = 8 in
$V_{CYL\ MAX}$ = Max Cylinder Volume (in^3)
$R_{minutes}$ = Time for Oil to Recirculate (minutes)
R_{sec} = Time for Oil to Recirculate (seconds)

First step is finding the max volume of the cylinder and converting to gallons:

$$V_{CYL\ MAX} = 0.7854\ (D^2)(S)$$

$$V_{CYL\ MAX} = 0.7854\ (4in)^2(8in) = 101in^3 \rightarrow (101in^3)\ \frac{1\ gal}{231\ in^3} = .44gal$$

Using the max cylinder volume, divide by the flowrate to find how many minutes it would take for the cylinder to recirculate. Then convert to seconds:

$$\frac{V_{CYL\ MAX}\ (gal)}{F} = R_{minutes} \rightarrow R_{minutes}\left(\frac{60\ sec}{1\ min}\right) = R_{sec}$$

$$\frac{.44\ gal}{6.4\ GPM} = .069\ min \rightarrow .069\ min\left(\frac{60\ sec}{1\ min}\right) = 4.14\ sec$$

Using the recirculation time in seconds, divide by the number of cycles:

$$\frac{R_{sec}}{\#\ of\ cycles} = activation\ time\ per\ cycle \rightarrow \frac{4.14\ sec}{5\ cycles} = 0.83\ \frac{sec}{cycle}$$

Answer:
The ARC™ should be active for approximately 1 second once the cylinder reaches the end of stroke to recirculate the oil in the cylinder once every 5 cycles.

4.1.2. Controlling ARC™ Flow

When designing a system using ARC™ technology, the designer may want to increase or decrease ARC™ flow or adjust the time that ARC™ is activated. The below points discuss ways to control ARC™.

- First, select either the High Flow or Low Flow ARC™ option. For example, at a 3000 psi, the High Flow option will top out around 7.8 GPM and the Low Flow will reach about 1.3 GPM.
- Recirculation flow will start when the piston is within 3/16” from the end-of-stroke, on the active side of the ARC™ cartridge, as long as the pressure is higher on the side of the piston away from the end cap (i.e. flow is pushing the piston towards the end-cap).
- If within 3/16” on the activated ARC™ side, ARC™ recirculation flow will stop once flow stops being provided or once flow is provided in the opposite direction. Flow from the opposite direction pushes the long stem poppet back, seals the plug poppet, closing the flow path through the piston. In addition, once the piston is 3/16” away from the end cap the pin will no longer be in range to contact the end cap.
- Directional control valve response: The below assumes starting from recirculation and then moving to the center position of the valve.
  - Closed Center & Tandem Center:

        - When the valve is moved to closed center (or tandem center), recirculation will stop.
        - Movement -Once in the closed center (or tandem center) position:
            - If the external load is pushing toward the endcap where ARC™ is located, the piston will remain at the endcap, or move towards the endcap (if not there already).
            - If the external load is pushing away from the endcap where ARC™ is located, the piston may move to 3/16" away from the end-cap. At 3/16", ARC™ will close. With ARC™ closed, some drift will occur (designed at 0.009 GPM)
    - Float Center & Open Center
        - If the piston is held against the endcap where ARC™ is located, ARC™ will remain open, and depending upon the orientation of the cylinder, position of the cylinder in the circuit, and back pressure, limited recirculation may continue to occur.
        - If the external load is pushing/pulling away from the ARC™ endcap, the cylinder may drift in the direction of the load. Recirculation flow will be minimal.

- If a cushion is being used on the ARC™ side, this may vary or limit the flow depending on cylinder size and cushion setting. (*See Section 6.1. Cushions*).

    Note: When adjusting the cushion needle valve, always adjust when the cylinder is depressurized and never exceed two turns from fully closed.

- If position control is available, the controller can be used to control how often and how long the cylinder is at the end-of-stroke.
    - If the cylinder can be stopped prior to 3/16" from the end of stroke, this will prevent ARC™ from activating.
    - If the cylinder is positioned to within 3/16" of the ARC™ activated end-cap side, ARC™ will activate. The controller can be used to control the time ARC™ is activated.
- Depressurizing the cylinder will stop ARC™ recirculation, for example, by shutting off the power unit
- If a cylinder is to remain at end-of-stroke where ARC™ is installed for extended periods of time, it is recommended to depressurize or reduce the system pressure to the cylinder after the desired recirculation is achieved, to prevent excessive heat build-up.

4.2. Heat Generation

4.2.1. Figuring Out ARC™ Heat Generation

When the cylinder reaches end-of-stroke and ARC™ is activated, the oil flowing through the ARC™ cartridge will generate heat similar to flow passing through an orifice. The heat generated will cause a temperature increase to the oil and surrounding components. The amount of heat generated depends on pressure differential, flow, orifice size, and duration of ARC™ activation. *See Section 4.2.2 Heat Generation* for suggestions on managing heat generation.

Note: The power unit should be designed to appropriately dissipate the heat being generated. Contact Milwaukee Cylinder for power unit design considerations.

The below tables provide approximate flow and heat generation when the ARC™ is activated (i.e. at the end-of-stroke and fully pressurized) and there is no cushion.

High Flow Table			
Pressure (psi)	*Flow (GPM)	HP	BTU/HR
3000	7.8	13.65	34,772
2500	7.1	10.36	26,376
2000	6.4	7.47	19,021
1500	5.1	4.46	11,368
1000	4.1	2.39	6,093
500	2.1	0.61	1,560
*Estimated Flow from chart			

Low Flow Table			
Pressure (psi)	*Flow (GPM)	HP	BTU/HR
3000	1.3	2.19	5,572
2500	1.1	1.60	4,086
2000	1.0	1.17	2,972
1500	0.9	0.74	1,895
1000	0.8	0.44	1,114
500	0.6	0.16	409
*Estimated Flow from chart			

Note: Since ARC™ is only activated at the end-of-stroke, the values in the above tables need to be reduced to determine an "effective" heat generation for the cycle. See the examples below for how to calculate heat generated, from one activation, in a duty cycle, and values in between what is provided above.

<u>Example: Heat Generated from ARC™</u>

This example shows how to calculate BTU per hour, given in the tables, and determine the "effective" ARC™ heat generation. For this example, assume the pressure is 3000 psi and the flow through the ARC™ is 7.8 GPM and the ARC will be activated for 5 seconds.

First step is to calculate the horsepower:

$$HP = \frac{Pressure\ (psi) * ARC\ Flow\ (GPM)}{1714} => \frac{3000\ psi * 7.8\ GPM}{1714} = 13.65\ HP$$

Converting HP to a heat generation rate of BTU per hour:

$$\frac{BTU}{hr} = HP * 2547 => 13.65 * 2547 = 34{,}772\frac{BTU}{hr}$$

Now that BTU per hour has been calculated, the next step is to convert to BTU per second and then multiply by the ARC™ activation time.

$$\frac{BTU}{hr} * \frac{hr}{sec} * ARC\ Time(s) => 34{,}772\frac{BTU}{hr} * \frac{1\ hr}{3600\ sec} * 5\ sec = \ 48.3\ BTU$$

Example: Heat Generated from ARC™ Using a Duty Cycle

In the example below, the cylinder is using a Low Flow ARC™ and operating at 2500 psi. The ARC™ is activated for 10 seconds for every 2-minute cycle, and 30 cycles are run every hour.

Variables and Assumptions:
Low Flow ARC™ Cartridge
Operating Pressure = 2500 psi
$\frac{BTU}{hr}$ from Low Flow Table = 4,086 $\frac{BTU}{hr}$
Activation time per Cycle = ARC™ is active for 10 seconds out of every 2-minute cycle
Cycles per hour = 30 cycles an hour

First step is to convert the heat generation into seconds, then multiply by how long ARC™ is active per duty cycle.

$$\frac{BTU}{hr} * \frac{hr}{sec} * ARC\ Time(s) => 4{,}086\frac{BTU}{hr} * \frac{1\ hr}{3600\ sec} * 10\ sec = \ 11.35\ \frac{BTU}{Duty\ Cycle}$$

$$\frac{11.35\ BTU}{Duty\ Cycle} * \frac{30\ Cycles}{1\ hr} = 340.5\ \frac{BTU}{hr}$$

Example: Heat Generated from ARC™ for Pressures not Listed on Table

If the system pressure falls in between the pressure listed above, interpolation can be used to find flow at that pressure. Once pressure and flow are determined a BTU/hr. rate can be calculated.

Variables and Assumptions:
High Flow ARC™ Cartridge

Operating Pressure = 1750 psi
Duty Cycle = ARC™ is active for 10 seconds out of every 1 minute cycle
Cycles per Hour = 10 cycles an hour

<u>Interpolation Variables:</u>
System Pressure (x) = 1750psi
Lower Pressure (x_1) = 1500psi
Higher Pressure (x_2) = 2000psi
Flow @ x_1 (y_1) = 5.1 GPM
Flow @ x_2 (y_2)= 6.4 GPM
Flow @ x (y) = ?

Begin by using the interpolation equation:

$$y = y_1 + \frac{(y_2 - y_1)}{(x_2 - x_1)} * (x - x_1)$$

$$y = 5.1 + \frac{(6.4 - 5.1)}{(2000 - 1500)} * (1750 - 1500) => y = 5.1 + \frac{(1.3)}{(500)} * (250)$$

$$y = 5.75\ GPM$$

Once the flowrate is found, plug the pressure and flowrate into the horsepower equation:

$$HP = \frac{P(psi) * Q(GPM)}{1714} => \frac{1750\ psi\ * 5.75\ GPM}{1714} = 5.87\ HP$$

Then, convert to BTU per hour:

$$\frac{BTU}{hr} = 2547 * HP => 2547 * 5.87 = 14{,}951\ \frac{BTU}{hr}$$

Convert BTU per hour into seconds and multiply by the activation time per cycle:

$$\frac{BTU}{hr} * \frac{hr}{sec} * ARC\ Time(s) => 14{,}951\frac{BTU}{hr} * \frac{1\ hr}{3600\ sec} * 10\ sec = 41.53\ \frac{BTU}{Duty\ Cycle}$$

Finally multiply by the number of cycles:

$$\frac{41.53\ BTU}{Duty\ Cycle} * \frac{10\ Cycles}{1\ hr} = 415.3\ \frac{BTU}{hr}$$

4.2.2. Controlling Heat Generation

When ARC™ is activated, the oil flowing through the ARC™ cartridge will generate heat based on the pressure and flowrate through ARC™. ARC™ heat generation can be managed with the following methods:

- Deactivate ARC™ or reduce ARC™ flow once desired result is achieved (Cooling, Deaeration, Recirculation) – *See Section 4.1.2 Controlling ARC™ Flow*.
- When ARC™ is activated continuously, reduce pressure and/or flow, potentially using a proportional valve or kidney loop, to reduce heat generation while continuously recirculating.

5. Application Categories

5.1. Removing Stagnent Oil from a Cylinder

The issue with current cylinder setups, depending upon the hose length, oil from the power unit may never recirculate to the power unit. This means the oil in the cylinder becomes stagnant, which over time breaks down, reducing the life of the cylinder.

ARC™ Technology can be used to flush new oil from the power unit through the cylinder, replacing stagnant oil with fresh oil, extending the cylinder life by 25% or more.

For ARC™ to become "activated" (i.e. start recirculation), two conditions must be met.

1) Piston side where ARC™ recirculation was selected, reaches within 3/16" from the end of stroke
2) When flow and pressure are applied holding the piston against the end-cap.

When activated, ARC™ will allow oil to circulate from the power unit, to the cylinder, through the piston, and out the cylinder to the tank of the power unit. When ARC™ is away from the end-cap, ARC™ closes, ensuring no speed or load capacity is lost during mid stroke in either direction.

For example, if ARC™ is installed on the blind end cap side, and the hydraulic cylinder is being retracted, when the piston reaches end-of-stroke (initiates 3/16" away from the end-cap), ARC™ will begin recirculationg oil.

Note: If a differential pressue is not maintained across a piston (for example, if a 3 position valve is moved to the center position), ARC™ will not recirculate oil.

Note: Too much ARC™ flow unnessesarily adds heat to the oil flowing through the ARC™ cartridge, which would then typically have to be dissipated at the power unit. *See Section 4.2. Heat Generation.*

5.2. Cooling Hot Running Cylinders

ARC™ can be used for removing heat from a hot running cylinder. A hot running cylinder will reduce the cylinder's operating life. Oil and seal life decrease when at higher temperatures for extended amounts of time. For every 18 °F above 150 °F the oxidation rate of hydraulic fluid effectivley doubles. As an example, a system running at a consistent 168°F would effectivly lose 50% of the fluid's useful life.

When ARC™ is activated, cool, filtered oil will circulate into the cylinder, pushing hot stagnant oil out of the cylinder. The cylinder will continue to cool until the temperature of the cylinder stabilizes relative to the oil temperature coming from the power unit. Keep in mind, as the oil flows through the ARC™ cartridge, it will generate some excess heat energy in the fluid (*See Section 4.2. Heat Generation).* Once the desired cooling is achieved, it is recommended to secure the ARC™ recirculation flow, until the cylinder reaches an undesired temperature again. By securing the ARC™ recircirculation, the extra heat being generated by the pressure drop across the ARC™ will not have to be to be dissipated at the power unit.

Always make sure the power unit and its cooling system has enough capacity to handle the cooling action and resultant heat flow associated with ARC™ activation. See the example in *See Section 4.1. Recirculation and Flow* regarding ARC™ activation.

5.3. Removing Air from the Cylinder and Circuit

Air in a hydraulic system negatively affects the hydraulic system response due to the compressibility of air relative to hydraulic fluid. Negative affects include inconsitent velocity due to air decompressing (i.e. cylinder bounce, cylinder sponginess), foaming, and accelerated deteriation of the hydraulic fluid.

Prior to ARC™ Technology, since pistons by design prevent recirculation, air would get trapped in the cylinder. To eliminate the trapped air, this would require cracking fittings, while oil is flowing, to bleed the air out through the cracked fittings. With ARC™ Technology, air recirculates out of the cylinder to the power unit tank, where it is safely vented out of the hydraulic system.

ARC™ Technology works well to deaerate hydraulic systems at commissioning and through-out the life of the system. At commissioning, it is recommended to operate for a minute or two at the end-of-stroke with ARC™ activated. Once the hydraulic system is deaerated, ARC™ only needs to be activated periodically to burp any air that gets entrained in the hydraulics. The frequency of periodic activation depends upon the specific system. As initial guidance, activating ARC™ after restarting the hydraulic system is reccomended. As more experience is gained with the specific application, the ARC™ activation schedule should be reviewed and adjusted as necessary.

6. Cylinder Feature Compatability

6.1. Cushions

When ARC™ is used with cushioning, on the same side as the ARC™ activation, it can affect the flow and heat generation. Depending on the cushion setting, the flow allowed through the cushion needle may be less than the flow allowed through the ARC™. If the cushion restricts the flow, this will reduce the BTU/hr generated and increase the amount of time to completely recirculate the oil in the cylinder. If necessary, the flow can be measured across the ARC™, and using the system pressure, the BTU/hr can be calculated. *See 4.2.1. Example Heat Generated from ARC™.*

Note: When adjusting the cushion position, always depressurize the cylinder and then fully close the cushion needle valve by turning the needle valve clockwise until it stops. Then, turn cushion needle counterclockwise to desired setting.

Caution: Do not turn the cushion out past 2 full turns.

6.2. Stop Tubes

ARC™ cannot be used on the rod end with a stop tube. This is because the stop tube will interfere by blocking the poppet from extending.

6.3. Transducers and Proximity Switches

ARC™ is compatible with position transducers and proximity switches.

7. Circuit Comments

ARC™ can be used with circuits containing PO Check Valves, Counterbalance Valves, and Servo Control Valves.

Design considerations:

- ARC™ begins activation when within 3/16" from the end of stroke.
- If there is equal pressure on both sides of the piston, piston drift may occur.
- Caution should be used in load holding applications.
  - ARC™ is near zero leakage at mid-stroke, but some minor leakage is possible. Designers should plan for around 0.009 GPM leak. If zero drift is required,

ARC™ is not recommended, or an accumulator can be used to supply replacement fluid for leakage. Accumulator size will depend on cycle time.

- The end that ARC™ is recirculating through is intended to be sent directly to tank. If ARC™ is being used in a phasing situation or similar, careful consideration should be used to consider how the flow being allowed by the piston will affect the downstream hydraulic circuit.