LoadAdaptive™ & LoadMatch™ Cartridges

Introduction

Sun Hydraulics' patented LoadAdaptive™ and LoadMatch™ counterbalance valves use novel mechanical designs to allow for either variable pilot ratio in the LoadAdaptive or self-setting pressure in the LoadMatch. In LoadAdaptive valves, the pilot ratio adjusts as the situation dictates for both stability and energy savings; in LoadMatch valves, the pilot ratio is fixed, with the pressure setting adjusting once the load-induced pressure goes above approximately 2000 psi (138 bar).

For the LoadAdaptive, a low pilot ratio is enabled when required for stability. Higher pilot ratios are enabled when the actuator is not moving or is not in an area of the operating envelope prone to stability problems. The higher pilot ratio generally will consume less energy.

For LoadMatch, the valve senses the load-induced pressure and self-adjusts to a pressure that maintains the recommended approximate 1.3 multiplier over the load-induced pressure. This happens dynamically as the load-induced pressure changes with either changing load or changing machine geometry. This helps minimize system pressure from the inverse relationship with light loads and reduces the need for high system pressure. Lab tests and field studies have demonstrated 20-30% energy savings over standard load-holding circuits.

Counterbalance Valves Overview

Counterbalance valves are used in hydraulic circuits to avoid uncontrolled movements of cylinders and motors due to an overrunning or gravity-assisted load. They are often installed in the return (load-holding) line between the actuator and tank.

The counterbalance valve can be seen as a relief valve with a setting high enough to support the highest expected load pressure. Most counterbalance valves incorporate an additional pilot-assist function which further reduces the valve relief setting. The pilot ratio describes how much the counterbalance valve setting is reduced per increase in pilot pressure. For example, if the pilot ratio is 10 and a 10-bar pilot pressure is applied, the valve relief setting is reduced by 100 bar.

In most counterbalance valves, the selection of the pilot ratio is a compromise between stability (low pilot ratio) and efficiency (high pilot ratio). With LoadAdaptive and LoadMatch valves, the design reduces or eliminates the need for compromise in the valve setting.

For standard counterbalance valves, Sun Hydraulics recommends a setting of 1.3 multiplier to the maximum load-induced pressure or 1.5 multiplier when the maximum load-induced pressure is less than 2000 psi (138 bar). Because machines do not often operate at the maximum load-induced pressure, this results in wasted energy because of the inverse relationship between the load-induced pressure and the system pressure necessary to open the counterbalance valve. This is particularly wasteful when moving light loads on a machine designed for heavy loads.

The LoadMatch valve is a unique solution that self-adjusts dynamically to the load-induced pressure when the load-induced pressure is about 2000 psi (138 bar) or higher. The 1.3 multiplier is maintained. The valve will self-adjust up to the rated relief pressure although Sun recommends that the maximum load-induced pressure should be no more than approximately 75% of the rated relief pressure.

The proper selection of a counterbalance valve for fluid power circuits with overrunning (gravity-assisted) loads is important to ensure optimum system performance. In particular, the balance between energy efficiency and dynamic stability must be considered in detail.

Energy efficiency is particularly important for mobile equipment where cost of fuel is a consideration, and the pump and fuel tank size are limited. Many times, unfortunately, efficiency is compromised at the expense of stability due to the limitations of most commercially available counterbalance valves.

Technical Tip

Design Concepts, Features and Applications

LoadAdaptive™ Valves

Three-port non-vented — CE**

Sun's LoadAdaptive counterbalance valves are designed to provide both stability and energy efficiency in a single-valve solution. LoadAdaptive counterbalance valves may be used in place of a standard counterbalance valve in nearly any application. However, not all applications can take advantage of the LoadAdaptive functionality, in which case the valve will be less economical than standard counterbalance valves.

Sun recommends considering the use of LoadAdaptive valves when these situations exist:

- Overrunning or gravity-assisted loads
- When energy and fuel efficiency are important
- Where stable load control is important
- Where the machine lift-lower-lift duty cycle against gravity is repetitive and regular
- Where load pressures range from 500-4000 psi (35-280 bar)
- For pilot pressures less than ~2000 psi (140 bar)

If the machine does not experience repetitive lift-lower-lift duty cycles, there will be lower energy savings to capture, and the LoadAdaptive counterbalance will not be as economically efficient.

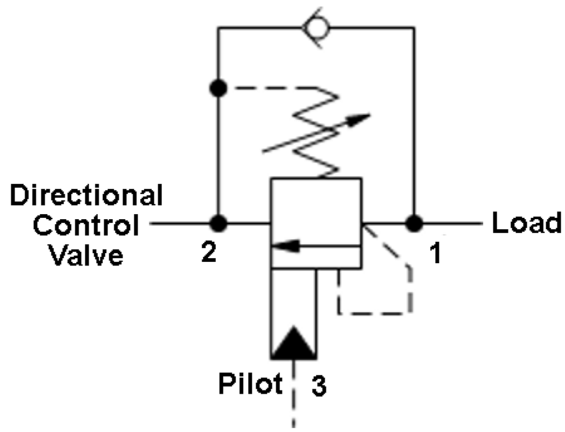


Figure 1
LoadAdaptive Valve Symbol

Why is a LoadAdaptive Valve Important?

The LoadAdaptive counterbalance valve is at its heart a counterbalance valve like any other. **Figure 1** shows the basic schematic symbol for this valve. Note it is the same symbol as any three-port, non-vented counterbalance valve.

So how does a LoadAdaptive valve differ from standard counterbalance valves? To answer this question we need to look at how types of counterbalance valves function.

Figure 2 shows a simple load-holding circuit where the counterbalance valve holds the suspended load in place against gravity.

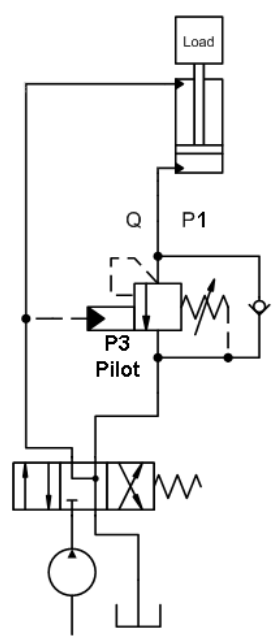


Figure 2
Simple Load-Holding Circuit

When the directional valve shifts to lower the load, pressure is applied to the rod side of the cylinder and to the counterbalance valve pilot (P3) simultaneously. The pilot pressure assists opening the counterbalance valve. Load pressure P1 is metered back to tank and the load is lowered.

To better understand how the counterbalance valve works, let's pull it out of the circuit and put it on a special test stand set-up to monitor the load and pilot pressures. **Figure 3** shows this test arrangement.

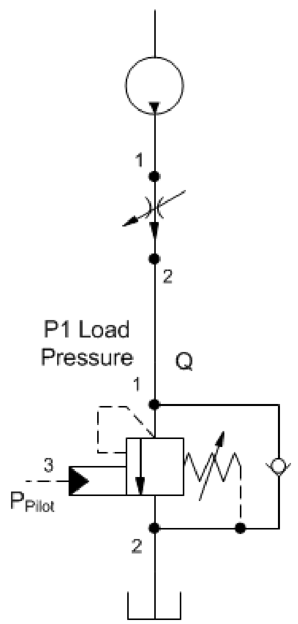


Figure 3
P1 v P3 Pilot Test Set-up

Note from **Figure 3** that:

- Pump flow is introduced at Port 1 and is limited to 5 gpm (20 L/min) maximum by a pressure-compensated flow control valve.
- Pilot pressure (Port 3) is gradually increased to reduce the valve's setting (open Port 1 to Port 2).
- P1 and P3 are measured and plotted per **Figure 4** for standard counterbalance valves with various pilot ratios.

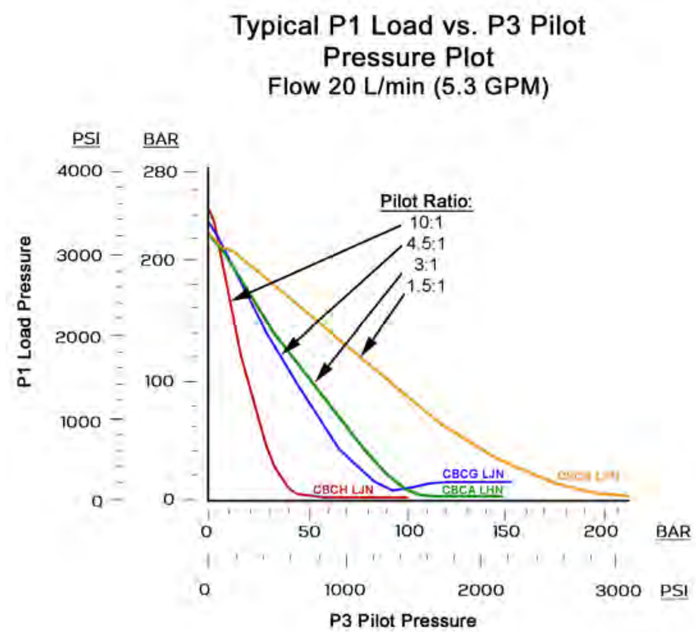


Figure 4
Typical P1 v P3 (Load v Pilot) Pressure Plot

Note from **Figure 4** that:

- Flow is limited to 5 gpm (20 L/min)
- At pilot pressure (P3) = 0, the valve is at its mechanical setting (spring preload only)
- As pilot pressure (P3) increases, load pressure (P1) decreases, and the physical load will be lowered or released as the counterbalance valve opens, ideally in a smooth and controlled manner.
- Higher pilot ratio valves require less pilot pressure to reduce load pressure.
- The slope of the lines approximates the pilot ratio — i.e., a 3:1 slope is approximately a 3:1 pilot ratio valve.

Curves to the left (higher pilot ratios) tend to improve energy efficiency while at the same time dynamic stability tends to decrease.

Figure 5 illustrates the potential power savings realized going from a 1.5:1 to a 10:1 pilot ratio. It is approximately the area under the shaded region as shown. This is the potential power saved for each lift-lower-lift cycle of the machine.

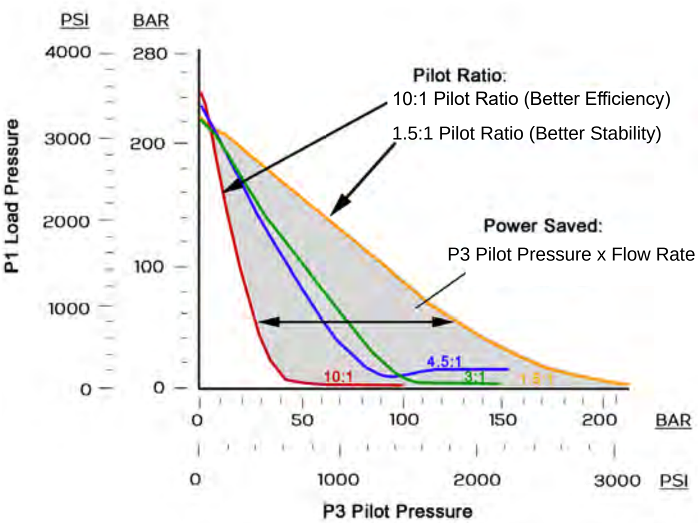


Figure 5
High vs Low Pilot Ratio Power

Remember this rule of thumb:

Hydraulic Power Consumption ~ Pressure x Flow Rate

Therefore, for a constant flow rate (5.3 gpm or 20 L/min in this case), if the pilot pressure (P3) required to lower the load is reduced by 25%, the total power consumed for that machine cycle will also be reduced by about 25%. Energy or fuel is saved.

Figures 4 and 5 address efficiency. Now let's examine the equally important topic of load stability.

Figure 6 shows three regions of cylinder control stability versus motion for a standard counterbalance valve for the simple circuit of **Figure 2.**

Region A shows a combination of load pressure P1 and pilot pressure P3 where the cylinder and load are not yet moving. The pilot pressure has not reduced the setting of the counterbalance valve to the point at which the valve can open and the cylinder can move (remember, counterbalance valves should be set at ~130% of the maximum load pressure). When the cylinder does not move, it cannot oscillate or go unstable. So a low-pilot-ratio counterbalance valve is not required in region A for stability.

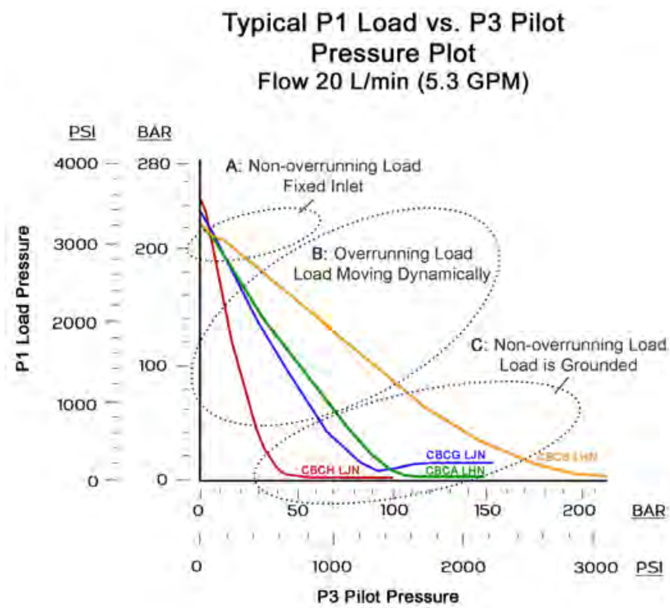


Figure 6
Load Stability Regions – Standard Counterbalance Valve

Region C shows a combination of load pressure P1 and pilot pressure P3 typical for non-overrunning positive loads. For example, if a winch is lowering a hook with no load attached to it, the required pilot pressure P3 can be very high while the load pressure P1 in the return line is low. This operating point (low load and full speed) also doesn't require a counterbalance valve with a low pilot ratio to maintain stability.

Region B, on the other hand, shows a combination of load pressure P1 and pilot pressure P3 for a typical overrunning load. In this region, the actuator is overrunning the pump and the resistance of the counterbalance valve due to gravitational force. This results in over-opening and closing the valve in a repeated, uncontrolled manner. Often referred to as counterbalance instability or chatter, this valve behavior may result in load oscillations and system instability.

High pilot ratios can exacerbate this phenomenon because relatively small changes in P3 can result in a relatively large counterbalance valve opening, reducing resistance and resulting in higher flow through the valve. This reduces P3 pressure, causing the valve to close until the pump flow catches up. P3 pressure increases to reopen the valve to restart the opening-closing cycle, creating unwanted oscillations. Therefore, lower pilot ratios may be needed in Region B to avoid instability.

An ideal solution to this dilemma would be high pilot ratios in Regions A and C for good energy efficiency plus a lower pilot ratio in region B for stability. Addressing that specific need was the goal of the LoadAdaptive counterbalance valve development effort.

How is a LoadAdaptive™ Counterbalance Valve Different?

The previous discussion applies to any type of counterbalance valve. Now that we understand the trade-offs between pilot ratio, efficiency and stability, what makes a LoadAdaptive counterbalance different?

Figure 7 shows P1 vs P3 for a LoadAdaptive counterbalance valve and shows the resulting pilot pressures required to move at 0.5 and 15 gpm (2 and 60 L/min) rates. The valve's relief setting is approximately 5000 psi (350 bar). The three stability regions of **Figure 6** are also noted in **Figure 7** for reference.

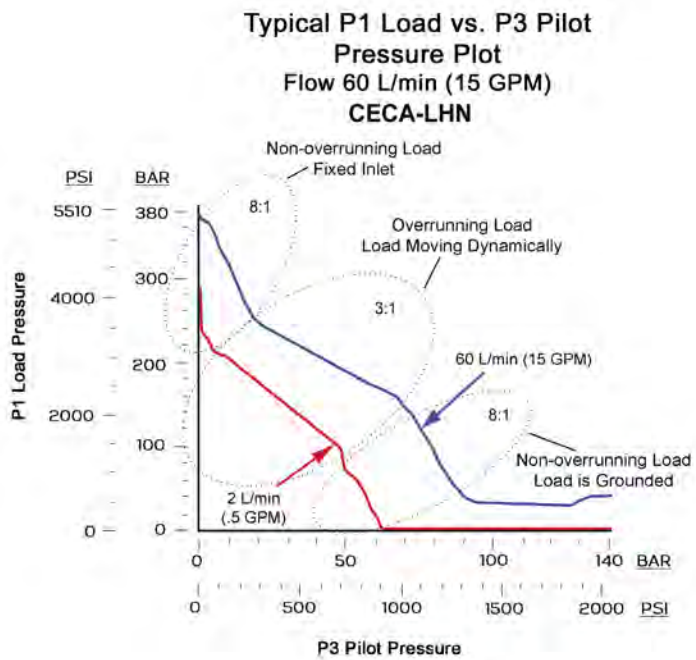


Figure 7
LoadAdaptive Stability Regions & Pilot Ratios

Contrast the curve shapes of Figure 7 against those shown in Figures 4-6. The LoadAdaptive counterbalance valves exhibit two distinct "knees" in the curve, indicating three distinct slopes and therefore three distinct effective pilot ratios. Figures 4-6 show just one slope and pilot ratio. The upper and lower portions of the curves have a pilot ratio of approximately 8:1 (better efficiency). The middle portions of the curves have a pilot ratio of approximately 3:1 (better stability). This curve shape results in an energy savings of approximately 30% with respect to the standard counterbalance valve as demonstrated by the following laboratory example.

The laboratory example in **Figure 8** below shows a winch lowering a cable with no load attached to the hook.

The pressures before and after the winch motor are equal (P3 = P1). Therefore, the pressures P1 and P3 on the counterbalance valve are also the same. The resulting pressures to move the motor can be measured on a test stand without an actual motor (neglecting friction and other losses in the motor and the attached gearbox).

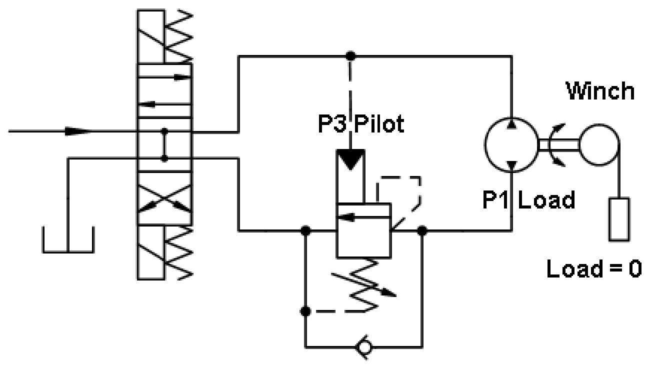


Figure 8
Winch Efficiency Example

Figure 9 below shows the resulting pressures vs flow for four different relief settings (4000, 3000, 2000 and 1000 psi or 280, 210, 140 and 70 bar) on a standard 3:1 ratio counterbalance valve.

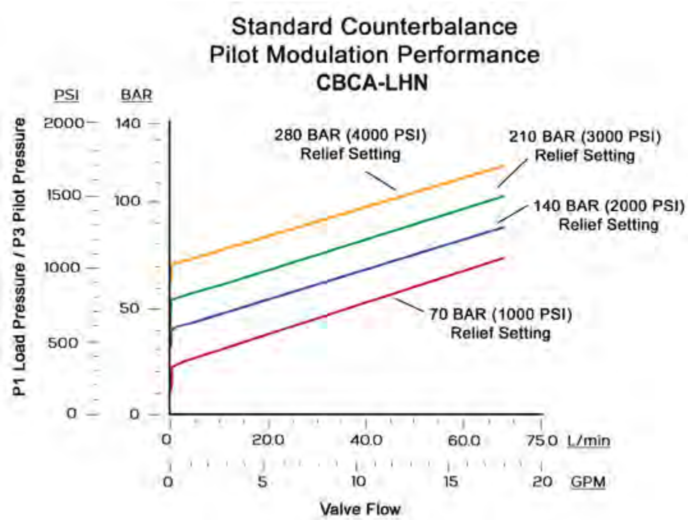


Figure 9
Standard Counterbalance Pilot Modulation Performance

Figure 10 shows the resulting pressures vs flow for the same four relief settings of a LoadAdaptive counterbalance valve for the winch in **Figure 8**.

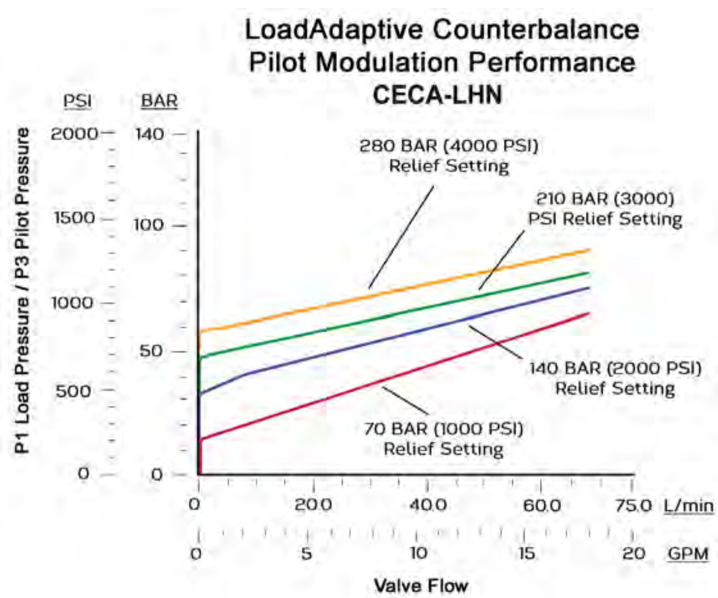


Figure 10
LoadAdaptive Pilot Modulation Performance

The standard 3:1 counterbalance valve with a 4000-psi (280-bar) relief setting requires about 1700 psi (120 bar) to be fully open at high flow (pilot pressure opens against the setting and flow forces). The LoadAdaptive valve is fully open by about 1300 psi (90 bar).

The LoadAdaptive counterbalance shows the resulting pressures required to open the valve are between 20% and 30% lower than for the same setting and flow through the standard counterbalance valve. Therefore, a power savings of 20% to 30% is realized.

Note that the LoadAdaptive valve gives no savings compared with a standard valve if a very high fixed pilot pressure is applied to fully open the valve. The high fixed pilot pressure will simply drive the valve wide open and overwhelm the energy-saving mechanism of the LoadAdaptive valve. Best energy savings will occur with pilot pressures of about 2000 psi (140 bar) and below.

LoadAdaptive Counterbalance Valve Construction

Figure 11 shows two valve cross sections. The upper cross section depicts a standard adjustable non-vented counterbalance valve. The lower cross section shows the LoadAdaptive version of the valve.

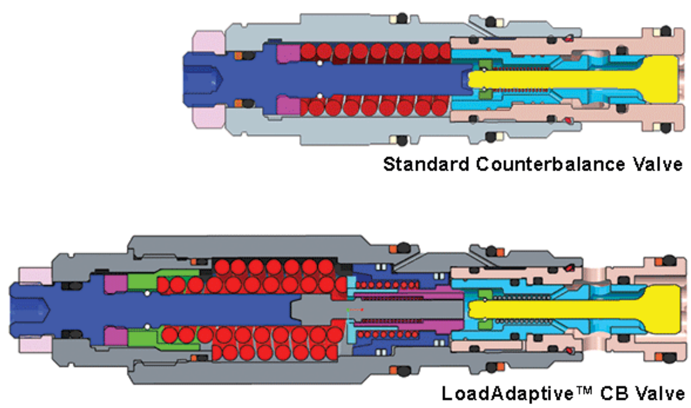


Figure 11
Typical Package Size Comparison

From the user's perspective, the operation for both is effectively the same. LoadAdaptive uses the same valve section as the standard valve. However, the LoadAdaptive actuator section assembly is very different, and that actuator construction is what creates the multiple effective pilot ratios.

The LoadAdaptive actuator accepts many different current production counterbalance valve sections. It also uses the same adjust mechanism. Therefore, many different counterbalance valves with pilot ratios between 0 and 10 and different nominal flows gains (standard, semi-restrictive, fully restrictive, super-restrictive) can be converted to a LoadAdaptive version of the valve.

After selecting the best possible standard counterbalance valve for the application (high efficiency and good stability), the valve can be replaced with a LoadAdaptive version to further improve efficiency. The energy savings are comparable to the most efficient standard valve that can be selected.

Additional Application Tips

Figure 12 below summarizes the preferred operating envelope for the LoadAdaptive CB based on the previous discussion.

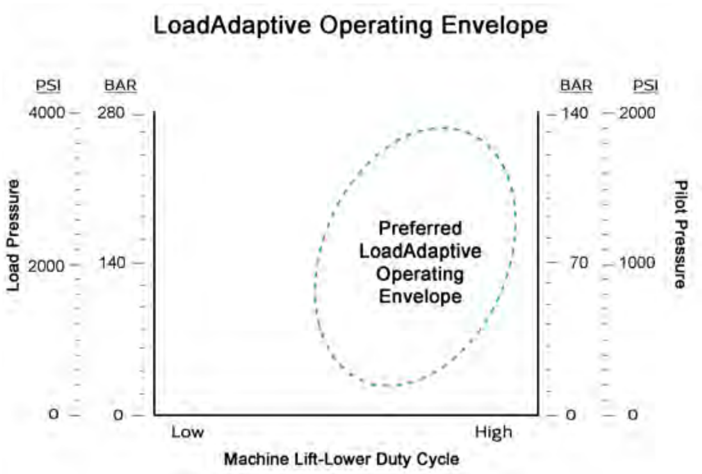


Figure 12
LoadAdaptive Operating Envelope

The LoadAdaptive counterbalance valve can be used as a standard non-vented counterbalance valve since the cavity and porting are identical.

But, as for all non-vented counterbalance valves, back pressure is additive to the setting of the counterbalance. In order to save energy, directional valves or proportional valves with low pressure drop in the return line are recommended. Backpressure can be avoided by adding an additional tank line for the counterbalance valve.

Although it is somewhat longer, the LoadAdaptive valve diameter is a standard size so it still can replace existing standard counterbalance valves in many applications both functionally and physically.

Design Concepts, Features and Applications

LoadMatch™ Valves

Three-Port non-vented, three-port atmospheric vent, and four-port vented — MB*P, MA*P and MW*P

The LoadMatch valve is a solution unique to Sun that self-adjusts to maintain the 1.3 multiplier when the load-induced pressure is 2000 psi (138 bar) or higher. The valve will self-adjust up to the rated relief pressure although Sun recommends that the maximum load-induced pressure should be no more than approximately 75% of the rated relief pressure. Below a 2000-psi (138-bar) load-induced pressure, the valve basically maintains a fixed setting of about 2000 psi.

Why is a LoadMatch Valve Important?

Like LoadAdaptive, the LoadMatch counterbalance valve is a counterbalance valve in many ways just like any other. The LoadMatch valve is based upon the 3:1 pilot ratio load-reactive load control valve. It has the same excellent modulating characteristics and hydraulic dampening that provide stable load control. Like the other load-reactive load control valves, the LoadMatch offers full flow relief protection, but it should be considered as thermal relief for relatively slow over-pressure events.

The unique feature of the LoadMatch is that it is self-setting to approximately 1200 psi (83 bar) above the load-induced pressure. This pressure offset approximates the setting of 1.3 times maximum load-induced pressure. This happens dynamically and automatically as the load-induced pressure changes as long as the load-induced pressure is above 2000 psi (138 bar).

The benefit of this dynamic setting is the energy savings when moving light loads that require high pilot pressure because of the low load-induced pressure. Reducing the effect of the inverse relationship between low load-induced pressure and high pilot pressure is how the LoadMatch saves energy. Additional benefits in the design of the LoadMatch is that there is no adjustment mechanism that can be tampered with. LoadMatch valves are selected by comparing the maximum load-induced pressure to the factory relief setting offered. The maximum system working pressure should be no more than 75% of the relief setting.

A detailed functional symbol is shown below in **Figure 13**. The valve has a minimum pressure of approximately 2000 psi (138 bar). The driver senses the load-induced pressure through internal checks that cause the driver to stroke to further pre-load the major springs in the valve that set the relief pressure. This sets the load-holding pressure. Orifices dampen the discharge of oil from the valve driver, ensuring that the load-holding pressure is not inadvertently dropping off due to pulsations in the hydraulic pressure. The simplified symbol of a standard counterbalance can be used in place of the detailed symbol to avoid confusion over the primary function of the valve.

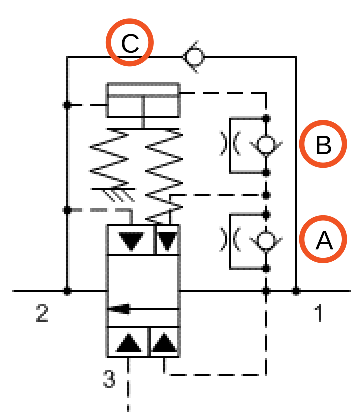


Figure 13
Detailed LoadMatch symbol

The LoadMatch is hydraulically dampened. Oil from the load port, port 1, flows into the spring chamber. As shown in **Figure 14**, the dampening collar at position A acts to slow the opening of the valve while not restricting the closing of the valve. The orifice at position B does not restrict the setting tube C from increasing the setting but slows the setting reducing. As the setting tube strokes toward the right, the setting increases. As the load-induced pressure changes the setting will increase with increasing pressure and decrease with decreasing pressure. The setting tube does not become active until about 2000 psi (137 bar). The maximum pressure is established by the setting tube being fully shifted.

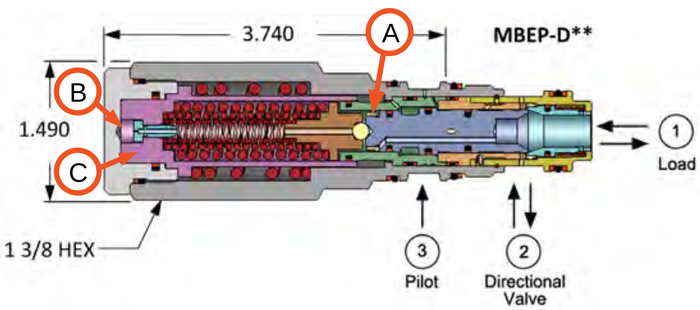


Figure 14
LoadMatch model MBEP-D**

Because there is no field settings possible, other means must be considered during the machine design if a manual load release is desired. The LoadMatch offers little benefit for low load pressures where the maximum load-induced pressure does not exceed 2000 psi (138 bar). It might not be suitable in paired actuators if individual valves are used for load holding in the individual actuators. The pilot-open pressures may not be matched closely enough, for example, to prevent binding of rigidly connected cylinders or motors.

Once the load pressure exceeds about 2000 psi (137 bar), the LoadMatch actuator becomes active. With the actuator active, the pilot pressure required to modulate flow for different load pressures is virtually the same. The following lab curve in **Figure 15** shows this.

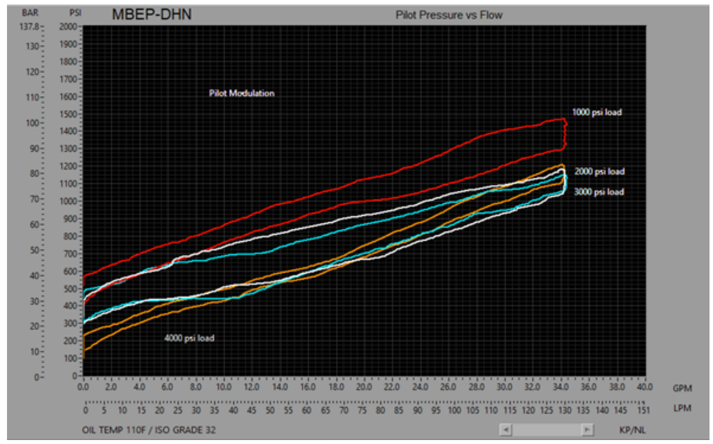


Figure 15
Lab curve showing pilot modulation for active and inactive LoadMatch driver

Many factors can affect energy savings, including duty cycle, back pressure, small load variation, flow rates, the overall circuit design, and others. Savings are difficult to predict, and simply substituting a LoadMatch might not produce the desired energy savings. The complete circuit must be considered with efficiency in mind. LoadMatch are not magic bullets. An unstable application might not be fixed by using a LoadMatch.

LoadMatch are available in Series 1 and 2 sizes. Three-port non-vented, three-port atmospheric-vented, and four-port vented versions are available. The four-port vented valve should be used in new designs.

In both the three-port atmospheric and four-port vented valves, approximately one drop will form in the chamber that is vented for every 4000 cycles of the valve. Given the long stroke of the valve, it is possible that an unacceptable amount of oil will be ejected from the atmospheric vent as the vent chamber accumulates oil. Three-port non-vented LoadMatch valves are sensitive to back pressure. Back pressure adds to the setting of the valve at 2x the back pressure. The vented versions of the LoadMatch like vented counterbalance valves are insensitive to back pressure. The four-port vented LoadMatch should have the vent port (4) connected immediately downstream of the source of back pressure. Atmospheric vented LoadMatch like counterbalance valves are sensitive to external contamination at the vent port. Care must be taken in the machine design to minimize the possibilities of contamination.

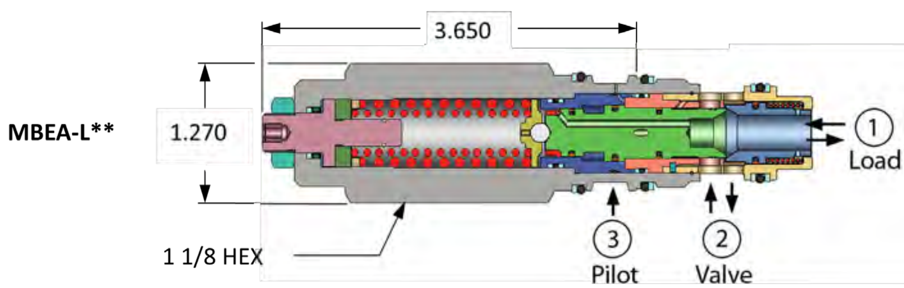
The LoadMatch valves are physically larger than M-valves. There must be space around the manifold where the LoadMatch is mounted to accommodate the Series 1 longer hex bodies and the Series 2 larger hex size and hex body diameter.

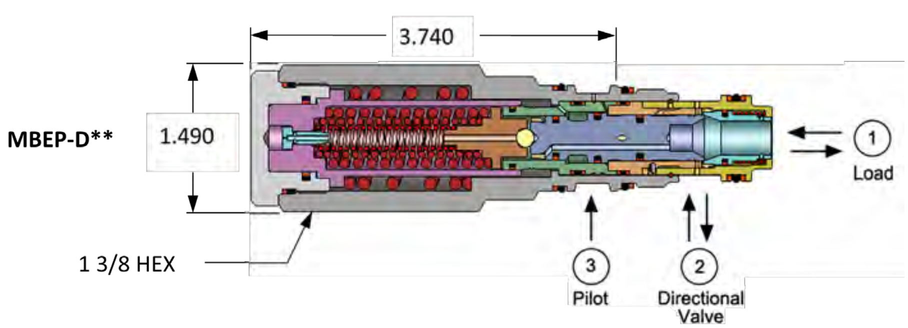
LoadMatch characteristics:

- Low leakage on closing. Specification maximum leakage is 5 drops/minute (0,4 mL/minute) at 77% setting on reseat
- Dynamic pressure setting for load-induced pressures from 2000 psi (138 bar) to the published maximum relief setting
- Low relief mode hysteresis over a wide flow range
- Flow capacities to 60 gpm (460 L/min)
- 25 psi (1,7 bar) check valve spring standard with no different check spring options available
- Pilot area is sealed
- Internally hydraulic dampened
- No adjust screw—no adjustment needs to be made

Physical Differences

When considering the LoadMatch valve whether in a new design or a retrofit, the physical size must be considered. Series 2 has a 1-3/8-inch hex size and is longer. Therefore, the cartridge will extend further from the locating shoulder and likely out of the manifold it is mounted in. Valves with larger hex bodies are still torqued to the same value for the cavity size.





LoadMatch™ Case Study

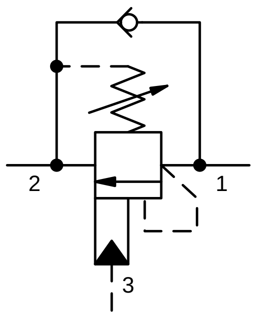
LoadMatch is particularly well suited for highly repetitive tasks. One case study performed on a mobile gantry crane that is typically used for example in ports and rail yards to move shipping containers found that approximately 1 US Gallon (3.8 L) of fuel was saved per hour of operation. Based on an eight-hour workday, five days per week it is estimated that the fuel savings amounts to $105 (based on $2.30/ US gallon fuel cost) per week or $5454 savings per year. The return on the investment of upgrading to the LoadMatch valve can have a very short payback period. Savings will vary and are dependent on circuit design and machine usage.

Fuel Consumption Data						
Valve Type	Relief Setting (PSI)	Lift Cycles Run	Test Duration (min)	Fuel Consumption (Gallons)	Fuel Consumption per Hour (GPH)	Fuel Consumption per Lift (GPL)
CAEL-LGN	5000	15	62	5.6	5.4	0.4
MAEP-DJN	5000	15	60	4.4	4.4	0.3

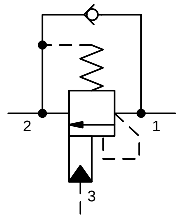
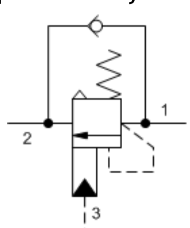
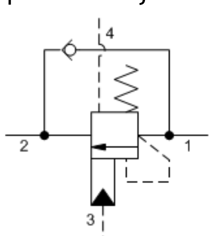
Fuel Savings with LoadMatch™					
Gallons per Hour Saved	Dollars per Hour Saved	% Savings per Hour	Gallons per Lift Saved	Dollars Saved per Lift	% Savings per Lift
1.0	$2.30	19	0.08	$0.18	21
Based on an assumed price of $2.30 USD/US gallon.					

Contact your local authorized Sun distributor if you have specific application questions.

LOADADAPTIVE VALVES

SYMBOL	CHARACTERISTIC	SERIES 1	PILOT RATIO
3-port non-vented		T-11A	
		15 gpm 60 L/min)	
	Standard	CECA	3:1
		10 gpm (40 L/min)	
	Semi-Restrictive	CEBC	3:1
		5 gpm (20 L/min)	
	Restrictive	CEBA	3:1

LOADMATCH VALVES

SYMBOL	CHARACTERISTIC	SERIES 1	SERIES 2	PILOT RATIO
		T-11A	T-2A	
3-port non-vented 		15 gpm (60 L/min)	30 gpm (120 L/min)	
	Standard	MBDP	MBEP	3.1
3-port non-adjustable 		15 gpm (60 L/min)	30 gpm (120 L/min)	
	Atmospherically Referenced	MAEP	MADP	3.1
		T-21A	T-22A	
4-port non-adjustable 		15 gpm (60 L/min)	30 gpm (120 L/min)	
	Vented	MWDP	MWEP	3.1

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