LoadAdaptive™ Counterbalance Valves

Technical Tip

Introduction

Sun Hydraulics' patent-pending LoadAdaptive™ counterbalance valves use a novel mechanical design to allow variable pilot ratios and pressures while maintaining load motion stability. 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 will generally consume less energy.

Energy efficiency testing shows the new valve allows the same or faster cylinder/motor speed with pilot pressures that are on average 30% less than a standard counterbalance while still maintaining excellent load stability.

CECA LoadAdaptive Counterbalance — **CBCA** Standard Counterbalance

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 setting of the CB valve 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.

The selection of the pilot ratio is a compromise between stability (low pilot ratio) and efficiency (high pilot ratio).

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. Many times, unfortunately, efficiency is compromised at the expense of stability due to the limited options of the counterbalance valves commercially available for the installation.

Energy efficiency is particularly important for mobile equipment where cost of fuel is a consideration and the pump and fuel tank size are limited.

Sun's "LoadAdaptive" counterbalance valve is designed to provide both stability and energy efficiency in a single valve solution.

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Application Guidelines

The LoadAdaptive counterbalance valve may be used in place of a standard counterbalance valve in nearly any application. However, not all applications will make use of the extra functionality, which makes the LoadAdaptive counterbalance valve less economical than the less expensive standard CB valves. Therefore, the following general guidelines apply.

Use LoadAdaptive counterbalance valves for these types of situations:

- 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 minimum load pressures exceed 500 psi (35 bar)
- Where maximum load pressures do not exceed 4000 psi (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 useful.

See the last page of this Tech Tip for additional application information.

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 CB valve.

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

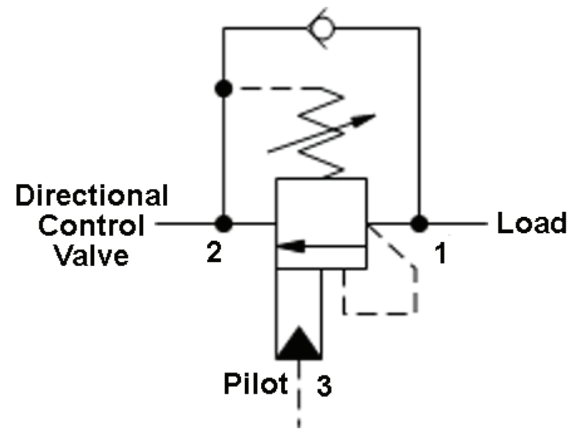

Figure 1
LoadAdaptive Valve Symbol

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

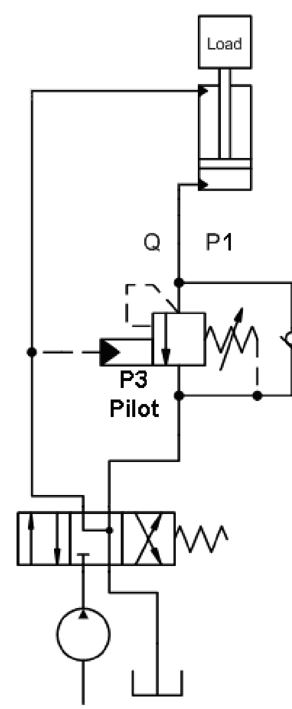

Figure 2
Simple Load-Holding Circuit

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 CB 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.

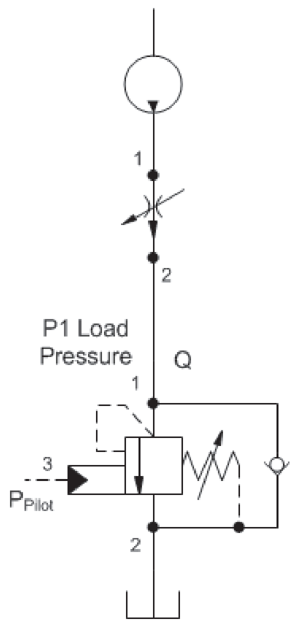

Figure 3
P1 v P3 Pilot Test Set-up

Note from **Figure 3** that:

- Pump flow is introduced at Port 1 and is limited to 20 L/min (5 gpm) 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 CB valves with various pilot ratios.

Typical P1 Load vs. P3 Pilot Pressure Plot
Flow 20 L/min (5.3 GPM)

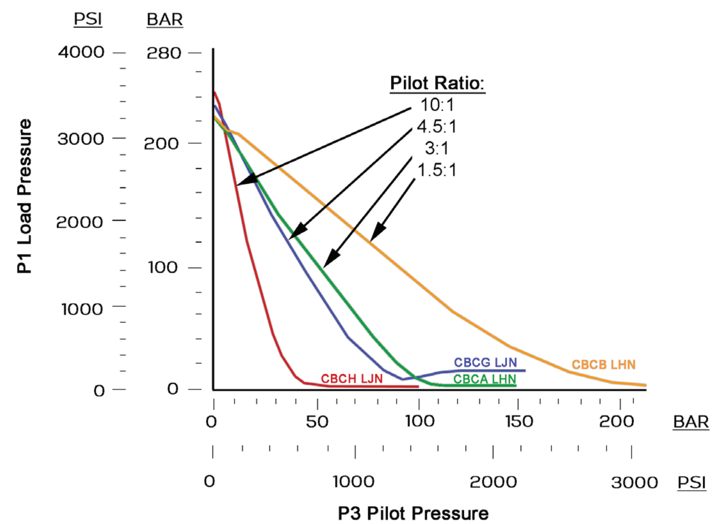

Figure 4
Typical P1 v P3 (Load v Pilot) Pressure Plot

Note from **Figure 4** that:

- Flow is limited to 20 L/min (5 gpm)
- 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.

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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.

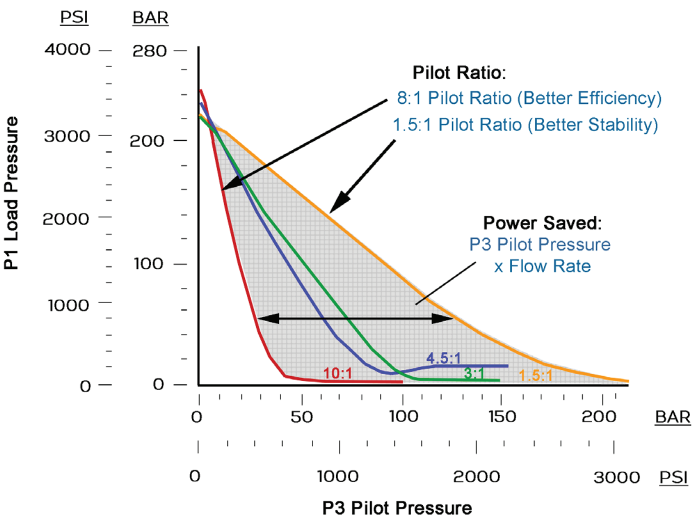

Figure 5
High vs Low Pilot Ratio Power

Recall that...

Hydraulic Power Consumption ~ Pressure x Flow Rate

Therefore, for a constant flow rate (20 L/min or 5.3 gpm 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%. Hence, 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.

Typical P1 Load vs. P3 Pilot Pressure Plot
Flow 20 L/min (5.3 GPM)

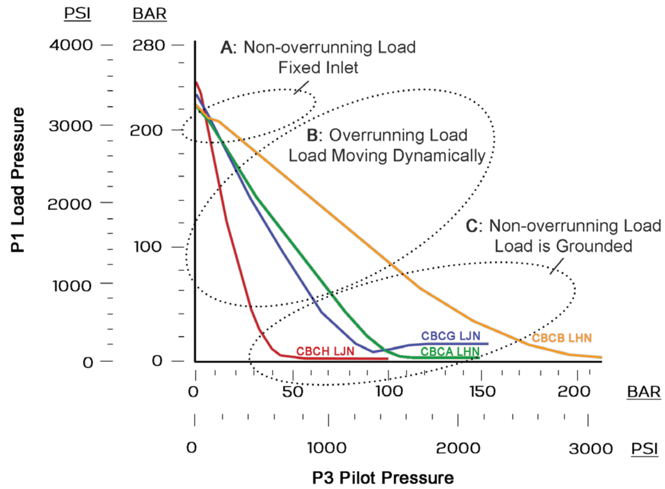

Figure 6
Load Stability Regions – Standard CB Valve

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. Hence the need for the LoadAdaptive counterbalance valve which provides this very functionality.

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How is a LoadAdaptive Counterbalance Valve Different?

The above 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 CB 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.

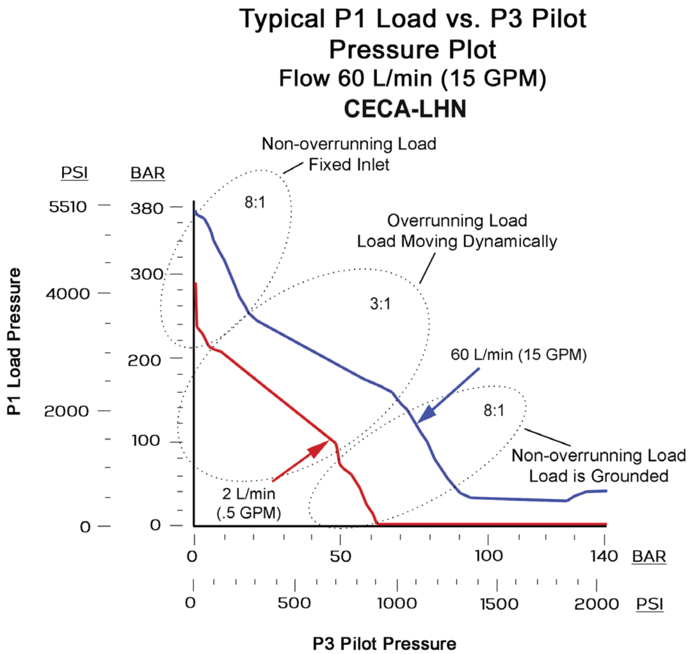

Figure 7
LoadAdaptive Stability Regions & Pilot Ratios

Contrast the curve shapes of **Figure 7** against those shown in **Figures 4-6.** The LoadAdaptive CB 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.

Figure 8 shows a winch lowering a cable with no load attached to the hook.

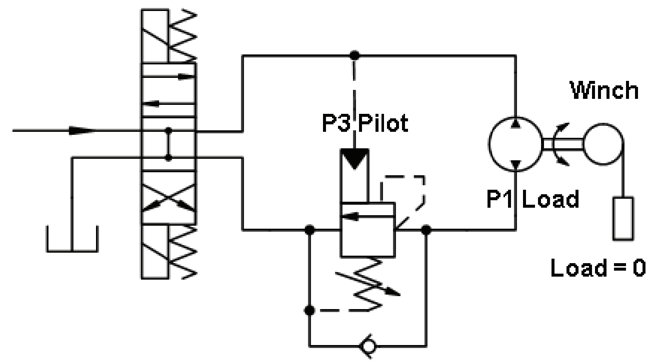

Figure 8
Winch Efficiency Example

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

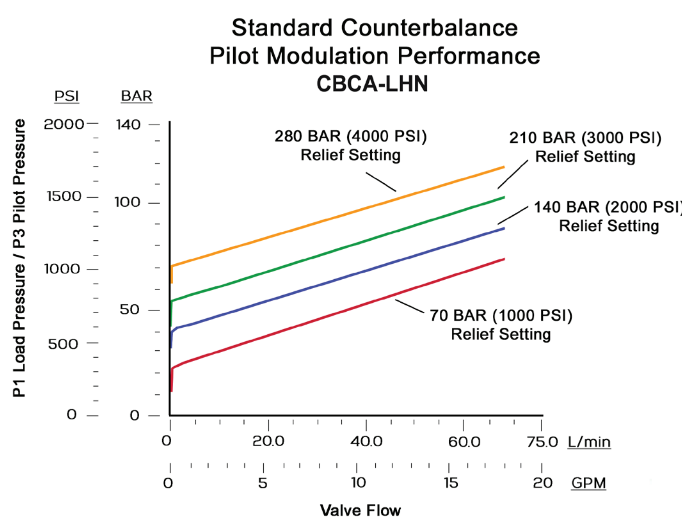

Figure 9
Standard Counterbalance Pilot Modulation Performance

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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**.

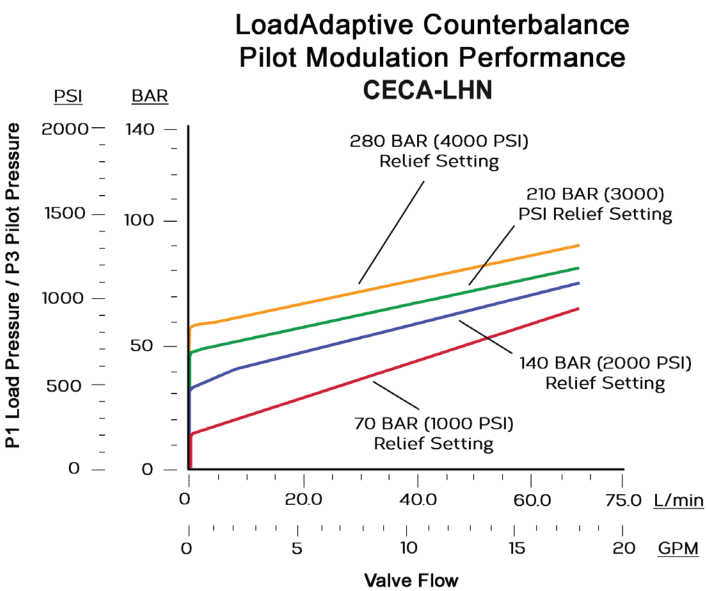

Figure 10
LoadAdaptive Pilot Modulation Performance

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 results 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.

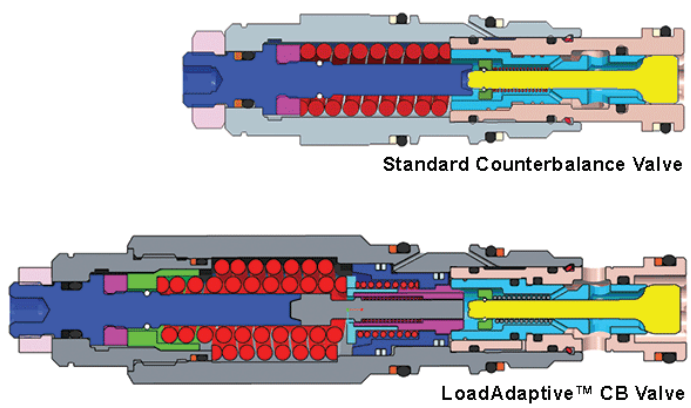

Figure 11
Typical Package Size Comparison

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 quite 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. So the energy savings are in comparison with the most efficient standard valve that can be selected.

Additional Application Tips

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

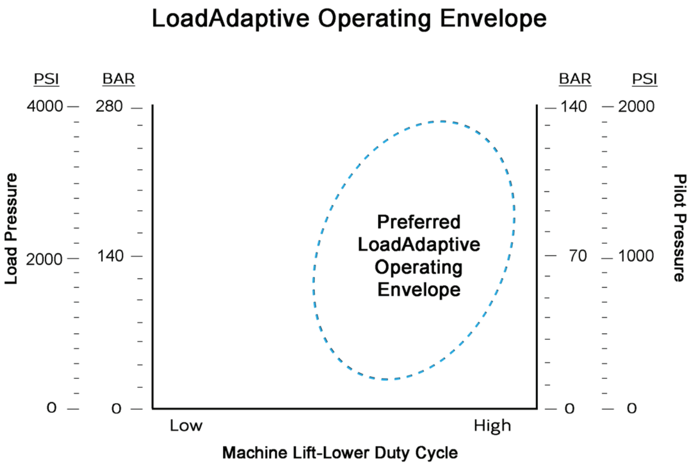

Figure 12
LoadAdaptive Operating Envelope

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.

Although not all configurations may be currently released, Figure 13 shows the planned Series 1 LoadAdaptive combinations. A selection of Series 2 valves is also planned. Sun will consider other configurations and series sizes that make commercial sense.

Contact your local authorized Sun distributor if you have specific application questions or would like to place an order.

As always, Sun Hydraulics would like to know about your application of this product so we may better assist you in the future.

REFERENCE

See our Technical Tip “Counterbalance and Pilot-to-Open Check” (link below). Many of the suggestions included in this Tech Tip are also applicable to the LoadAdaptive counterbalance valve.

http://www.sunhydraulics.com/sites/default/files/media_library/tech_resources/TT_US_Ctrbal_POCk.pdf

Series 1 LoadAdaptive™ Counterbalance Valve Product Matrix			
Adaptive Pilot Ratio	Flow Gain		
	Standard	Semi Restrictive	Restrictive
1.5:1 or 5:1	CECB	CEBB	Not Available
2:1 or 6:1	CECY	Not Available	CEBY
2.3:1 or 7:1	CECL	CEBL	Not Available
3:1 or 8:1	CECA	CEBC	CEBA
4.5:1 or 10:1	CECG	CEBD	CEBG
10:1 or 20:1	CECH	Not Available	Not Available

Figure 13
Product Matrix

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