Design a safer machine with Eaton overcenter valves

Testing demonstrates superior performance of Eaton valves

Increase machine stability, efficiency and operator comfort with Eaton overcenter valves

When it comes to selecting a load-holding valve, one factor outweighs all others: safety. Given the valve's role of holding a load—or personnel—in the air, instability is unacceptable. While judder is an all-too-common occurrence on machines such as telehandlers and aerial work platforms, it doesn't have to be. Eaton's overcenter valves can eliminate judder, resulting in a safer, more stable machine. They also eliminate valve noise, which increases operator comfort, and reduce pressure drop to improve system efficiency.

To prove the superior performance of its overcenter valves compared to a leading competitor's offerings, Eaton conducted a series of laboratory and field tests. Lab testing was conducted on standard and specialty overcenter valves, such as two-stage, part-balanced and vented valves. The lab testing compared flow and pressure to get a performance benchmark. In field testing, the competitor's load reactive, semi-restrictive and vented valves were replaced with Eaton two-stage and part-balanced valves on a telehandler. The field tests compared performance in terms of oscillation and noise.

Figure 1: Overcenter valves play a key role in safely holding loads or personnel in position.

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A tale of two architectures: direct-acting valves vs. differential-area valves

To understand why Eaton valves outperform competing valves, it's important to understand the differences in valve architecture. Eaton's standard overcenter valves are direct-acting instead of differential-area valves, as shown in figure 2.

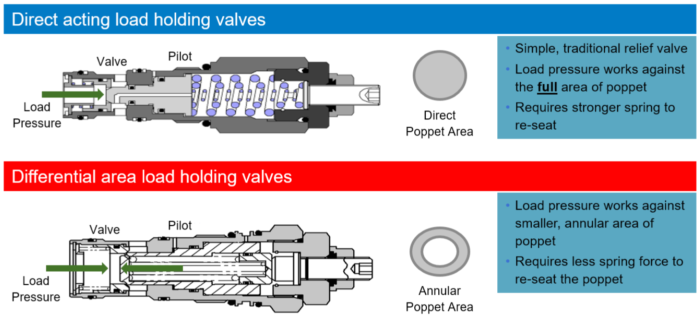

Figure 2: Eaton's standard overcenter valves are direct-acting valves, instead of differential area valves.

With direct-acting valves, the pressure from the actuator is applied directly on the full area of the poppet. With differential-area valves, the force is applied to a smaller area, the annular area of the poppet. Differential-area valves can employ lighter springs than direct-acting valves, as the pressure is acting on a smaller area. However, this means the flow through the valve can change rapidly with very little change in pilot pressure or load pressure. Variations in pilot or load pressure will cause these valves to overreact, leading to instability.

Overcenter valves are pilot operated, meaning the valve is opened by the inlet pressure assisted by the pilot pressure. The inlet pressure affects the pressure at which the valve opens, but the actual opening of the valve is controlled by the pilot pressure.

How two-stage valves address the telehandler problem

In addition to direct-acting valves, Eaton also offers two-stage overcenter valves. The two-stage valve was developed to address a common yet considerable issue on machines with long, unstable booms, the best example being telescopic handlers.

A telescopic boom usually has a long cylinder that acts as a capacitor when fully extended. The pressure rises to system pressure at the end of stroke, and the nature of the overcenter valve re-seat locks that pressure in the cylinder, regardless of the load-induced pressure. When the operator lowers the load, this stored energy gives the overcenter valve the message that a heavy load is on the boom, so less pressure is needed to open the valve. The valve subsequently opens very quickly and allows the stored energy to dissipate, causing a momentary runaway condition. This prompts the valve to react and battle to bring the load under control, resulting in boom oscillation. The number of jerks will depend on the stiffness of the system at the time of lowering; the instability can sometimes continue through the entire cylinder stroke. This judder can cause loss of load, posing a significant safety risk.

Valve instability can be further understood by examining the two ways an overcenter valve can open. The first instance is if the load on port 1 (the valve port) exceeds the spring setting, and the valve functions as a relief valve. The second instance occurs if a load is placed on the valve and pilot pressure is applied to another port. The force created by the pilot pressure is amplified due to the larger pilot area compared to the area at port 1, referred to as the pilot ratio. If a large load is present on port 1, a lower pilot pressure is needed at port 3 (the pilot port) to open the valve. Once the valve is open, the pilot pressure on port 3 falls rapidly and the valve closes. The valve quickly cuts off the oil flowing to the tank via port 2, and pressure from the trapped oil builds on port 1. The pilot pressure then rises quickly, opening the valve. This instability continues until the load equalizes with the pilot pressure and the system is able to operate smoothly.

To mitigate instability, machine designers typically specify a valve with a lower pilot ratio. This requires more pilot pressure to open the valve, which reduces oscillation. While a lower pilot ratio can be effective in reducing oscillation, it requires more energy to open the valve than one with a higher pilot ratio.

Another option is to use a two-stage valve, which has two pilot ratios. The valve operates in the same way as the standard valve until the pilot pressure drops in a runaway condition. The poppet will then close more quickly, creating a counterbalance pressure to prevent rapid acceleration of the load, thus eliminating the instability.

Eaton's two-stage overcenter valve maintains a counterbalance pressure momentarily when the valve is opening. This prevents total decay of the stored energy in the cylinder, preventing the valve from overreacting. The valve allows the pressure to fall to the counterbalance setting, which can be adjusted depending on the severity of the system. This back pressure can also help to stiffen the boom during its movement further through its stroke when wear pads on the box sections of the boom create a changing frictional force. With a primary pilot ratio of 4:1 and a secondary ratio of 0.5:1, the initial unloading of the stored pressure happens at a low pilot pressure, followed by a more gentle reduction as the pilot pressure increases. The overall setting of the valve is a combination of the outer and the inner spring forces divided by the seat area.

Field testing shows Eaton valves eliminate oscillation and noise

Field testing was conducted in August 2018 to measure valve performance in actual operating conditions. A telehandler with an 8,000-pound (3629 kg) lift capacity, as shown in figure 3, was used to test the performance of Eaton and competitive valves in terms of oscillation and noise.

Figure 3: A telehandler was used to test valves under typical operating conditions.

For the oscillation tests, the machine was instrumented with string potentiometers on the extend and lift cylinders. Pressure gauges were placed on the manifold from the control valve to the overcenter valve to monitor the lift, extend and tilt functions. The gauges were placed on both the base and rod side of the cylinder. An inertial measurement unit (IMU) sensor was placed at the end of the boom to measure movement.

From judder to stable

To compare the performance of Eaton and competitive valves in terms of oscillation, and to determine the conditions in which oscillation occurs and those in which it is most pronounced, a series of tests was conducted:

- Test 1: Up-down (raising then lowering the boom while the telehandler is stationary)
- Test 2: Up-retract-down (raising, retracting then lowering the boom while the telehandler is stationary)
- Test 3: Obstacle course (raising and lowering the boom while driving the telehandler over a series of wooden planks)

Test 1: Up-down

The up-down testing was performed at three engine speeds:

- 1,040 RPM (idle)
- 1,500 RPM
- 2,300 RPM

Tests were performed with the telehandler's forks both loaded and unloaded. The load was a 1,000-pound (453 kg) weight. The test procedure was:

1. Starting from neutral, raise the boom from the ground to maximum height at full command. Hold at maximum height for 2 seconds.
2. Lower the boom at full command. Release the joystick when the boom is on the ground.

The up-down testing showed the Eaton valves handled boom movement with less oscillation than the competing valves. As shown in figure 4, the boom experienced two spikes in acceleration with both the Eaton and the competitor valves: one when the boom reaches its maximum height, and one when the boom is commanded down. The main difference occurs after the second spike, when the boom outfitted with the competing valves continued to produce significant fluctuations in acceleration, indicating instability and oscillation of the machine.

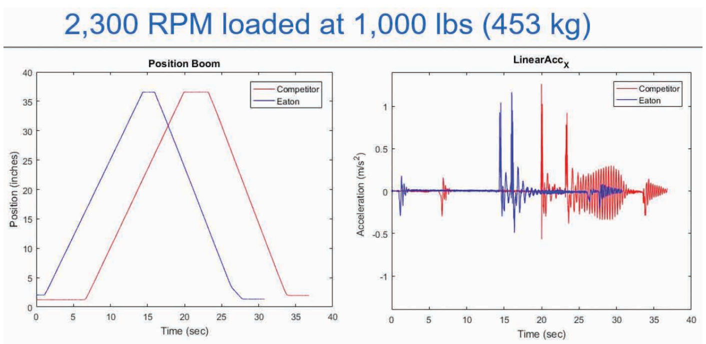

Figure 4: When outfitted with Eaton valves, the boom exhibited less oscillation and more stability in up-down testing.

The instability seen in the competitive valve is most pronounced at 1,040 RPM with the forks loaded; results at 1,500 RPM showed similar performance between the valves, as shown in figure 5. Differences are also apparent at all speeds with the forks unloaded.

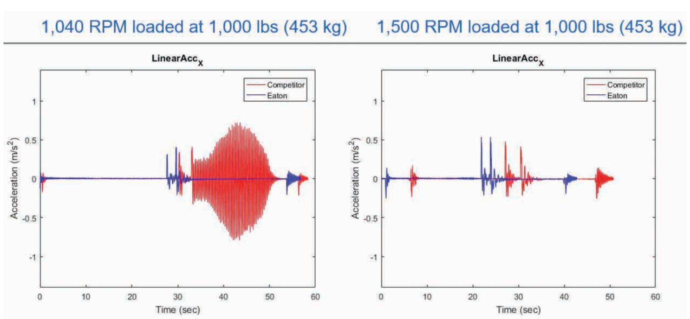

Figure 5: Oscillation differences were most pronounced at engine idle.

Pressure data also provide a strong indicator of valve performance. Figures 6 and 7 show how system pressure can be dampened with the proper valve. In the pressure boom tilt down graph in figure 7, oscillation can be observed that resonates through the system, causing greater instability of the load on the forks. The reduced pressure fluctuations in the Eaton valves indicate less oscillation and greater stability.

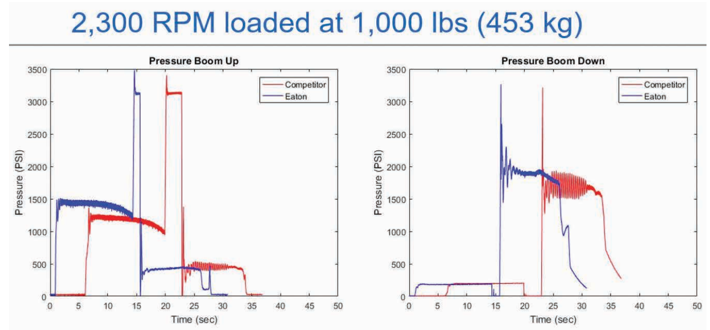

Figure 6: Pressure fluctuations within the valves also indicate instability.

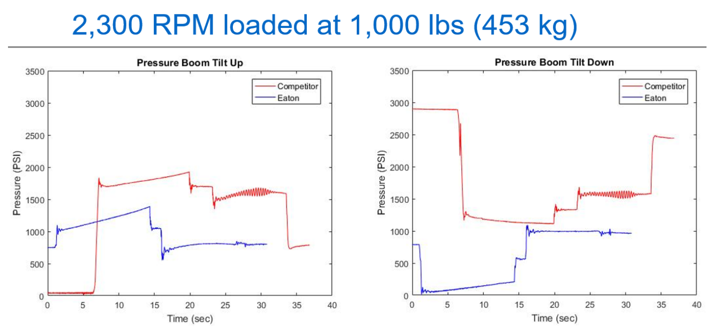

Figure 7: Pressure fluctuations observed in the pressure boom tilt down function show how oscillation can resonate through the system.

Test 2: Up-retract-down

Like the up-down test, the up-retract-down test was performed at three engine speeds: 1,040 RPM, 1,500 RPM, and 2,300 RPM. Tests were performed with the telehandler's forks both loaded and unloaded. The load was a 1,000-pound (453 kg) weight. The test procedure was:

1. Starting from neutral, raise the boom from the ground to maximum height at full command. Hold at maximum height for 2 seconds.
2. Retract the boom at full command. Hold for 2 seconds.
3. Lower the boom at full command. Release the joystick when the boom is on the ground.

Again, considerable stability differences were observed. The effect is significant at all three engine speeds when loaded. When unloaded, the effect is highest at engine idle, but still present at 1,500 and 2,300 RPM. As shown in figures 8 through 11, acceleration and pressure data indicated more stability with the Eaton valves.

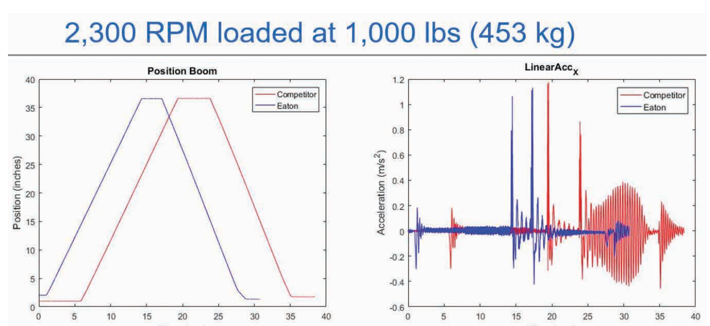

Figure 8: Up-retract-down testing indicated greater boom stability with Eaton valves.

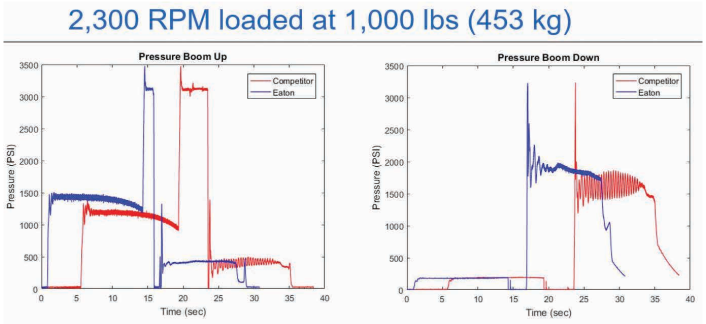

Figure 9: Pressure fluctuations within the valves during the up-retract-down test also indicate instability.

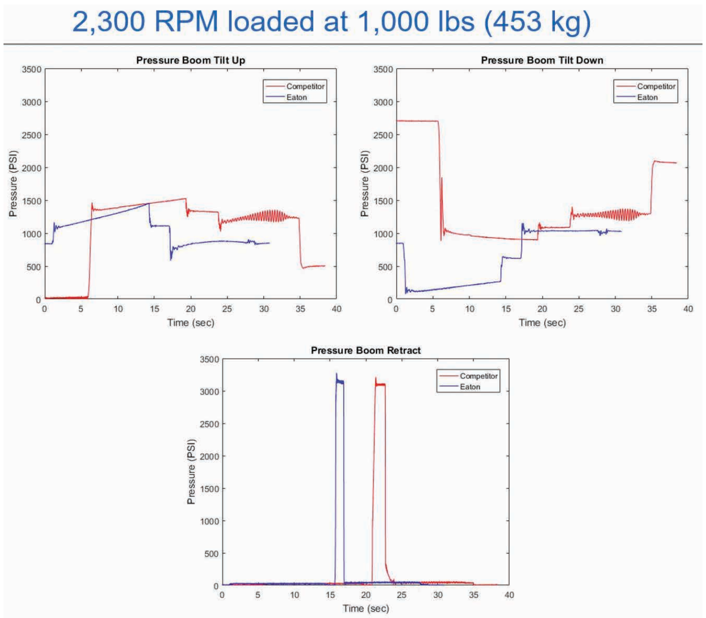

Figure 10: Pressure fluctuations observed in the up-retract-down test show how oscillation can resonate through the system.

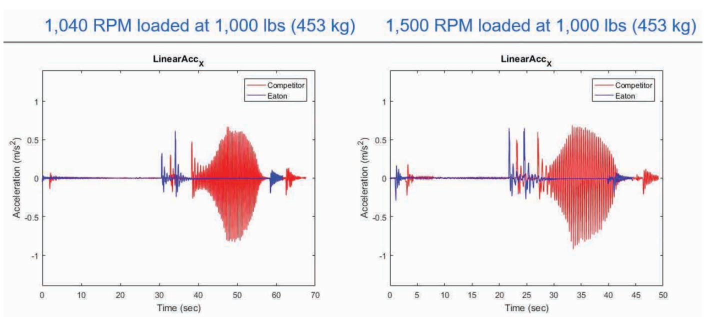

Figure 11: Oscillation differences were significant at both 1,040 RPM and 1,500 RPM with the forks loaded in the up-retract-down test.

Test 3: Obstacle course

In the obstacle course testing, stability was monitored as the boom was raised and lowered while driving the telehandler. The test was performed at three boom extension positions:

- Fully retracted
- Extended to 5 feet (1.5 m)
- Extended to 12 feet (3.6 m)

A series of 1-inch by 4-inch by 10-foot (25 mm by 101 mm by 3 m) wooden boards were spaced evenly to provide obstacles. The telehandler was driven over the boards in first gear with the engine speed at 2,300 RPM. The forks of the telehandler were not loaded.

The test procedure was:

1. Begin driving and raising the boom.
2. Upon crossing the first board, lower the boom and continue driving.
3. Upon crossing the second board, raise the boom and continue driving.
4. Repeat the lower-raise cycle until all boards have been crossed.

As shown in figures 12 and 13, Eaton valves consistently showed less pressure fluctuation as the boom was raised and lowered. The further the boom was extended, the greater the oscillation and the more pronounced the effect is with the competitive valve.

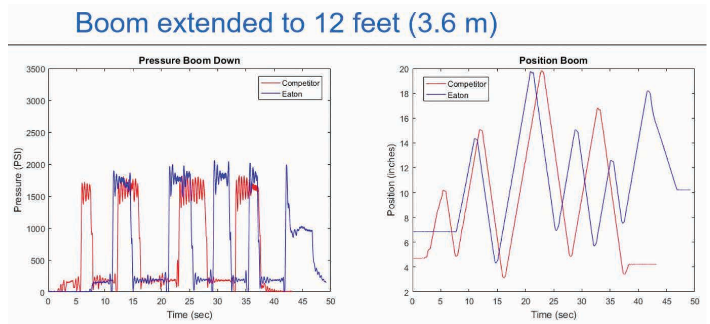

Figure 12: Eaton valves showed less pressure fluctuation as the boom was raised and lowered.

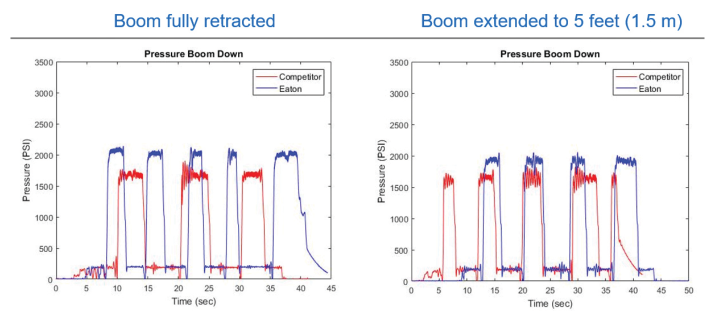

Figure 13: Eaton valves showed less pressure fluctuation as the boom was raised and lowered.

Pilot pressure ramp testing

Laboratory testing provides an explanation as to the differences in stability. Eaton standard valves and competitive valves were subjected to a pilot pressure ramp test. While the valves tested were not those used on the telehandler in field testing, the data can explain why the oscillations are seen in the field. The test procedure was:

1. Set the system relief valve (RV) to slightly above the rated pressure for the overcenter valve.
2. Set the overcenter valve screw set to its minimum pressure setting.
3. Set the flow at 15.8 gal/min (60 L/min) at the inlet, and ramp the RV1 pressure from 0 to 3,045 psi (0 to 210 bar) over 30 seconds, then back to 0 over 30 seconds.

The test was repeated with low, high and maximum pressure settings on the overcenter valve. A schematic of the testing is shown in figure 14.

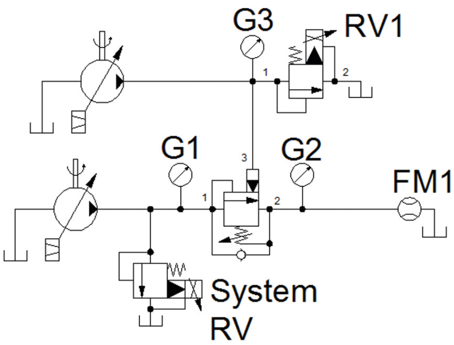

Figure 14: Schematic of pilot pressure ramp testing.

As pilot pressure increases, the overcenter valve gradually opens, allowing more flow. When pilot pressure decreases, the valve gradually closes, so flow drops. Thus, the desired outcome is a banana-shaped flow curve.

The results of the pilot pressure ramp test are shown in figure 15. On the competitor valve graphs, the flow curves cross, showing that the flow could be rising or falling as pilot pressure increases; the same phenomenon occurs when pilot pressure decreases. This means that as pilot pressure fluctuates, the valve is not certain if it should open or close. This uncertainty in valve response, with large variations in flow rate out of the valve, is what results in machine oscillation. The Eaton valve has smoother flow-vs-pressure curves and reduced hysteresis, indicating the valve opens and closes as expected. This results in greater machine stability in the field.

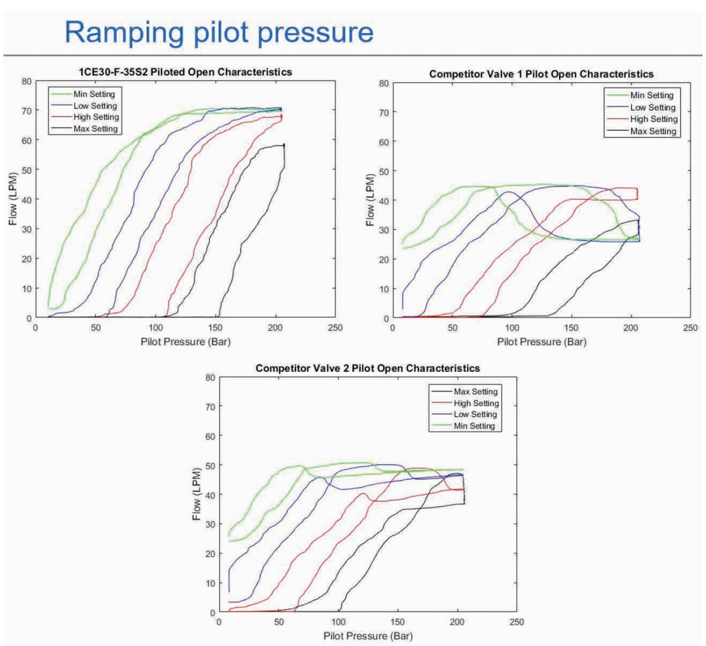

Figure 15: In pilot pressure ramp testing, Eaton flow-vs-pressure curves were smoother than those of competitive valves, indicating greater stability.

Additional testing and findings

Two additional field tests were conducted with the telehandler:

- Test 4: Boom extend-retract (fully extending then fully retracting the boom while the telehandler is stationary)
- Test 5: Tilt cycle (tilting forks fully up, fully down then back to level while the telehandler is stationary)

These tests were conducted to determine if the machine will succumb to oscillation in stationary boom extend-retract functions and fork tilt functions, as it does in boom up-down functions. The telehandler did not exhibit visible instability in either of these tests, and quantitative data show the performance of the competitive valves was equivalent to Eaton valves.

During testing, engineers discovered that the tilt function on the telehandler utilizes an atmospherically vented overcenter valve to eliminate back pressure effects. Use of atmospherically vented valves can lead to long-term contamination. The Eaton part-balanced overcenter valve eliminates back pressure effects without being vented to atmosphere, and should be considered for vehicle applications like this.

Conclusions

Field testing established three boom up-down situations in which competitive valves exhibit instability, resulting in machine oscillation:

1. Raising and lowering the boom from a stationary position
2. Raising, retracting then lowering the boom from a stationary position
3. Raising and lowering the boom while driving

In comparison to competitive valves, Eaton part-balanced and two-stage valves offer increased stability, eliminating machine oscillation.

From screech to quiet

Excess noise during machine operation can adversely affect comfort of the operator and those working nearby. For some brands of overcenter valves, squealing is a known issue. Like oscillation, however, this isn't the case for all brands.

Noise testing was conducted in August 2018 on the same rented telehandler as was used for the oscillation tests. To determine the difference in noise levels between Eaton valves and the competitor's valve, a ½-inch (12.7 mm) CCP free-field microphone was located 39.5 inches (1 m) to the rear of the overcenter valve in the rod side of the extend cylinder, and 86.5 inches (2.2 m) above ground. The test procedure was:

1. Starting with the boom fully retracted, dead-head the retract.
2. Return joystick to neutral.

A total of 12 runs were recorded with the Eaton valve and 12 with the competing valve. As shown in figure 16, the competitive valve consistently generated excess noise. Noise levels spike from approximately 75 dBa to about 98 dBa in each of the 12 runs. The spike occurs during the dead-head on the retract.

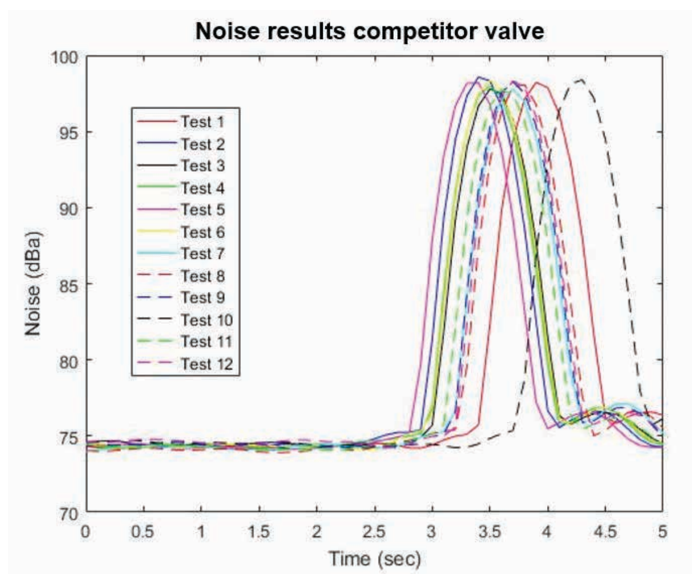

Figure 16: Noise spiked to about 98 dBa on each run of the competitor's valve.

Eaton valves were consistent in their lack of excess noise. As shown in figure 17, noise stayed between 72 and 76 dBa in each run. The slight drop in noise that's seen starting between 2.5 and 3.5 seconds occurs during the dead-head on the retract because the engine speed decreases, reducing ambient noise.

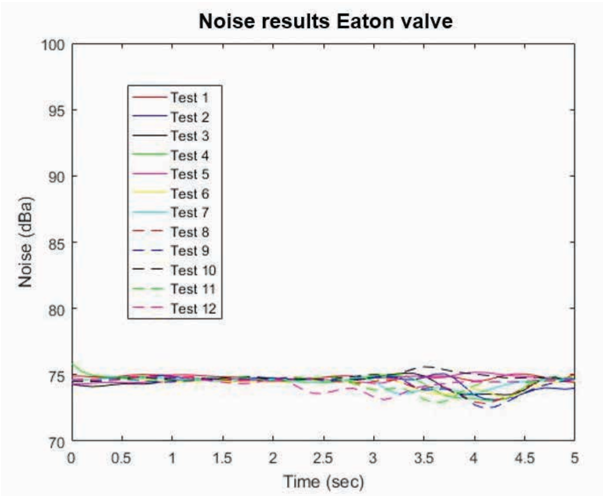

Figure 17: Noise remained fairly constant throughout each run with the Eaton valve

The results of this testing show that noise is not a problem common to all overcenter valves, and not something that machine OEMs and operators need to accept. Eaton overcenter valves eliminate nuisance excess noise.

Laboratory testing shows Eaton valves reduce pressure drop

Laboratory testing was conducted in October 2017 to compare Eaton and competitive valves in a controlled environment. Several tests were conducted, including free flow and maximum flow pressure drop. Pilot pressure ramp testing was also conducted, as reported above. Testing was conducted at Eaton's hydraulics engineering test lab, located in Eden Prairie, Minnesota.

From heat to cool

Pressure drop results in excess heat, a condition that can lead to reduced efficiency, increased fuel consumption and shortened component life. The lower the pressure drop, the more efficient the system will be. Like oscillation and noise, when it comes to pressure drop, not all valves are created equal.

To compare the performance of Eaton and competitive valves in terms of pressure drop, two tests were conducted:

- Test 1: Pilot open pressure drop
- Test 2: Free flow – maximum flow

Test 1: Pilot open pressure drop

Eaton and competitive standard valves were subjected to pilot open testing. The test procedure was:

1. Set the system RV pressure to 725 psi (50 bar).
2. Set the RV1 to 1,015 psi (70 bar).
3. Set the overcenter valve to its minimum setting.
4. Ramp flow from 0 to 15.8 gal/min (0 to 60 L/min) over 30 seconds, then back to 0 over 30 seconds.

The schematic of the pilot open test is the same as that of the pilot pressure ramp test, shown in figure 15.

The pressure drop of most Eaton valves tested was significantly lower than competing valves, as the example in figure 18 shows.

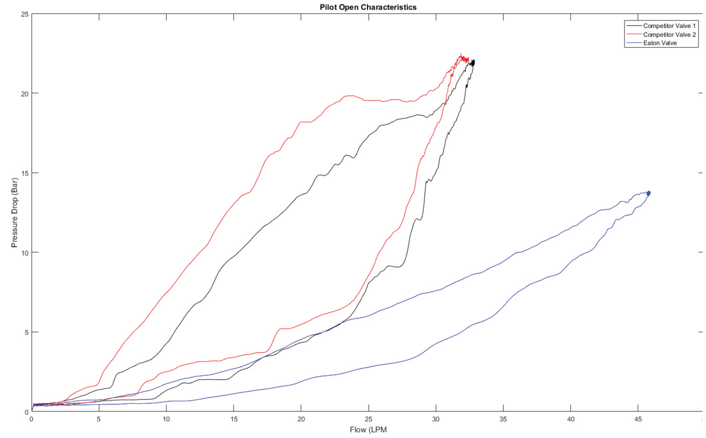

Figure 18: In pilot open testing, pressure drop in the Eaton valve was significantly less than that of competing valves.

Test 2: Free flow – maximum flow

Eaton and competitive standard valves were subjected to free-flow pressure drop testing. The test procedure was:

1. Set system RV to 3,000 psi (207 bar).
2. Ramp flow from 0 to 15.8 gal/min (0 to 60 L/min) over 30 seconds, then back to 0 over 30 seconds.

A schematic of the free-flow test is shown in figure 19.

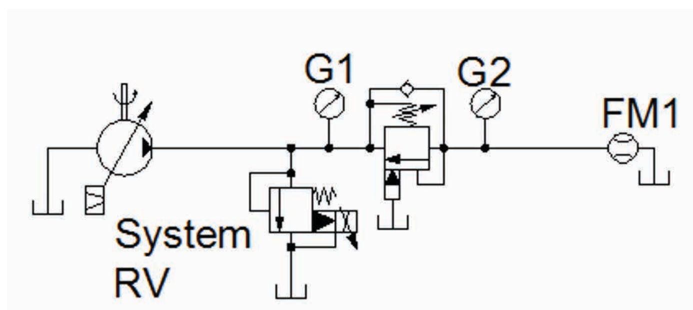

Figure 19: Schematic of free-flow test.

Eaton valves consistently showed a lower pressure drop in the free-flow test, as the example in figure 20 shows.

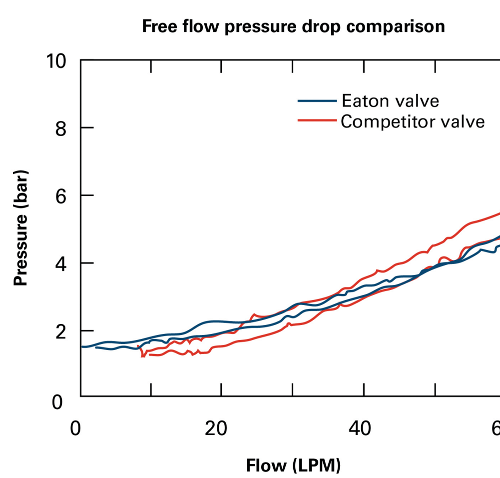

Figure 20: Pressure drop was lower in Eaton valves than in the competitor's valves.

Overall, Eaton valves had lower free-flow pressure drop (an average of 30 psi [2 bar]) and lower pilot open pressure drop. The lower pressure drop exhibited in Eaton valves is a result of better flow characteristics, which contributes to overall system efficiency.

From doubt to confidence

Designers and owners of machines with long, unstable booms have long considered oscillation and valve noise a fact of life. The results of this testing show that oscillation and noise can be eliminated. Machine OEMs can design safer, more efficient machines by specifying the correct valve for the application: in the telehandler, for example, Eaton two-stage overcenter valves on the base lift cylinder.

The test results presented here show that Eaton valves outperform competitive valves in both static and dynamic scenarios.
In summary:

- Competitive valves were shown to be unstable in certain boom up-down applications, causing the whole machine to oscillate. Eaton valves eliminated this instability.
- Competitive valves squealed during boom retract operations. Eaton valves did not squeal.
- Eaton valves have a lower free-flow pressure drop of 30 psi (2 bar), on average.
- Eaton valves reduce hysteresis by up to 20 percent.

In the machine testing, a 1,000-pound (453 kg) weight was used on the telehandler's forks for the loaded tests. Why wasn't a larger weight used, considering the telehandler's capacity of 8,000 pounds (3629 kg)? Very simply, none of the operators involved in the testing felt comfortable operating the machine with any more than the 1,000-pound (453 kg) weight, due to the boom oscillation with the competitor's valve.

Eliminating boom oscillation gives operators the confidence to complete the job without worrying about their safety or the safety of those working around them. Eaton overcenter valves will take you from judder to stable, screech to quiet, heat to cool, and from doubt to confidence.

To learn more about Eaton overcenter valves, consult with an engineer or request a quote, contact your Eaton sales manager or distributor. Or, fill out the form at Eaton.com/PTSconsult, and we'll be in touch.

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