White Paper

Simplifying setup and controls with smarter components

Jason Kraft
Engineering Specialist

Eaton Corporation,
7945 Wallace Rd.
Eden Prairie,
MN, 55347, email:
JasonTKraft@ eaton.com

Introduction

Today's hydraulic equipment is smarter than ever with the rise of intelligent components, better communication between operator and machine and automated decision making. This is important, as end users are looking to manufacturers to deliver better machine performance, tapping the unmatched power density of hydraulics without the traditional downsides of conventional hydraulic systems – particularly the tendency of conventional systems to be reactive and difficult to control.

Smart machinery is on the rise. However, there is still some hesitancy among customers to adopt the equipment. While conventional hydraulics may have some negative attributes, they have been on the market for decades and machine builders are comfortable and familiar with them. Electronics provide many benefits, but struggle with the perception that they are less familiar and more difficult to tune initially and de-bug if issues arise

Electrohydraulics, or adding electronic controls and algorithms to hydraulic components, has been around for a number of years, and the capabilities have expanded quickly. Engineers and component designers are now looking to electronics as a potential solution to help ease customer concerns and increase comfort with the new technology.

Electronics as challenge and solution

Many traditional hydraulics customers worry that switching to electrohydraulic solutions will require a great deal of expertise for initial set up, operation and troubleshooting. But, as electronics advance, it becomes clear that they can help solve the very issues that have slowed adoption of this technology.

Intelligent components like Eaton's CMA Advanced Mobile Valves, for example, are electrohydraulic valves including on-board electronics, enabling sophisticated software algorithms to run directly on the valves. These software algorithms open the door to endless possibilities in mobile markets – allowing engineers to solve customer problems and allay their concerns of needing technical expertise to use electrohydraulic solutions.

Machine tuning from mechanical to digital

Consider the example customer, worried about the complexities of setting up a mobile electrohydraulic system. Proper control set up and tuning is key to having a machine behave as intended. Often, manufacturers do not have controls experts on staff, which can make setting the controls up a challenge.

Tuning can be a complex process. When a machine is initially set up, the valves and HRCs need to be adjusted to meet the needs of a particular work circuit. Typical general-purpose valve products have many different applications, and need to be tailored to the particular dynamics of each piece of equipment.

Purely mechanical tuning is particularly challenging. A valve or pump is supplied and installed at the customer's site. Engineers test operation and note any concerns. Then, they proceed to make adjustments to the circuit. This could involve switching parts, adjusting valve or HRC springs or even introducing new components to the circuit to dampen out behaviors. After this process, the circuit is reassembled and tested again. This method can take weeks and cause a great deal of frustration for challenging circuits – so much so that the product is sometimes returned or the machine is considered to be "good enough," and the customer settles with a less than optimal solution.

In some cases, a machine is tested and tuned for a few days until the machine is up and running. The engineer, usually a representative of the distributor or manufacturer, leaves the newly tuned equipment with the end-user. But what happens if the operator finds a situation where the machine needs to be retuned? Either the end user settles for less than ideal performance or calls the engineer back for more hours or days of retuning and testing.

Smarter products make it easier

Eaton's controls engineers knew there had to be a better way – and there is. Smarter products have the capability to add algorithms to components, making it easier to reach satisfactory performance across the board more quickly than ever before, even without expertise in dynamics and control.

For example, Eaton's most advanced mobile product, the CMA valve, allows end users to tune machines in their own language. With sophisticated control algorithms embedded on the valve, the end user only needs to input data they are familiar with – pressure, flow, actuator and hose dimensions – and the algorithm translates these details into the appropriate settings for the machine. This physics-based approach to tuning can be done by one engineer with a laptop in a matter of seconds, minutes or hours instead of days, weeks or months.

Most components that rely on algorithms need a programmable logic controller (PLC) to customize machine performance or introduce advanced functions. Smarter equipment with embedded control algorithms make the process of programming the PLC much easier. Software embedded on the valve has intimate knowledge of the valve with which it is integrated. This knowledge is used for high performance control algorithms, which run directly on the valve and reduce burden for the PLC programmer.

Beyond the basic set up and commissioning of a machine, tuning is important in setting the "feel" of a machine. Feel is very subjective, difficult to quantify and varies from one operator to the next. Oftentimes, feel and control stability are confused with one another. With a control system that can handle stability and deliver maximum performance, all of the tuning that remains is tailoring feel of a work section to operator preferences. Some large OEMs understand this and offer adjustable operator preference settings with their EH control systems. These bigger companies have the luxury of time and expertise in determining exactly how to maximize control performance for each of their machine services. For smaller volume machines with shorter development times and less resources available to arrive at satisfactory performance, Eaton's CMA valve addresses the control performance problem and allows time to achieve the exact feel machine builders want for their equipment designs.

How does it work?

Eaton's CMA valve features an independent metering arrangement that has a three-way proportional valve on each port for per work section, as seen in Figure 1.

Each main stage valve can function primarily as a flow control valve or a pressure control valve. Pressure control isn't all that simple with a proportional valve, especially when it's expected to perform in a large spectrum of conditions (pressure, flow, temperature) for a variety of different applications. In order to set up pressure control on a machine, an engineer need only inform the valve of the size of your conveyance and actuator. With that information, the machine now has pressure control.

With the ability to make a proportional valve behave like a flow or pressure controller, engineers can now perform flow control on a double acting actuator with controlled and reduced backpressure to save energy for your machine. Simply tell the valve the cylinder dimensions as well as maximum pressure & flow conditions and the CMA Valve's twin spool flow control algorithms will determine which valve will be used as a flow or pressure controller in all conditions, including passive/overrunning, speed and direction. Thus, setup for a fairly advanced controller was just reduced to a few hydraulic parameters and no control loop tuning was required.

Fast commissioning is an important feature for end users. Products that were once simply hydraulics components are now sophisticated pieces of equipment that are more complex to set up. With embedded control algorithms and smart components, end users can reap the benefits of these smart components without the worry about an extended tuning process.

Conclusion

By translating the language of controls into the end-user preferred hydraulics schematic dialect, machines can be up and running much more quickly and with less required expertise. Experienced engineers need not get lost in the technical weeds of setting up a machine, opening the doors for more general users to aid in the set up process. Setting up the controls so the machine behaves as intended no longer needs to be the most difficult part of commissioning a new machine.

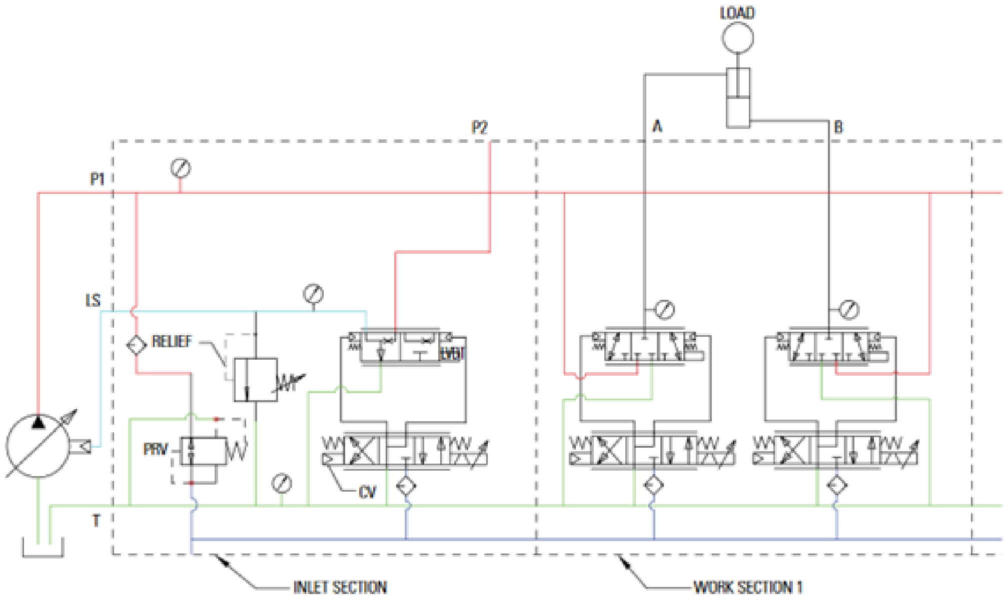


Figure 1

Tuning a load sense interaction

Load sense interactions are more complex, but important to the overall control of the machine. Figure 1 shows the simplest possible schematic representation of a load sense system.

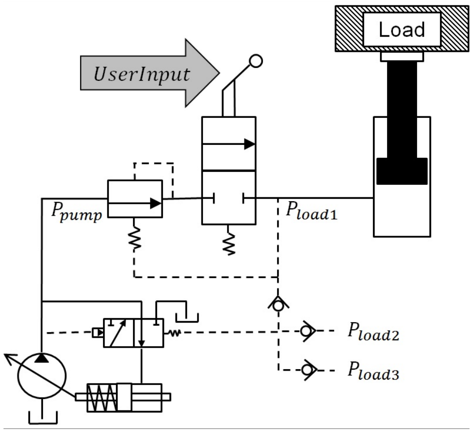


Figure 1 : Simple Load Sense Schematic Example

The schematic view captures logic and basic functionality in the circuit. The pump should always adjust itself for any pressure/flow conditions induced by the valves and corresponding loads, and each valve will locally compensate to maintain a consistent pressure drop across the proportional valve. From this perspective, this circuit is fairly intuitive and seems like it should work without issue. In practice, this isn't always the case.

There are some important details missing in Figure 1. There are dynamic behaviors associated with each of the components in this schematic that, when compounded with each other, can sometimes be problematic.

Let's try an alternative view: control block diagrams. Figure 2 shows what the system really looks like from a dynamic perspective.

Figure 2 ignores a few details and is only valid for small perturbations around specific operating points, due to the nonlinear properties inherent in hydraulic systems. However, this diagram does help establish a much stronger sense of the order of dynamics we are dealing with. For those keeping track, the small green blocks are integrators, so we are working with a 17 state system, and the four-way proportional valve is modeled as direct acting, so additional states must be added if you want to pilot the proportional valve.

There are a handful of research papers and publications written around this topic, many of which are full of large equations and impressive control terminology – but that is another topic for another paper. Our goal is to take the burden of complexity out and make things simple for our customers, so there's no sense in overwhelming anyone with the details of what is illustrated in Figure 2.

Each hydraulic component has some behaviors ignored in the schematic view. Each component is fairly high order. Most are not well damped, or in other words, they have resonant dynamics. From a mechanical perspective, resonance is the tendency for a mechanism to want to vibrate at its natural frequency when excited by an external input. Resonance occurs everywhere in hydraulic actuators and valves. When you connect a group of resonant components together with similar or harmonic resonant frequencies, its quite likely those components will eventually get excited, resonate and interact with one another.

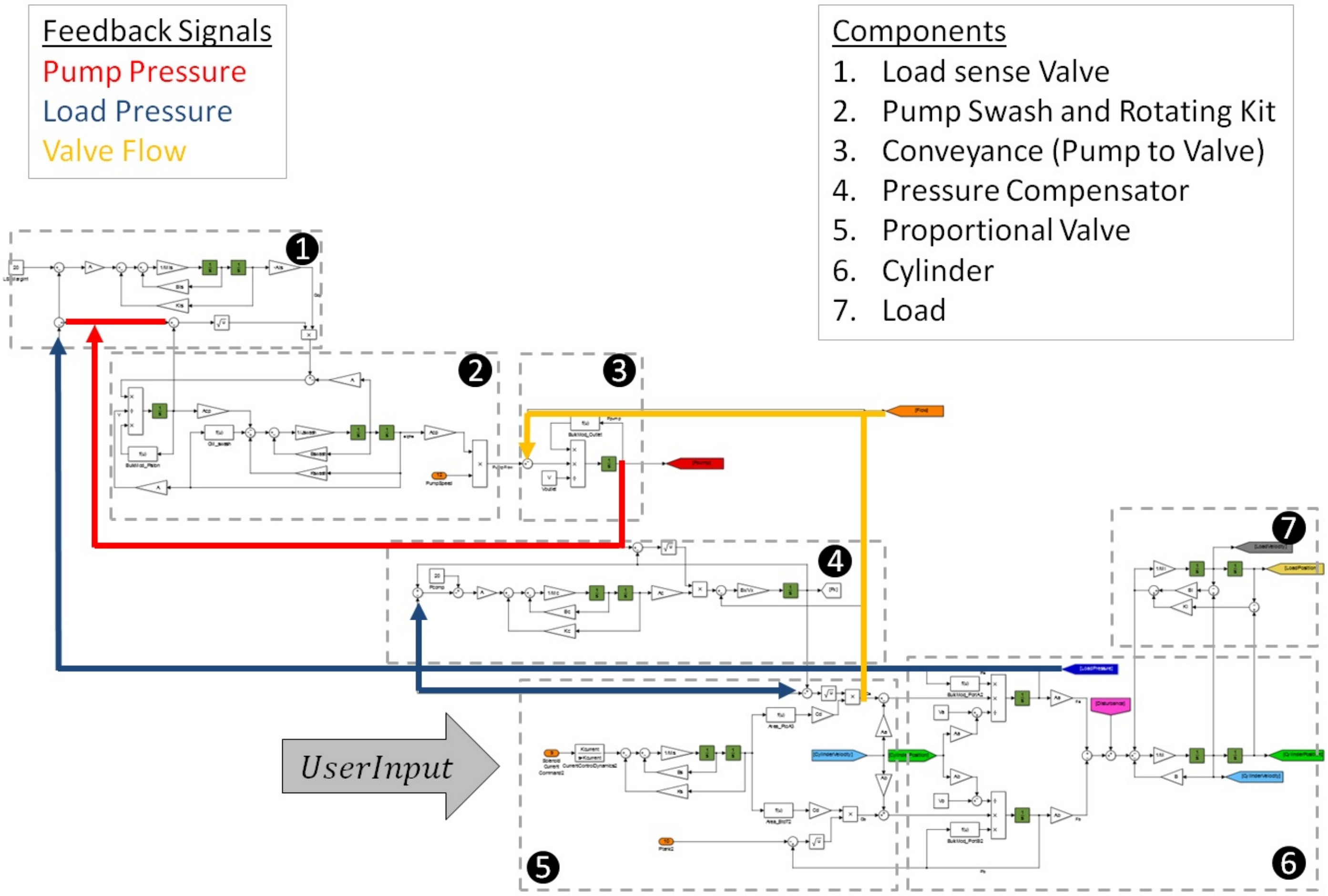


Figure 2 : Detailed Control Block Diagram

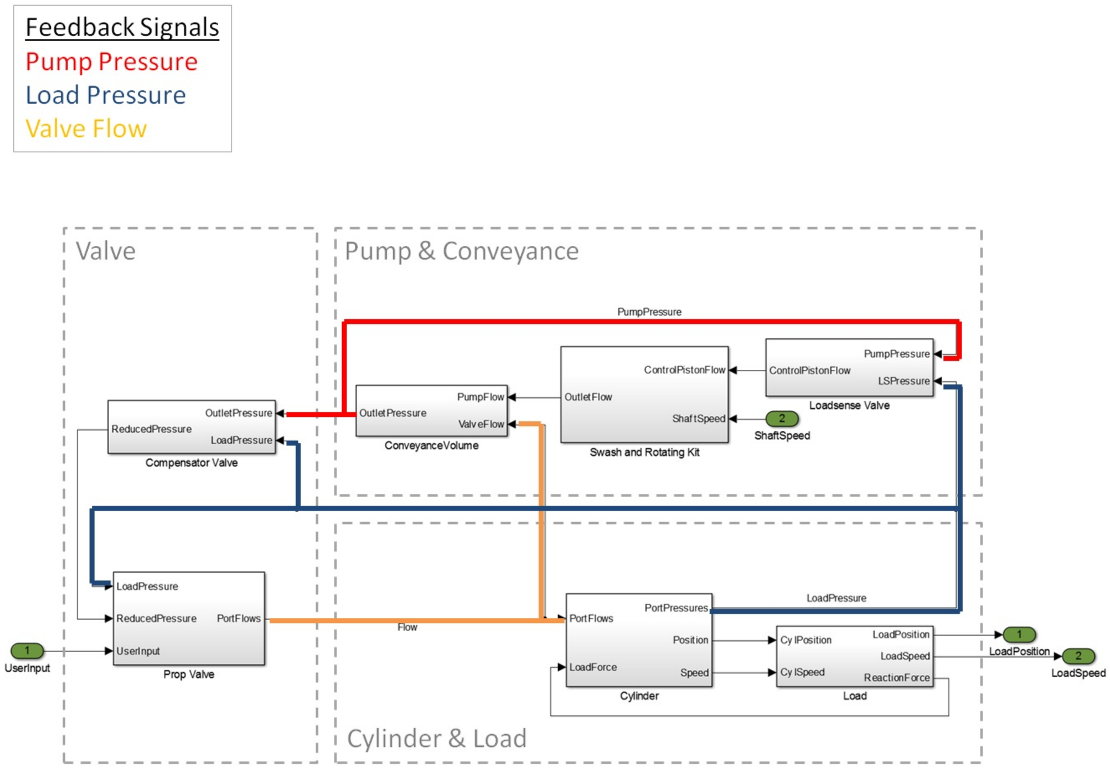


Figure 3 : Simplified Control Block Diagram

Let's simplify the diagram, in Figure 3, it's now a lot easier to see all the feedback loops in this system and potential for interactions:

Load Pressure: The cylinder and load communicate out a pressure signal, which is acted upon by a number of different components in the system. Note the two pressure control valves (valve compensator and pump loadsense) acting on the same signal. In a single service scenario, these two components have very similar, if not the same roles in terms of maintaining a constant pressure drop across the proportional valve. Also, remember the comment about resonance? These two valves are no exception. If the two are set to the same pressure margin or if they have similar resonant frequencies, the two will interact with one another.

Pump Pressure: The pump is feeding back on itself, increasing or decreasing flow so sufficient pump pressure is generated to match load sense. The pump is also trying to meet these pressure demands while receiving flow feedback from the valve, which acts negatively against pump pressure, and is likely faster to act on load pressure lead the pump in terms matching load sense conditions. One last detail worth noting is load sense pumps are typically tuned to meet fast response times and can oftentimes exhibit resonant behaviors on the order of single digit or low double digit Hertz.

Cylinder and Load: These can also have resonant properties that are sometimes negligible, but become more prominent with large conveyance, large load mass, and structural resonance in the machine service. A good example is a boom. Resonant frequency for these type of services can sometimes occur in the same range as pump resonant frequency.

Overall System: This system is designed to deliver flow per the user input at all cost. This assumes loads can be accelerated as fast as the user can move the joystick. When it comes to loads with high mass or inertia, this assumption is not valid. What can end up happening is this:

a) The user quickly moves the joystick.

b) The load doesn't move immediately, so the system builds pressure because there is no place for the demanded flow to go.

c) The load over accelerates, or worst case, a resonance is excited from being hit by fast changing pressure.

d) The valve delivers oil to make up for the load displacement, which pulls pressure away from the pump. The pump reacts and works to build pressure back up.

e) The delivered oil isn't enough to make up for the over accelerated load, so load pressure starts to drop,

f) The valve compensator sees the lower load pressure and increasing pump pressure, so it closes off, which causes pump pressure to overshoot the load condition.

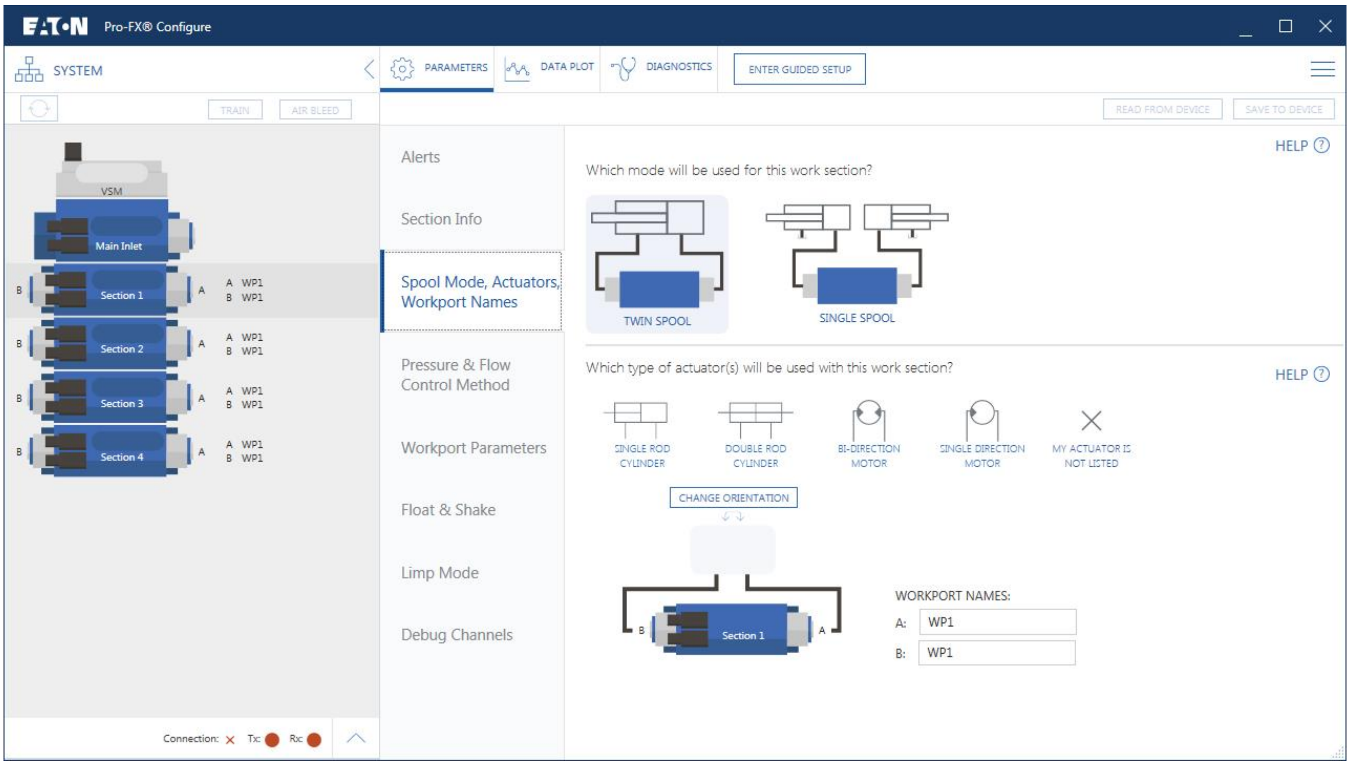
g) As the load decelerates back to the desired speed, it gets hit again with pressure backed up from previous steps and the cycle starts all over again.

There are a whole host of tricks practiced in the field to 'tune' the system and address potential problems described above. These include adding bleed-down load sense orifices or throttling load sense signals, as well as changing valve and pump compensator settings. Feel and stability can be adjusted via HRCs. Some of these tricks result in secondary issues. Stabilizing these issues can sometimes be a time consuming trial and error process. Consider tuning for stability versus feel. In some of these situations, simply 'tuning' a service to maintain stability can be so challenging that fine tuning gets pushed out of the schedule entirely.

Eaton's CMA Advanced Mobile Valve with Independent Metering takes a different approach. Its pressure compensation is performed digitally and is very stable compared to a resonant pressure control valve. Control algorithms are designed with the load in mind from a performance and stability perspective, and can prevent user inputs from exciting load resonance while actively dampening out unstable behaviors detected at the load. They can also prevent unachievable demands from getting into the system and causing the over acceleration case described above. These algorithms only need to understand the size of conveyance and actuator, and further adjustments can be made through the user-friendly Pro-FX® Configure 2.0 service tool, which guides the user in selecting the correct control strategy and fine tuning different actuators and loads, as seen in Figure 4.

One recent customer struggled with a few challenging services on their machine for months with a standard load sense valve. After replacing that valve with the CMA valve, all services were up and running well on the machine in one afternoon.

By removing the burdens of troubleshooting services and properly mitigating undesired behaviors through good control strategies, development times can now be significantly reduced and allow for time for machine builders to establish the exact 'feel' they want on their products.



Which mode will be used for this work section?

Which type of actuator(s) will be used with this work section?

WORKPORT NAMES:
A: WP1
B: WP1

Figure 4 : Pro-FX Configure 2.0

Eaton
1000 Eaton Boulevard
Cleveland, OH 44122
United States
Eaton.com

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