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Hydraulic Pump Controls

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Introduction

Movable bridges powered by hydraulic machinery have many options available when it comes to deciding how to control the structure movement. Choosing a control method should not be taken lightly and is not always a simple task. Close coordination with the electrical control system design is necessary to make the selection and throughout design development. Consideration of bridge owner preferences is also important. The familiarity of bridge maintenance staff with PLC's, motor VFD's, and hydraulic controls should guide the decision of how to implement the bridge controls. This paper will discuss several options, highlighting the benefits and drawbacks. The following discussion is intended to be high level, focusing on general types of control combinations. Each type of pump control has many more functional options to consider when fully detailing the hydraulic system that are beyond the scope of this paper.

General Information

Before getting into pump control details, we will review the two main types of actuators used to drive movable bridges: hydraulic motors and hydraulic cylinders. Hydraulic motors are rotary actuators with two main ports herein called Port A and Port B. When pressurized hydraulic fluid is supplied to Port A, the output drive shaft of the motor rotates in a given direction. The fluid exits the motor from Port B. Fluid exchange in hydraulic motors is equal, such that the volume of fluid supplied to the motor is equal to the fluid volume exiting the motor. Reverse rotation of the shaft can be achieved by supplying pressurized fluid to Port B, which then exits the motor from Port A. Since the symbols used for hydraulic pumps and motors are similar, Figure 1 illustrates examples of open-loop pumps, closed-loop pumps, and hydraulic motors.

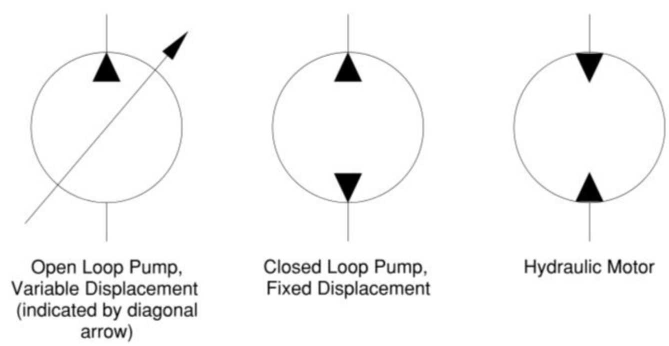

Figure 1 - Examples of Hydraulic Pump and Motor Symbols

Hydraulic cylinders are linear actuators that also have two main work ports. When pressurized fluid is supplied to the bore side through Port A, the cylinder extends. Fluid exits the cylinder rod side from Port B. Most hydraulic cylinders have a different area on the rod side and bore side of the internal piston. The volume of the fluid exchanged between Ports A and B is directly proportional to the ratio of these areas. When extending an unequal area cylinder, the volume of fluid exiting the rod side from Port B is less than the volume entering the bore side through Port A because the area on the rod side of the piston is smaller than the bore side. Conversely, retracting a cylinder by supplying fluid to the rod side through Port B results in a larger volume of fluid exiting the bore side from Port A. This area ratio affects the pump flow control requirements when specific span speeds are desired. It is possible for hydraulic cylinders to have equal areas by adding a rod on the bore end, however this is less common.

Closed-Loop Systems

A closed-loop system is distinguished by routing the hydraulic fluid returning from the actuator back to the pump, rather than to a reservoir. Fluid travels in a closed loop between the pump and actuator. This arrangement allows for the electric motor to provide load control in that any overhauling of the actuator creates increased pressure in the return line, which tries to accelerate the pump and is resisted by the electric motor. This type of flow is also easily reversible. Direction of the actuator is changed by changing the direction of the pump flow through the closed loop. This arrangement is generally referred to as a hydrostatic transmission. It should be noted that closed-loop systems require equal flow to and from the pump. Without providing some other way of adding or removing flow from the system, closed-loop pumps generally require the use of hydraulic motors or equal area cylinders. Pumps and motors leak internally at their various sliding interfaces, producing a small amount of drainage flow back to the reservoir. To account for this case drain flow in closed-loop systems, a separate charge pump is required. The charge pump creates a base level of pressure in the loop to ensure proper operation of these components.

<u>Fixed Pump – Vary the Motor Speed and Direction</u>

The first type of closed-loop pump control we will discuss is a fixed displacement pump with a variable speed motor. In this type of system, the pump displaces a fixed volume of fluid with each rotation. Varying the flow rate is achieved by varying the speed of the pump rotation, which can be accomplished by driving the pump with a variable speed electric motor controlled by a motor control system. Flow rate (and span speed) is proportional to the rotational speed of the pump (see Figure 2). Initially, this seems to create a simplistic hydraulic system with a few notable benefits. First, the electric motor control system provides the span speed control. This arrangement may be a more familiar control scheme to maintenance personnel and operators who service other movable bridges that do not have hydraulic machinery. Also, the electric motor and pump are reversible to change flow and span movement direction. Overhauling loads are directly transferred from the hydraulic actuator to the pump and electric motor. However, after a closer look, a few drawbacks for this arrangement appear. Additional components are required to maintain the charge pressure required for closed-loop systems. To maintain the base level of pressure in the loop during operation, charge pressure must be provided by a separate pump. Since the speed of the electric motor that drives the main pump in this control arrangement is variable and is not always spinning, the charge pump cannot be coupled to the back of the main pump. Insufficient charge pressure would be supplied at low motor speeds. Therefore, a separate, yet smaller, electric motor and pump is necessary to provide charge pressure. In systems where two main pumps are provided for

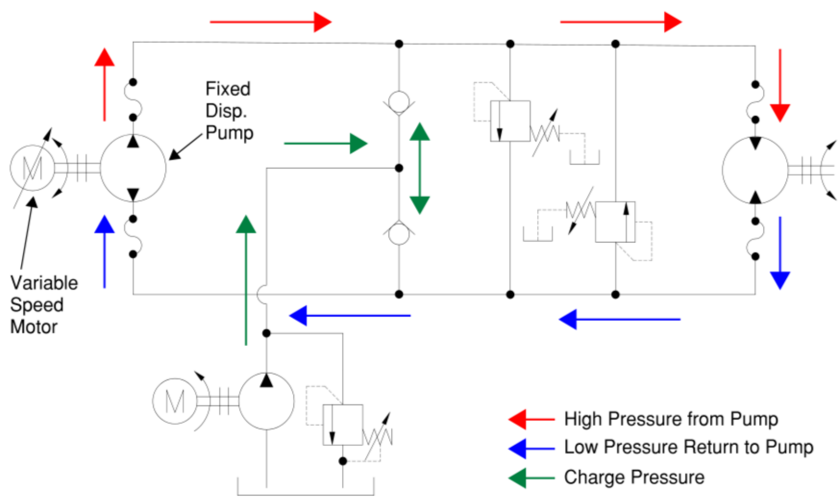

Figure 2 - Fixed Displacement Pump with Variable Speed Motor

redundancy, it may be necessary to provide two charge pumps and motors to maintain full system redundancy. Additionally, this system not generally able to provide hydraulic power for other ancillary systems, if present. Even more electric motors and pumps are often added for the ancillary systems, adding to the required component totals.

<u>Fixed Motor Speed – Vary the Pump</u>

Another type of closed-loop pump control is a displacement-controlled pump driven by a constant speed electric motor (see Figure 3). In this system, the electric motor is energized to run at a constant speed, and the pump is controlled to produce the desired displacement. The controls for the fixed speed electric motor are simplified in this system. Instead, speed controls are applied to the hydraulic pump. There are numerous methods available to control pump displacement, with a few of the more general approaches listed here:

- Pressure control – internal components in the pump to control flow are adjusted by supplying continuously variable pilot pressure. The pump displacement is varied from zero flow to full displacement in either direction depending on the pilot pressure supplied.
- Electronic control – internal components in the pump to control flow are adjusted by valves that receive an electronic signal (i.e. 4 - 20 mA, or +/- 10 vdc), which varies the pump from zero to full displacement in either direction
- Direct control – a mechanical actuator acts directly on a lever on the pump. The pump can produce zero to full displacement in either direction depending on the position of the lever

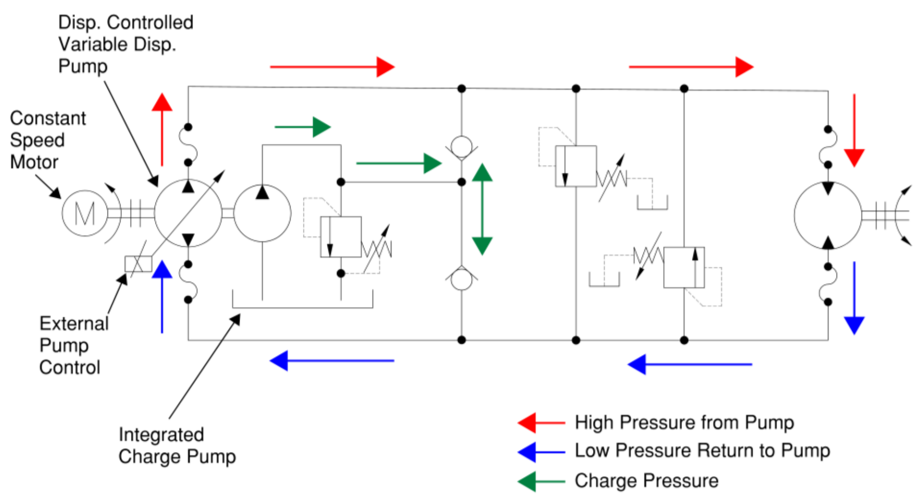

Figure 3 - Closed-loop Pump with Constant Speed Motor

Multiple options are available for accomplishing the above three main control types, but in general some type of control system is required to provide the pump with a necessary input signal to produce the flow rate desired. While this control signal adds some complication to the HPU, there are many benefits. Since the electric motor maintains a constant speed, charge pressure can be provided by a pump coupled to the main pump. A separate electric motor is not necessary. This way, charge pressure is available any time the electric motors are energized. Ancillary hydraulic systems can also be powered by another pump coupled to the main pump and driven by the same main electric motor. When the span is required to move, the primary pump is actuated while the ancillary pump idles and produces no flow. When the ancillary devices need to operate, the ancillary pump is actuated while the primary pump produces no flow. If necessary, both pumps can produce flow simultaneously, however the electric motor must be sized for this scenario and the torque transmitted from the primary pump to the ancillary pump must be within its parameters.

Open-Loop Systems

An open-loop system is distinguished by routing the hydraulic fluid returning from the actuator back to a reservoir instead of the pump. Open-loop pumps are typically one-way devices where the pump ports are designated as inlet and outlet, and fluid direction is not reversible. Since the returning oil does not enter the pump inlet, the returning flow rate does not have to match the pump outlet flow rate, making open-loop pumps a common choice to use with unequal area hydraulic cylinder applications. However, since the returning oil does not return to the pump, overhauling loads must be controlled with separate valving. Open-loop pumps are not able to absorb overhauling loads. In addition, since the pump flow is one direction, valving is required to change direction of flow to the actuator.

<u>Fixed Motor Speed – Vary the Valve</u>

Several options are available for controlling open-loop pumps. One option that is rather simple is using a pressure compensated pump with a variable flow control valve, such as a proportional directional control valve (see Figure 4). In this arrangement, the pump displacement is not controlled directly, rather flow control is achieved by controlling the pressure at the pump outlet. This can be done by adding a restriction to increase pressure at the pump outlet with a flow control valve. The opening of this flow control valve is controlled to allow the pump to gradually increase or decrease its displacement because the pressure at the outlet gradually increases or decreases, due to the flow control valve opening. The opening of a proportional flow control valve can be varied from zero to fully open using pilot pressure or electrical signals, similarly to how a displacement controlled pump is controlled. Any hydraulic ancillary devices can also be driven by the main pump, by adding separate directional and flow control valves. It should be noted that since the pump displacement is not controlled directly, care must be taken to control pressure and flow rates, as necessary, based on the ancillary systems.

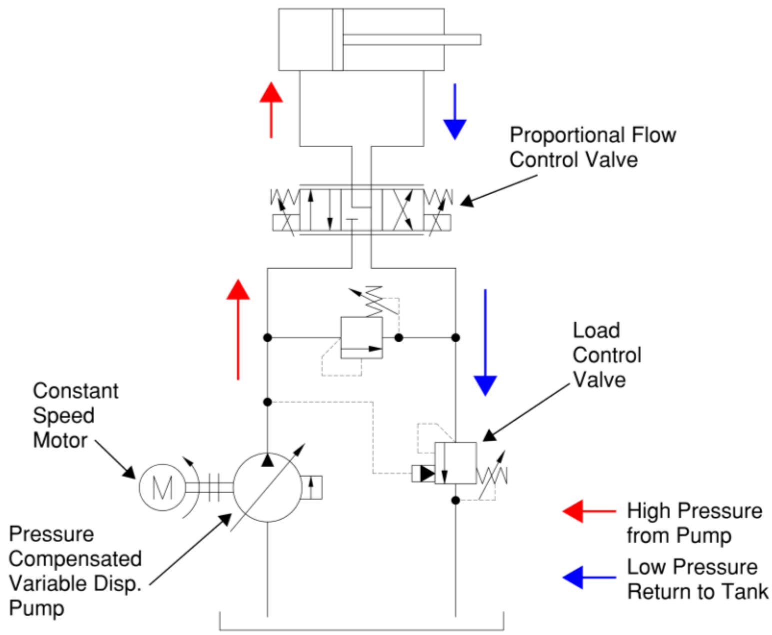

Figure 4 - Pressure Compensated, Variable Displacement Pump with Constant Speed Motor

Fixed Motor Speed – Vary the Pump

Another option, similar to the closed-loop solution, is a displacement controlled pump (see Figure 5). This type of pump is driven by a constant speed electric motor, and the pump displacement is controlled by pilot pressure or electrical signal, similar to the closed-loop style described above. However, direct displacement control is not a common option on open-loop pumps. As a benefit, accurate, repeatable flow rates and span speeds are achievable with displacement controlled pumps. Also, ancillary devices can receive hydraulic fluid from the main pump with separate control signals, or from a separate pump coupled to the main pump. One disadvantage is some added complication to the pump, making replacement and setup more involved.

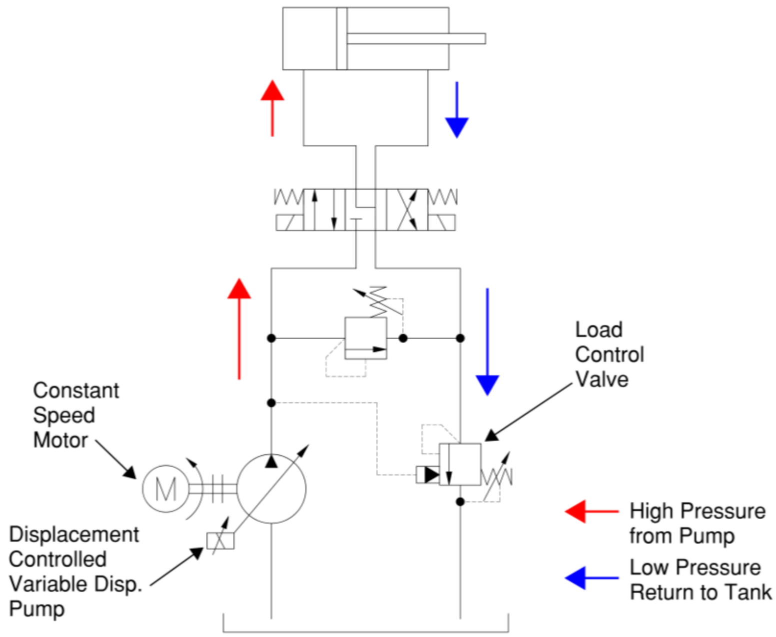

Figure 5 - Variable Displacement Pump with Constant Speed Motor

Fixed Pump – Vary the Motor Speed

A third option for an open-loop system is an arrangement that couples a variable speed motor with a fixed displacement pump (see Figure 6). Similar to the closed-loop variant described above, this requires control of the motor speed, while the hydraulic portion of the system acts as an open-loop version of a hydrostatic transmission. The disadvantages of the closed-loop version do not apply to the open-loop version. Charge pressure is not needed for open-loop systems, so multiple additional motors and pumps are not necessary. Separate load control valves are still necessary to handle overhauling loads, and since the pump flow is one-direction, directional flow control valves are needed to change bridge movement direction. A clever option for this style of control is to use a pressure compensated pump, with the compensator set to the normal working pressure for the system, which takes advantage of this pump control's inherent pressure limiting function. The pump will produce max displacement during operation unless pressure increases to the compensator

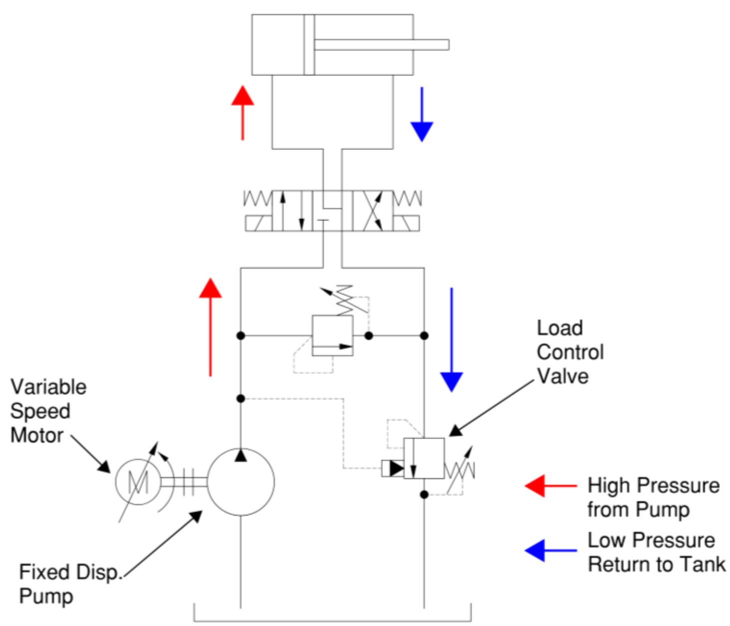

Figure 6 - Fixed Displacement Pump with Variable Speed Motor

set point. If hydraulic ancillary devices are needed, the same pump can be used to power these as well. The motor control will need separate speed settings for each device so they operate at the intended speed. This option offers a reasonable compromise of using a hydraulic drive system while controlling speed and ramping in ways similar to non-hydraulic systems, which may be more familiar to designers and maintainers of a given bridge.

Summary

There are many considerations when selecting a hydraulic pump control method, with varying levels of priority that change from project to project. Owner preference, electrical control interface, and system complexity must be weighed when deciding how a system will be controlled. It is best to make this decision early in the design process so that the electrical and hydraulic systems can be developed in parallel.

Options in addition to those presented above are available for controlling hydraulic pumps, however the combinations described here are the more commonly seen solutions on movable bridges. Providing a system that is straightforward and robust, while remaining within the capabilities of maintenance personnel to adjust, repair, and maintain is the ideal solution. This will require a unique solution and combination of controls to suit the given bridge application and owner’s preferences. Familiarity of the variety of options in hydraulic systems is key for the designer to deliver satisfactory solutions to bridge owners.