MULTI-FUNCTION REALIZATION OF A GENERIC PROGRAMMABLE E/H VALVE USING FLEXIBLE CONTROL LOGIC

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ABSTRACT

This paper reports the development of a generic programmable electrohydraulic (E/H) valve using spool-type cartridge valves. This generic valve consists of fixed hardware of five sub-valves and flexible software of control logics for each sub-valve. Multi-functions, such as open-center, closed-center, and "regeneration" functions, can be realized with different control logics. Validation tests verified that the generic programmable E/H valve could realize the desired functions by simply switching the control logics in real-time. With advanced control algorithms, the generic programmable valve is expected to be able to replace conventional proportional direction control valves in many hydraulic systems.

KEYWORDS

Programmable valves, smart valves, E/H controls

INTRODUCTION

Proportional directional control valves are by far the most common means for motion control of hydraulic motors or cylinders in fluid power systems [1]. Normally, a proportional direction control valve uses a sliding spool to control the direction and the amount of fluid passing through the valve. For different applications, the spool in a proportional direction control valve is often specially designed to provide the desired control characteristics. As the result, the valves cannot be interchangeable even if they are exactly the same size. In turn, it is inconvenient and costly to manufacture, distribute, and service such specially designed valves.

A generic programmable electrohydraulic (E/H) control valve is a set of individually controlled E/H valves, and capable of fulfilling flow and pressure control. A generic programmable valve can replace a proportional direction control valve and other auxiliary valves such as line release valve at the same time. Therefore, the development of a programmable E/H valve is very economically attractive. Due to the complicity in valve control for realizing desired characteristics, it is very difficult to realize generic programmable functions on conventional hydraulic valves.

The adoption of electrohydraulic technology makes it possible to apply electronic control on hydraulic valves for better controllability, which removes the major obstacle for developing generic programmable valves. A couple of successful efforts have been reported in the past a few years [2] [3].

Researchers at the University of Illinois at Urbana-Champaign have developed and proved a concept of building a generic programmable valve using five spool-type cartridge valves [4]. In this research, a set of basic control logic was developed for controlling all five sub-valves simultaneously in achieving various fundamental functions from the generic programmable valve. It consisted of the construction of a prototype generic programmable E/H valve using spool-type cartridge valves, the development of a test facility including a fluid power test stand and a computer-based control system, the design of the fundamental control logic, and the conduction of validation tests.

PROTOTYPE VALVE AND TEST BENCH

The prototype generic programmable E/H valve was constructed using five Eaton[1] bi-directional, spool-type proportional flow control sub-valves, four pressure sensors, and a computer controller. The sub-valves were actuated using solenoid actuators in response to a pulse width modulated (PWM) control signal. The pressure drop across the sub-valves was 1.9 MPa under the maximum flow rate of 0.3 m^3/s. All five sub-valves were connected using hoses, and mounted on the test bench as one package for demonstration purpose (Figure 1). The test bench consisted a fixed displacement pump which could supply 0.15 -0.25 m^3/s flow depending on the operating pressure.

[1] The mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the University of Illinois, and does not imply the approval of the named product to the exclusion of other products that may be suitable.

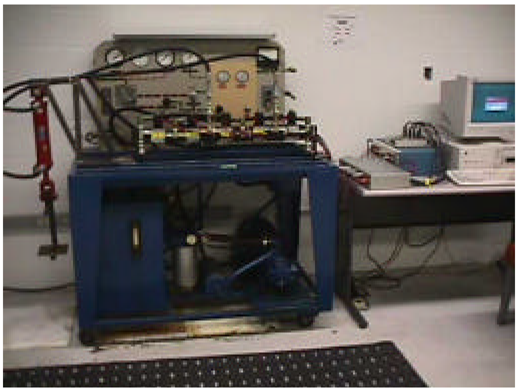

Figure 1. Prototype valve setup and test bench.

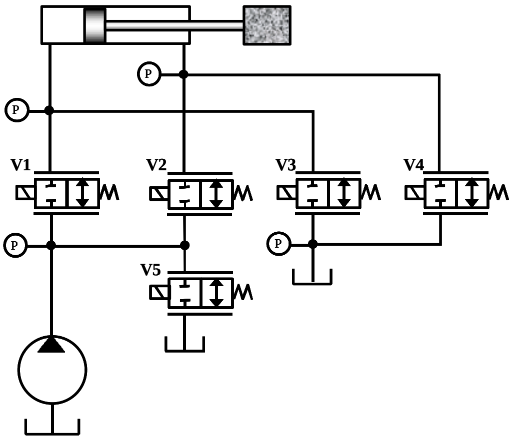

Figure 2. Schematic diagram of the generic programmable valve constructed using five individually actuated spool-type proportional flow control valves.

To provide feedback information in support of the study, four Omega pressure sensors (operating range of 0-20.7 Mpa) were installed in the valve circuit. Figure 2 shows the schematic of the generic valve circuit constructed by five individually actuated sub-valves and four pressure sensors. Sub-valves 1 and 2 connected the pump and the head-end or the rod-end chambers of the cylinder, and provided equilibrium ports of P-to-A and P-to-B of a conventional direction control valve, while sub-valves 3 and 4 connected cylinder chambers A or B to the tank, and provided equilibrium ports of A-to-T and B-to-T of a direction control valve. Sub-valve 5 connected the pump and the tank directly, and provided a dual-function of line release and an equilibrium port of P-to-T in a direction control valve. By controlling the open and close of these sub-valves, the basic functions of the generic valve could be realized.

To implement the logic control using an electronic controller, a computer-based control system was

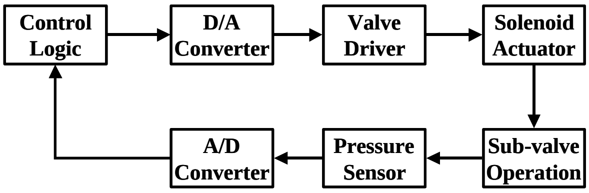

Figure 3. Information flow of the control system for the generic programmable valve.

developed in support of this research. As shown in Figure 1, the hardware of the controller consisted of a hosting computer, an interface box, and a sub-valve PWM driver. The computer hosted the logic control algorithm programmed under Simulink environment and supported by Wincon interface software. The interface box consisted a Quanser MultiQ board and supported eight 13-bit A/D and eight 12-bit D/A conversion channels. The PWM driver contained five High Country Tek HAU proportional valve drivers converting voltage signals to PWM signals for driving the sub-valves.

Figure 3 shows the information flow in the control system of the generic programmable valve. In operation, the controller output control signals for each sub-valve based on a predefined control logic. A D/A converter converted the digital signals into voltage signals, and a set of five valve drivers converted the voltage signals into PWM signals for each sub-valves. The solenoid actuators then opened the corresponding sub-valves to realize the basic functions of the generic programmable valve. The pressure sensors were used to provide system pressure information for confirming the realization of the desired functions. With advanced control algorithms, this control system should be able to support multiple functions in actual applications.

BASIC FUNCTIONS AND CONTROL

With proper logic on-off control of all five sub-valves, the generic programmable valve was capable of realizing several basic functions, including open-center, closed-center, float-center, make-up, and pressure release functions. By applying modulation control, the generic valve can realize proportional functions such as meter-in/meter-out, load sensing, regeneration, and anti-cavitation.

This paper reports only the realization of basic functions using simple logic on-off control. Table 1 summarized the control logic for realizing the basic functions on the generic programmable valve.

In conventional tandem-center or closed-center direction control valve, the ports A (head-end) and B (rod-end) are normally closed for holding the pressure in cylinder chambers, while the ports P (pump) and T (tank) are

Table 1. Control logic for basic functions

FUNCTIONS	V1	V2	V3	V4	V5
Open-center	X	X	X	X	X
Tandem-center	0	0	0	0	X
Float-center	0	0	X	X	S
Closed-center	0	0	0	0	S
Pressure release	0	0	0	0	S
Regeneration	X	X	0	(S)	S
Make-up (HE)	X	0	S	0	0
X=open, 0=closed, S=open at a preset pressure					

either normally open or closed. To fulfill this function, the generic valve keeps sub-valve 1 to 4 closed to hold the cylinder chamber pressure, and fully opens sub-valve 5 to bleed the flow back to the tank either at low pressure (tandem-center function) or when the system pressure exceeds a preset level (closed-center function).

In conventional open-center direction control valve, all ports are normally connected. To fulfill this function, the generic valve keeps all sub-valves open. Similarly, to provide float-center function, the generic valve needs to open sub-valves 3 and 4 to release pressure in both the head-end and the rod-end chambers of the cylinder. In both cases, sub-valve 5 will be opened only when the system pressure exceeds a preset level.

It is almost impossible to achieve the regeneration function from a conventional direction control valve. In achieving this function, a generic valve needs to open sub-valve 1 and 2 to lead the returning flow of the rod-end chamber back to the head-end chamber to provide additional flow for increasing the extending speed.

Make-up function in a conventional hydraulic system is provided by a separate make-up valve for supplying fluid directly from tank in case of cavitation. The generic valve can also provide this function by actuating the corresponding cylinder-to-tank sub-valves open when the system pressure is below a certain level.

VALIDATION TESTS AND DISCUSSION

A series of validation tests were designed and conducted on the test stand to verify the capability of realizing the basic functions using the generic programmable valve by means of simple logic control. Due to the limitation of the current test facility, the make-up control logic was the only basic function not able to be validated.

Before the basic function validation tests, a test on sub-valve opening performance was conducted to verify its capability of opening the sub-valve fully against the flow force. In this test, a step input of full-open signal was sent to the sub-valve. The upstream pressure was used to

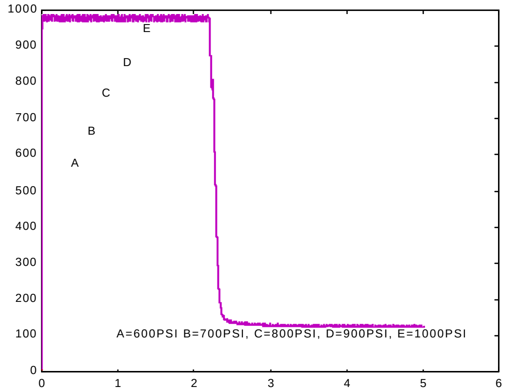

Figure 4. Sub-valve opening performance. The quick drop of upstream pressure indicates that the sub-valve can be opened promptly and fully.

check the sub-valve could be opened promptly and fully. Figure 4 shows the upstream pressures dropped promptly and completely. The transition time for fully open a sub-valve was about 0.2 s. The results indicated that the sub-valves could be fully open under the test range (4.1 to 6.9 Mpa). It indicates that the selected sub-valves could provide satisfactory characteristics.

The multi-function validation tests of the generic programmable valve were conducted in two steps: the basic functions validation and the regeneration function validation. In basic function validation, the open-center, tandem-center, float-center, and closed-center functions were tested in sequence. The results (Figure 5) showed that both the system pressure and the cylinder pressures were low at open-center operating condition (1). In tandem-center operation (2), the system pressure was slightly higher than that under open-center operation because the pump flow was bleeding to the tank using only one sub-valve. The reduced flow passing area

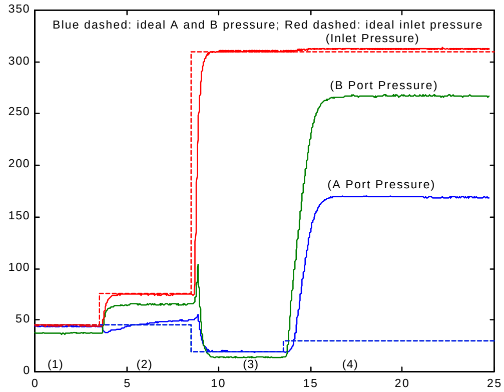

Figure 5. Validation of basic functions on the generic programmable valve. In turn, the tested functions were open-center, tandem-center, float-center, and closed-center operations.

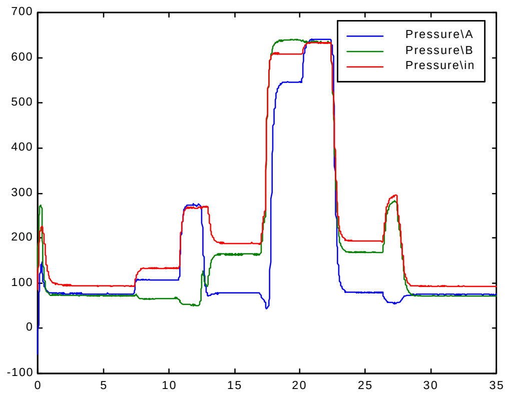

Figure 6. Validation of regeneration function on the generic programmable valve. A regular extension and a regeneration extension were performed in the same test, and results indicated this generic valve could be easily switched between two modes.

caused in the increase in system pressure. In float-center operation (3), both chambers of the cylinder were connected to the tank directly, and the pump flow was bleeding to the tank by cracking sub-valve at a preset cracking pressure. It resulted no pressure on the cylinder, and a maximum system pressure. In closed-center operation (4), the cylinder chamber pressure could be built-up when the spool of the sub-valve was either critical-lap or under-lap. The above results verified that the generic programmable valve achieved the requirement for its basic functions.

In regeneration validation, a series of control logic was designed to test the capability of the generic valve in providing the regeneration function and in handling load change during the operation. The detailed control logic is listed in the table below.

ORDER	Control Logic
1	Open-center
2	Extending (no load)
3	Extending (add load)
4	Retracting (no load)
5	Extending in regeneration mode (no load)
6	Extending in regeneration mode (add load)
7	Retracting (no load)
8	Retracting (add load)
9	Open-center

Figure 6 shows the pressure responses of the hydraulic actuator system using the generic valve. The result showed that the system pressure increased significantly in the regeneration mode as comparison to in the normal extending mode. Such pressure increase is caused by re-energize the returned flow and is the price paid for obtaining higher flow rate supplying to the head-end chamber of the cylinder. This fact verified that the regeneration mode could only be used when system load is low. Another fact observed from the result was that the rod-end chamber pressure was higher than the pump outlet pressure. Add a safety assurance function by creating a pressure control logic to open sub-valve 4 when the rod-end chamber pressure is above a preset level will add an additional line release function to the branch circuit and improve the safety of the hydraulic system.

CONCLUSIONS AND FURTHER WORKS

A prototype of generic programmable E/H valve and associated basic control logic for multiple functions have been developed based on a laboratory testing system. Two validation tests of basic functions and regeneration functions have been conducted on the laboratory setup. The results indicated that it is possible to realize satisfactory performance in open-center, closed-center, tandem-center, float-center, and regeneration modes operation on this generic programmable valve with simple control logic.

Before adopting this generic programmable valve in more advanced applications, it is necessary to study its dynamic characteristics of the sub-valves and that of the hydraulic system using the generic valve. It will include the modeling and identification of the system using the generic valve, multi-logic or multiple control algorithms implementation on the same sub-valve, and the synchronization of controllers for each individual sub-valves according their functions in the system.

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