EFFICIENCY IMPROVEMENT OF HYDRAULIC SYSTEM WITH BOOSTING SUCTION LINE AND LOAD SENSING TECHNIQUE

Ryo Yagisawa*, Kazuhisa Ito*

*** Department of Machinery and Control Systems, Shibaura Institute of Technology**

bq12095@shibaura-it.ac.jp

ABSTRACT

This paper discusses the energy-saving and the control performances of a novel cylinder control system combining accumulator (ACC) and load sensing (LS) system with heavy load. This system composes a pure-hydraulic hybrid system. In addition, this system sends the saving energy of ACC to suction line directly and achieves to decrease the output torque of the electric motor. Furthermore, the novel LS system gives better balance between two performances. The simulation results show that the proposed system can be operated in 21% of required energy of conventional system.

1. INTRODUCTION

The energy-saving system for cylinder control system has been widely applied. Recently, the electric energy-saving system has been proposed [1]. However, this system has large energy conversion loss because of its mechanical loss [2]. Therefore, energy-saving system with ACC has potential to achieve higher energy-saving performance because of no energy conversion loss [3]. In addition, the pressure of outlet port of pump fluctuates. By contrast, supplying the energy to the suction line is easier to realize. In this research, two energy-saving systems which regenerate the potential energy to the suction line without hydraulic motor are proposed and compared. This aims to assist the output torque of the electric motor.

On the other hand, the LS system has been widely applied to hydraulic machines. This system has been proposed to supply only demanded energy regarding cylinder control system [4]. This technique controls the supply flow to make supply pressure keep an expected value via the feedback of the load pressure. In this system, the higher reference value of the difference between supply pressure and load pressure the designer gives, the better control performance the system achieves. However, higher reference pressure leads to more energy consumption. In this research, the novel LS system is proposed by introducing variable reference pressure value. The cylinder system doesn't require the energy in descent motion but in ascent motion. For this reason, this paper focuses on the reference cylinder speed. The reference pressure is changed by this speed. By this method, the system achieves better balance between the energy-saving and the control performances. As a result, the proposed circuit with the novel LS system can decrease about 80% of the output energy.

Chapter 2 explains two proposed circuits. Chapter 3 states about the proposed LS system. Chapter 4 simulates and discusses four cases, conventional circuit, proposed circuit, conventional circuit with LS system and proposed circuit with LS system.

2. PROPOSED CIRCUIT

Figure 1 shows hydraulic cylinder drive circuit used in this study.

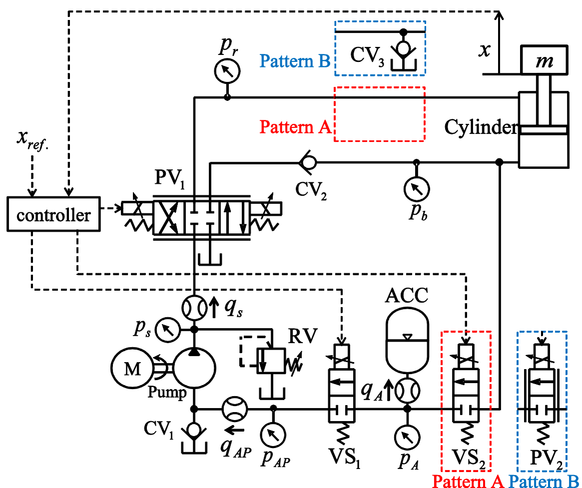


Fig.1 Proposed cylinder drive circuit for energy recovery

This paper proposes two hydraulic circuits; Pattern A and B. In Pattern A, the cylinder displacement is always controlled by servo valve (SV), that is, meter-in control. In Pattern B, the cylinder displacement is controlled by SV in ascent motion, whereas it is controlled by proportional valve (PV) in descent motion, that is, meter-out control. The operation of each valve is summarized in Table 1. And, the inverter controls the speed of the electric motor. The detail is explained in Chapter 3.

Table 1 Operation of each valve

	Pattern A		Pattern B	
	Descent motion	Ascent motion	Descent motion	Ascent motion
SV	control	control	close	control
VS_2 / PV	open	close	control	close
VS_1	close	open	close	open

3. PROPOSED LS SYSTEM

Figure 2 shows the block diagram of LS system. Load pressure p_L can be expressed as Eq.(1).

$$p_L = p_b - p_r \tag{1}$$

We define Δp_{LS} as the difference between p_s and p_L. The inverter (INV) controls the speed of electric motor (M) so that $\Delta p_{LS.}$ maintains constant reference pressure value $\Delta p_{LSref.}$. The energy and the control performances are influenced by this value, hence the designer must decide priority. This paper proposes the novel LS system which balances these performances. This LS system changes the value of $\Delta p_{LSref.}$ depending on the reference cylinder speed $\dot{x}_{ref.}$. In descent motion, $\Delta p_{LSref.}$ is higher value, on the other hand, in ascent motion, it takes lower value.

4. SIMULATION RESULTS AND DISCUSSION

4.1 Simulation Conditions

Figure 3 shows the reference cylinder displacement. ACC saves the potential energy in descent motion, and the energy is only used in ascent motion. We assume that m=3000[kg], with adiabatic change of energy charge to ACC, and the volume of ACC is of 24[L].

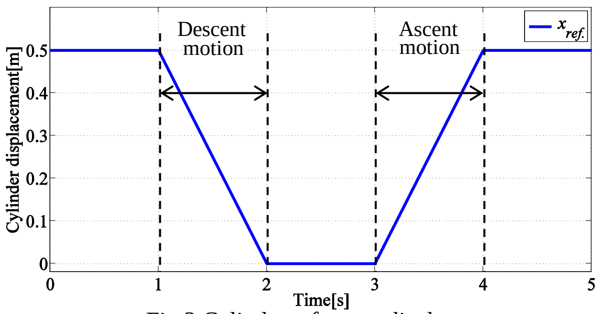


Fig.3 Cylinder reference displacement

This paper simulates four cases; conventional circuit, proposed circuit, conventional circuit with LS system and proposed circuit with LS system.

4.2 Conventional circuit

In Figure 4, the conventional circuit is shown. In this simulation, the speed of M is constant. The controller makes $x_{conv.}$ track $x_{ref.}$ by controlling the spool of SV. In this circuit, the potential energy and the load of pump are all wasted in descent motion.

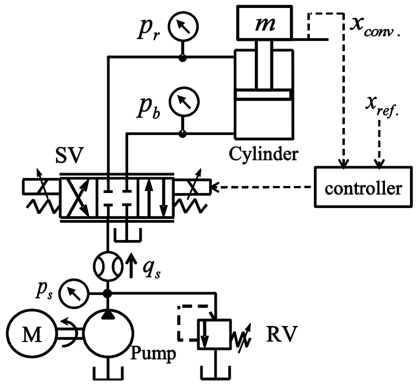


Fig.4 Conventional circuit

4.3 Proposed circuit

This paragraph simulates proposed circuit in Figure 1 with constant speed of M. Figure 5 and 6 show the cylinder displacement in the case of Patten A and B, respectively, where $p_{pre.}$ takes various precharge pressures of ACC. The p_s and p_{AP} are shown in Figure 7.

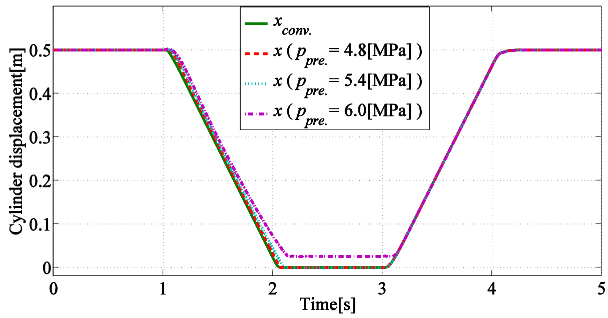


Fig.5 Cylinder control performance in Pattern A

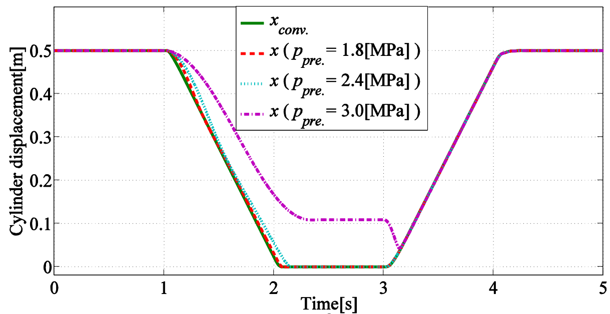


Fig.6 Cylinder control performance in Pattern B

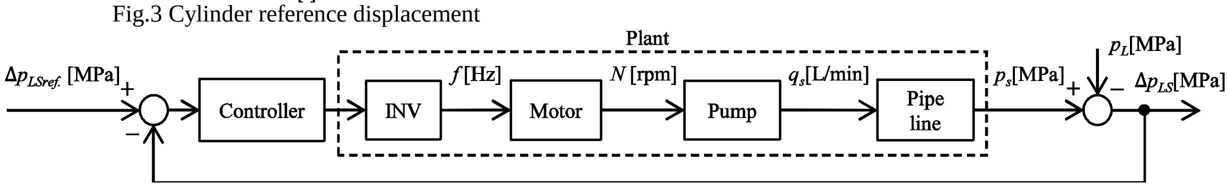


Fig.2 Block diagram of LS system

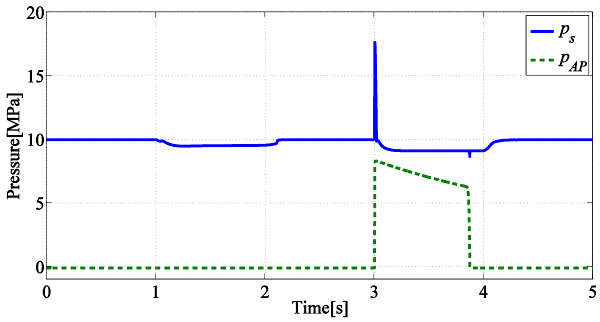


Fig.7 p_s and p_{AP} in Pattern A ($p_{pre.}$=5.4[MPa])

The energy efficiency which shows energy consumption for conventional circuit is defined as Eq.(2).

$$\eta = \frac{E}{E_{conv.}} \times 100 \tag{2}$$

where E is the output energy of M in each system, defined as

$$E = \int_{t_1}^{t_2} N \cdot T dt + \int_{t_3}^{t_4} N \cdot T dt \tag{3}$$

where t_1 and t_2 are the start time of cylinder descent and end time of cylinder descent, and t_3 and t_4 are the start time of cylinder ascent and end time of cylinder ascent, respectively. $E_{conv.}$ is the output energy of M in conventional circuit. T is the torque of M and can be expressed as

$$T = \Delta p \cdot V \tag{4}$$

where Δp is the pressure difference through the pump. V is the displacement of pump. As a simulation result, the energy-saving performance and the control performance are shown in Table 2, where the condition which the cylinder cannot get decent motion for pressure balance is shown as x.

Table 2 Energy-saving and control performances of proposed circuit

	$p_{pre.}$ [MPa]	Energy consumption[kJ]		η [%]	Max. time delay for $x_{conv.}$[s]
		Descent motion	Ascent motion		
Conven-tional circuit	–	46.67	53.99	100	–
Pattern A	4.8	45.79	29.68	75	0.03
	5.4	45.84	26.64	72	0.05
	6.0	×	×	×	×
Pattern B	1.8	0	45.00	45	0.03
	2.4	0	41.92	42	0.05
	3.0	×	×	×	×

Regarding Figure 7 and Eq.(4), the output energy of M decreases in descent motion because the torque of M depends on the pressure difference through the pump. According to Table 2, $p_{pre.}$ should take higher value in pattern A because this pattern requires energy in ascent motion. Therefore, the energy consumption of pattern A in ascent motion is lower value. On the other hand, pattern B does not need energy in descent motion. Thus, this pattern has better energy performance.

4.4 Conventional circuit with LS system

This paragraph simulates conventional circuit with conventional LS system and proposed LS system. The speed of M in Figure 4 is controlled by the inverter. In simulation of proposed LS system, $\Delta p_{LSref.}$=5[MPa] for $\dot{x}_{ref.}>0$, $\Delta p_{LSref.}$=2[MPa] for $\dot{x}_{ref.}=0$, $\Delta p_{LSref.}$=0.1[MPa] for $\dot{x}_{ref.}<0$. The pressure in the case of proposed LS system is shown in Figure 8. Simulation results are summarized in Table 3.

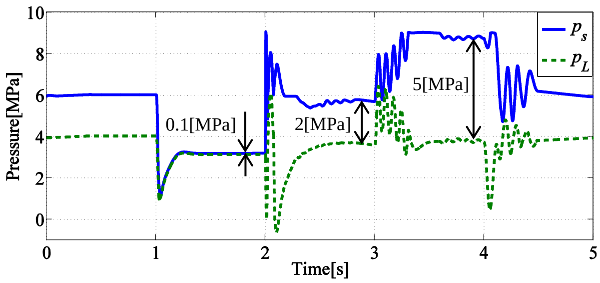


Fig.8 Pressure (proposed LS system)

Table 3 Energy and control performances of system of conventional circuit with LS system

	Energy consumption[kJ]		η [%]	Max. time delay for $x_{conv.}$[s]
	Descent motion	Ascent motion		
Conventional LS system ($\Delta p_{LSref.}$= 2[MPa])	9.60	23.98	33	0.12
Conventional LS system ($\Delta p_{LSref.}$= 5[MPa])	15.31	36.57	52	0.02
Proposed LS system	7.14	34.07	41	0.02

According to Table 3, the case with $\Delta p_{LSref.}$=2[MPa] is the most efficient case. However, the time delay in this case during ascent motion is too large because cylinder device system needs energy in ascent motion. Since $\Delta p_{LSref.}$ should be large value to reduce time delay in ascent motion. In contrast, proposed LS system is high energy performance with high control performance like the case that $\Delta p_{LSref.}$=5[MPa]. The proposed LS system achieves better balance between two performances.

4.5 Proposed circuit with proposed LS system

This paragraph simulates proposed circuit with proposed LS system. Table 4 shows the simulation results. According to Table 4, the energy consumption of Pattern A in descent motion decreases because of proposed LS system. However, the control performance of this pattern gets worse because the energy supply in descent motion decreases. Pattern B shows better control performance than Pattern A.

According to Table 2-4, the energy efficiencies are summarized in Figure 9. Pattern B with proposed LS system gives the highest energy performance because of no energy supply in descent motion and proposed LS system. Moreover, according to Table 2 and 4, the control performance of Pattern B with LS system is almost same to the control performance of this pattern without LS system.

Table 4 Energy-saving and control performances of proposed circuit with LS system

	$p_{pre.}$ [MPa]	Energy consumption[kJ]		η [%]	Max. time delay for $x_{conv.}$[s]
		Descent motion	Ascent motion		
Pattern A	2.8	9.02	19.42	28	0.05
	3.4	7.77	16.29	24	0.09
	4.0	×	×	×	×
Pattern B	1.8	0	24.61	24	0.03
	2.4	0	21.47	21	0.06
	3.0	×	×	×	×

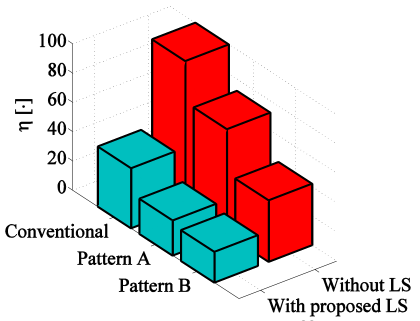


Fig.9 Comparison of energy efficiency

CONCLUSIONS

In this paper, a cylinder control system with boosting suction line by ACC saving-energy and LS system was proposed and its efficiency and control performances were discussed. By combining proposed circuit and LS system, we confirmed that energy saving efficiency was greatly improved. Especially, Pattern B with proposed LS system gave high energy-saving performance and the control performance which was almost same to conventional system.

REFERENCES

[1] Wang, T., Wang, Q., An Energy-Saving Pressure-Compensated Hydraulic System With Electrical Approach, IEEE/ASME TRANSACTIONS ON MECHATRONICS, vol.19, no. 2, pp.570-578, 2014.

[2] Ochiai, M., 建設機械のハイブリッド化とハイブリッドショベル (in Japanese), 建設の施工企画, 2009.

[3] Sanada, K., 油圧シリンダで駆動される負荷の位置エネルギーの再生 (in Japanese), SICE IA Division Conference, Tokyo, 2012.

[4] Loverc, D., Kastrevc, M., Ulaga, S., Electro-hydraulic load sensing with a speed – controlled hydraulic supply system on forming-machines, Springer-Verlag London Limited, 2008.

NOMENCLATURE

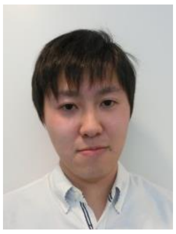
x : Cylinder displacement
m : Mass
f : Frequency
N : Rotational speed
p : Pressure
q : Flow
T : Torque
V : Displacement of pump

abbreviation

ACC : Accumulator
LS : Load sensing
SV : Servo valve
RV : Relief valve
VS : ON-OFF valve
CV : Check valve
PV : Proportional valve
INV : Inverter
M : Electric motor

subscripts

n : $n = 1,\ldots,3$ Number of valve
ref. : Reference
ACC : Accumulator
AP : ACC to pump
LS : Load sensing
s : Supply from pump
L : Load
b : bottom
r : rod
conv. : Conventional
pre. : Precharge pressure of ACC



Ryo Yagisawa is the B.E. student in machinery and control systems from Shibaura Institute of Technology.
His current interests include energy saving and control system for hydraulic circuit.

Kazuhisa Ito received the B.E.(1993), M.E.(1995), and D.E.(2001) degrees in mechanical engineering from Sophia University. He is a full Professor, Department of Machinery and Control Systems, Shibaura Institute of Technology.
His current research interests include the controller design for nonlinear systems and its application to the mechanical system and agricultural engineering.