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The Design of a Real-Time Simulator on the Hydraulic Servo System

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ABSTRACT

In this study we suggest real-time simulator that could describe real system without ordinary DSP card. This simulator is composed of 80196kc-16bit ordinary microprocessor, which is widely used up to now and personal computer. DSP card that has calculated complex numerical equation is replaced by personal computer and 80196kc generates control signals independently out of the personal computer. In all process personal computer is synchronized with one-board microprocessor (80196kc) within sampling time in the closed loop system. This makes it possible to be described in hydraulic servo system in real time.

Keywords : Real time simulator, 16bit ordinary controller, Synchronize, 80196kc, DSP card, One-board microprocessor

1. Introduction

Highly developed electronics have produced mechatronics that is the combination of mechanics and electronics. As mechatronic's developments, it is possible for application on workstation to work on personal computer. As a result, superiority in personal computer's development is possible to apply use of actual application with superior algorithm. 16bit or 8bit one-chip microprocessor is usually used as general-purpose controller in industry because engineering has relation with cost and time. Because hydraulic servo system is difficult to be made up and each component is very expensive, it takes long for actual system to make and test and it costs a high price. Because of these characteristics of hydraulic servo system a real time simulator that could describe behavior of real system is highly demanded without assembling real hydraulic system. Therefore many studies have been done on these subjects and many simulators are developed with superiority. Because commercial common computational analysis programs deal with control-force and real-system in one microprocessor it is difficult to describe real systems in real time. In comparison with dos-environment in which sampling time of all system works constantly by calling of system interrupt it is really difficult to divide the time of system in real time under windows environment. Since the nonlinearity of a hydraulic system common simulator have composed of many calculative times by using DSP (Digital Signal processing) and calculating hydraulic simulation and controller separately form DSP have made it possible to find the situations of the system in real time. Usually it is possible to calculate nonlinear characteristic using DSP card that could simulate the hydraulic system in real time. Because DSP card includes numerically computational routine these simulators with DSP card have good advantage of describing the real-time response of the system. But it is too expensive to compose the simulator with DSP [1-2].

In this study, we suggest real-time simulator that could describe real system without ordinary DSP card. This simulator is composed of 80196kc-16bit general-purpose microprocessor that is widely used up to now and personal computer [3-5]. DSP card that has calculated complex numerical equation is replaced by personal computer and 80196kc generates control signals independently out of the personal computer. In all process, personal computer is synchronized with one-board microprocessor (80196kc) within sampling time in the closed loop system. This makes it possible to be described in hydraulic servo system in real time.

2. Mathematical Model of Hydraulic Servo System

2.1 Hydraulic servo system

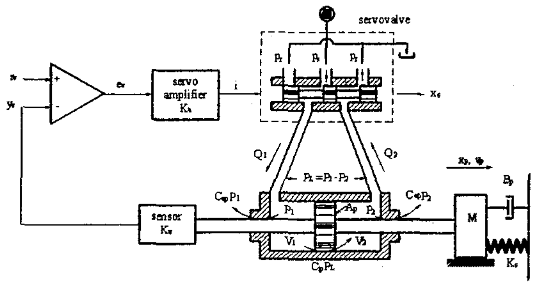

Fig. 1 Schematic diagram of electro-hydraulic servo system

Table 1 Parameters of the system used in computer simulation of electro-hydraulic system

Parameter		Value	Dimension
Servo amp.	k_a	10	mA/V
Servo valve	k_t	0.00833	cm/mA
	ω_v	219.9113	rad/s
	ζ	0.9	
	C_d	0.61	
Cylinder	A_p	8.76	cm
Displacement	K_f	1.6	V/m
Load	M	0.054	$kg_f s^2/cm$
	B_p	2	$kg_f s/cm$
	K_s	400	kg_f/cm
Sampling Time	T	1	ms

Hydraulic servo system is composed of hydraulic supply unit, servo valve, inertia load, position sensor, the amplifier of servo valve, ...etc. In case of position control it is schematically shown in Fig. 1. By using reference signal and the feedback signal that comes from the position sensor with hydraulic cylinder, controller transmits the control signals that are calculated from control algorithm to servo amplifier. Servo amplifier amplifies control signals and then operates servo valve. Exact equations of the mathematical model based on each hydraulic component and all of the system are needed to simulate the dynamic characteristic of hydraulic servo system through computer simulation exactly [6-7]. Types of hydraulic component is very various by composed system. It is difficult to derive exact mathematical model, which needs many test and actual experiment because mathematical models are different depending on applications and operating ranges.

In this study, applied parameters are used by the result of actual experiments based on assumption that doesn't have individual difference of each hydraulic component [8].

2.2 Mathematical model of servo valve

Generally, linear transfer functions of the servo valve are highly complex devices that exhibit high-order, nonlinear responses. Servo valve is approximated to proportional, first-order, second-order factor from differential equation based on frequency response curve regarding the displacement of valve spool by input current [9]. In this study, considering the characteristic of frequency response we can approximate second-order term.

$$\frac{d^2x_s(t)}{dt^2}+2\zeta_v\omega_v\frac{dx_s(t)}{dt}+\omega_v^2x_s(t)=\omega_v^2\cdot K_t\cdot i(t) \quad (1)$$

where K_t is torque motor gain, ζ_v is reduction ration of the servo valve, ω_v is undamped frequency of servo valve, x_v is spool displacement of servo valve, i is input current of servo amplifier.

2.3 Load-pressure characteristic of servo valve

The arrow represented in Fig. 1 is in the direction of positive. By spool displacement of servo valve, flows of supply and return which comes through spool is given by,

$$Q_1(t) = C_d\omega\, x_s(t)\sqrt{\frac{2}{\rho}(P_s - P_1(t))} \quad (2)$$

$$Q_2(t) = C_d \omega x_s(t) \sqrt{\frac{2}{\rho} P_2} \quad (3)$$

where C_d is orifice flow coefficient of valve spool, ω is area gradient of valve port, ρ is density of hydraulic oil, P_s is supply pressure of pump, P_1 and P_2 is supply and return pressure of hydraulic cylinder. The spool of servo valve is symmetric and critic center, equation is given by,

$$Q_1(t) = Q_2(t) \quad (4)$$

$$P_s - P_1(t) = P_2(t) \quad (5)$$

and defines load pressure and flow as Eq.(6) and Eq.(7)

$$P_L(t) = P_1(t) - P_2(t) \quad (6)$$

$$Q_L(t) = \frac{Q_1(t) + Q_2(t)}{2} \quad (7)$$

and derives Eq.(8) and Eq.(9) from Eq.(6) and Eq.(7)

$$P_1(t) = \frac{P_s + P_L(t)}{2} \quad (8)$$

$$P_2(t) = \frac{P_s - P_L(t)}{2} \quad (9)$$

for matched and symmetrical valve Eq(4), Eq(5), Eq(8), Eq(9) are applicable, and Eq(7) become,

$$Q_L(t) = C_d \omega x_s(t) \sqrt{\frac{1}{\rho}(P_s - P_L(t))} \quad (10)$$

2.4 Load-flow equation of a double rod hydraulic cylinder

For a symmetrical double rod cylinder, flows in each line (supply flow: $Q_1(t)$, return flow: $Q_2(t)$) become,

$$Q_1(t) = C_{ip}(P_1(t) - P_2(t)) + C_{ep}P_1(t) + \frac{dV_1(t)}{dt} + \frac{V_1(t)}{\beta_e}\frac{dP_1(t)}{dt} \quad (11)$$

$$Q_2(t) = C_{ip}(P_1(t) - P_2(t)) + C_{ep}P_2(t) + \frac{dV_2(t)}{dt} + \frac{V_2(t)}{\beta_e}\frac{dP_2(t)}{dt} \quad (12)$$

where C_{ip} and C_{ep} is internal, external leakage coefficient, β_e is volumetric elastic coefficient. Thus, the general load-flow equation of the double rod cylinder can be written,

$$Q_L(t) = A_p \frac{dx_p(t)}{dt} + C_t P_L(t) + \frac{V_t}{4\beta_e}\frac{dP_L(t)}{dt} \quad (13)$$

where V_t is volume of valve, hydraulic line, cylinder, $C_t = (C_{ip} + \frac{C_{ep}}{2})$ $[cm^5 / kg_f / s]$ is total leakage coefficient.

2.5 The dynamic equation of a double road hydraulic cylinder

Therefore, the dynamic equation of a double rod cylinder becomes,

$$A_p P_L(t) = M \frac{d^2 x_p(t)}{dt^2} + B_p \frac{dx_p(t)}{dt} + K_s x_p(t) + F_L \quad (14)$$

where A_p is pressure area of the cylinder, M is the load of inertia mass, B_p is the load of the viscosity, K_s is the elastic load, F_L is the total disturbance of load and co-friction and static friction.

3. The Organization of The Real-Time Simulator

Real-time simulator is schematically shown in Fig. 2 and it is made up one-board microprocessor that acts as controller and simulator PCs (personal computer). One-board microprocessor, digital-analog converter that is connected to one board microprocessor and the circuit used to shift voltage range were made by ourselves as shown in Fig. 3, Fig. 4.

Generated signals that come from the controller (one-board microprocessor) in real-time simulator are transmitted to simulator PCs through D/A (digital-analog) converter in the one-board microprocessor. A position signals of hydraulic cylinder is transmitted to one-board microprocessor through A/D (analog-digital), which is connected to PCL812 that is kind of data acquisition card of PCs. The main program of the real time simulator consists of hydraulic simulator PCs and outside controller (one-board micro processor). The former is the program that is operated by PCs it is important to simulate actual system.

Control signals that come from the one-board controller are transmitted to PCs simulator through analog-digital converter with PCL812 and then operating systems, generated position signal that comes from sensor with microprocessor, is transmitted to one-board controller through digital-analog converter that is connected to simulator PCs. Because of the position signals of a cylinder that is generated voltage output from sensor with simulator PCs, it must be input through analog-digital converter in the one-board microprocessor.

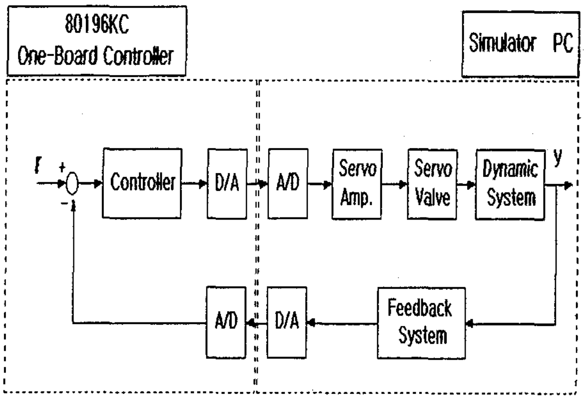

Fig. 2 The real time simulator of Electro hydraulic servo system

Fig. 3 The one-board microprocessor of the Electro-Hydraulic real time simulator

The later is the program that is operated by the one-board microprocessor that generated control signals through analog-digital converter with one-board microprocessor based on position signals of PCs and controls the simulators in real time through digital-analog convert of one-board microprocessor.

Control signals that come from the controller need the process of the digital-analog converter because the amplifier of servo valve has the characteristic of voltage output in real systems. Therefore, control signals that come from one board and the simulator of PCs are programmed by synchronizing each other in real time, when it generates control signals.

Fig. 4 The experimental setup of Real-time simulator

Regarding the modeling of the valve and cylinder as shown in chap. 2, we program the real-time simulator based on each hydraulic module. The entire real-time simulator is programmed by C language, using Runge Kutta fourth order method [10] that is numerical analysis method and then in order to prove the result of the real-time simulator we compare it with Matlab that is commercial simulation packages and is commonly used for the analysis of control systems.

4. Comparing The Result of The Real-Time Simulaotor with Simulation Program

Schematic diagram of the real time simulator that simulates the hydraulic servo system is shown in Fig. 2. Control signals that come from with one-board microprocessor come through digital-analog converter, control signals that come through analog-digital converter with PCL812 in the PCs operate valve driver in the simulator and final position signals of the cylinder is outputted by using digital-analog converter with PCL812 [11].

Output signal that comes from the PCs that are inputted by analog-digital converter and then input signal generates new control signal and then outputs signals, which is done in real time. Table 1 presents the parameters of the real-time simulator and we choose main parameters out of many experimental results.

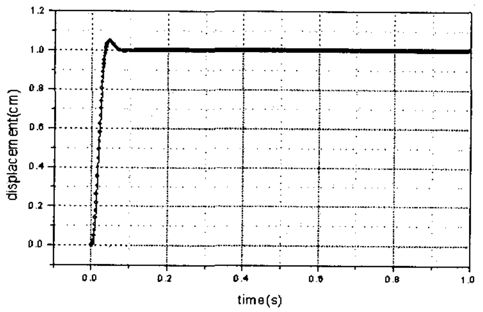

Fig. 5 The simulation result of Electro-hydraulic servo system

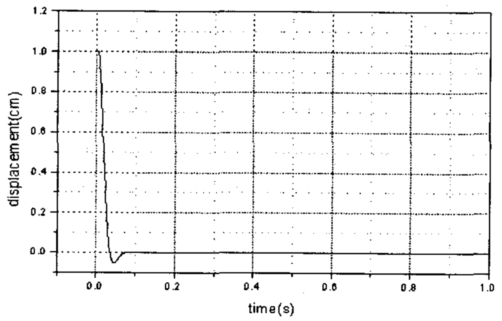

Fig. 6 The control input of Electro-hydraulic servo system

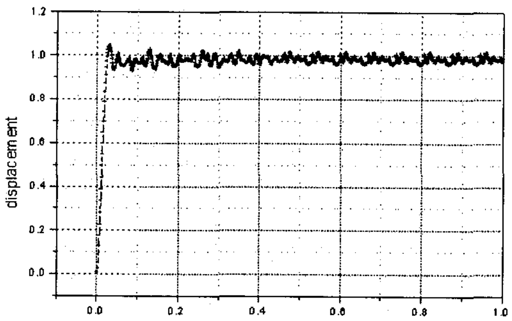

Fig. 7 The result of Electro-hydraulic servo system usingreal time simulator

Considering the frequency bandwidth of a servo valve, the bandwidth of that is about 100[Hz], we choose 0.5[ms] from the interval time of the closed loop to the numerical computation model on the simulator PCs. Regarding the response bandwidth of total closed loop system, we choose 1[ms] that is sampling time.

At this simulator -it is very important that the signals that are generated by one-board microprocessor- have to synchronize with the signal of the simulator PCs in real time. If not, it is impossible to get the exact result. In this study, in order to synchronize the simulator PCs and one-board microprocessor, all of hydraulic simulator can't operate until the checking for the synchronization of the signals between he simulator PCs and one-board microprocessor. Because of common position control system of the hydraulic servo system as shown in Fig. 1 that is not opposite loading, applying proportional control at that system (proportional gain, Kp: 4), we have a good result of the test [12].

Fig. 5, Fig. 6 and Fig. 7 present the result of experiment in the real-time simulator and simulation package, and those are good agreement as shown in Fig 5, Fig. 7. Small error signals of steady state in the real-time simulator as shown in Fig. 7, reflect on actual output of the real system, which is generated from the process of analog-digital convert and digital-analog. Regarding continuous system passed through real-time simulator in simulation, this situation that is changed discrete system -actual digital system is generated. So influence of sampling time, noise and resolution of analog-digital converter fluctuates errors that generated in the process of discrete system and changes the magnitude of error.

To increase resolution of analog-digital converter and digital-analog converter that uses one-board microprocessor in the real-time simulator make it possible to reduce trouble that is the error of fluctuation in steady state is shown in Fig. 7 [13-14].

5. Conclusion

Comparing computer simulation with real experience in order to find characteristic of actual systems, computer simulation costs a little time and expenses [15]. But composing real system base on the computer simulation, it has many trouble that is not to be considered computer simulation [16]. In order to minimize the troubles and find accurately characteristic of real-hardware, real-time simulator highly needs that is intermediate grades of real systems and computer simulation.

Real-time Simulator as hydraulic servo systems is composed of personal computer 1EA and controller 1EA, which is widely used up to now in industry. Comparing DSP card that is used for numerical analysis at the general-purpose simulator, with PCs, personal computer is not only ordinary and powerful execution also cheap costs. As synchronized with controller in real time, personal computers make it possible to simulate the features of the real system's properties without DSP card. By using this method in this paper, we maintain the performance of simulator and expect the effect of cost reduction. The test of the controller that is possible to be applied hydraulic control system is done together, by using 16bit one-board microprocessor with real-time simulator. So we confirmed that real time simulator reduces time and minimizes troubles when we make real-hardware.

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