Optimal energy saving model for RCL(Re-Coiling Ling) hydraulic system (ICCAS 2003)

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Abstract: POSCO Kwang-Yang Works #2 Cold Rolling Mill RCL has the main hydraulic system that controlled on/off control method. In the aspect of the consumption of electrical energy this system has some problem. So, we present a continuous control method instead of on/off control method that controls the pressure of main hydraulic system with saving the electric energy.

Keywords: RCL, Main hydraulic system, Energy saving, Inverter, Optimal controller

1. INTRODUCTION

POSCO Kwang-Yang Steel #2 Cold Rolling Mill RCL (Re-Coiling Line) is the line that coats the preventive rust oil to the surface of strip and divide or cutting the strip according to request of demander.
RCL has many hydraulic equipments like as walking beam, mandrel, shearing machine, etc. These hydraulic equipments supplied hydraulic power from the main hydraulic system. This main hydraulic system controls the pressure using on/off the mechanical valves. The on/off control method that applied the #2 RCL main hydraulic system is good in the side of to maintain the target pressure but it has a some problem in the aspect of energy consumption. So, we solve the problem using continuous control method.

2. COMPOSITION OF RCL MAIN HYDRAULIC SYSTEM [7]

Main hydraulic system of #2 RCL is composed pump unit, accumulator unit and oil storage tank and pipes lines

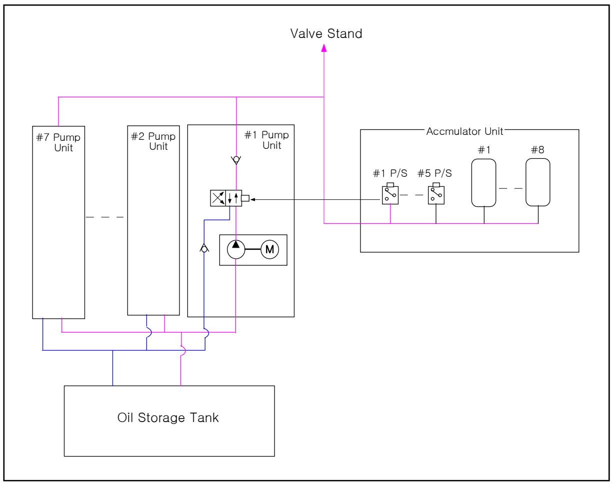

Fig.1 Lay-out of the #2RCL main hydraulic system

Pump unit have 7 motors (AC, 75KW, 6 Poles) and solenoid valves. 7 motors grouped lead pump, #1 lag pump, #2 lag pump and stand-by pump.
Each lead and #1, #2 lag pumps have 2 motors and stand-by pump has 1 motor.
Solenoid valves perform on/off the hydraulic power line that triggered by pressure switch.

Accumulator unit has two components, one is the pressure switch and the other is accumulator. Accumulator is function as a reducer of hydraulic pulsation and assistance of energy source. #2 RCL Main hydraulic system have 5 pressure switches, each switch has their own setting values and using this setting values, pressure switches control the loading/unloading timing.

4 grouped 7motors go to the unloading mode when the output pressure is over 140 [Kgf/㎠]. The starting pressure of loading mode is different each by each. In the case of lead pump, if the pressure is 120 and below 120 [Kgf/㎠] than #1 pressure switch trigger relay that connected with lead pump solenoid valve. #1 lag pump enter the loading mode when the pressure is below 112 [Kgf/㎠], and the case of #2 lag pump, the starting loading pressure is under 100 [Kgf/㎠]. If the hydraulic system pressure under 90[Kgf/㎠], #5 pressure switch operate alarm signal relay and all the pumps to stop the rotate, consequently RCL line is down.

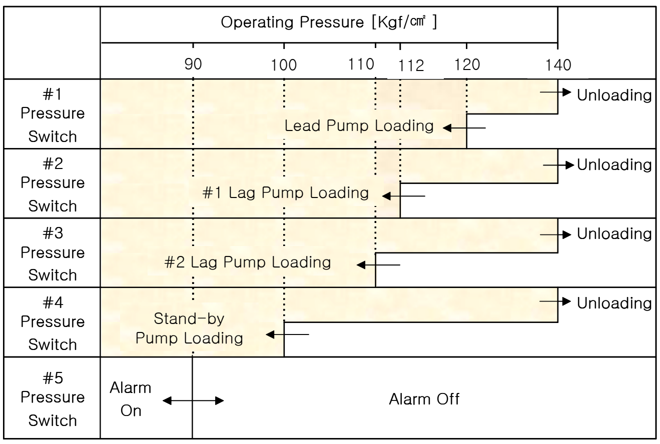

Fig.2 Setting values of the loading/unloading pressure

The action of loading/unloading is accomplished by execute of pressure switch and on/off of solenoid valves.
When the hydraulic system is in the loading mode, the hydraulic line has a path that oil tank → hydraulic pump → valve stand (following the solid line in Fig.3) and in this case the motor is working in the boundary of a rated current. During the unloading mode, the hydraulic system has the path that oil tank → hydraulic pump → oil tank (following the dotted line Fig.3), while the oil flow this path, the hydraulic system is not in working state but in idle condition and the motor consume the electric power nearly 40% of loading mode condition.

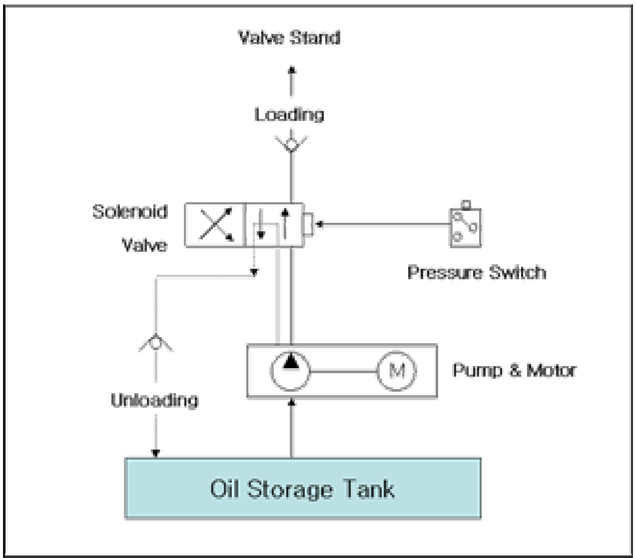

Fig.3 The action of the pump in loading or unloading mode

In the aspect of energy consumption, the #2 RCL main hydraulic control system has some problems. The first problem is the number of pumps. To obtain the stability of target pressure this system has so many assistant pumps. For example the #2 lag pump is not loading in 72 hours, in the 72 hours the #2 lag pump is in the unloading mode to prepare the sudden change of pressure. The second problem is the unnecessary energy consumption of unlading term. In the unlading term the main hydraulic system consume the energy to idle rotate the oil. In the unloading mode the system consume the electric energy nearly 40% of loading mode. Consider about the #2 RCL running 292 days in a year, the unloading energy part is not small. We measure the consumed electric power of #2 lag pump in 3 day. #2 lag pumps consumed electric power 1,008 KWh per a day and that means The #2 lag pumps consume the electric energy nearly 300,000 KWh per year.

Because of this problem, we use continuous control method instead of on-off control method. In order to control the plant continuously, we use an inverter which controls motor speed. Fig 4 represents the diagram of pump using inverter

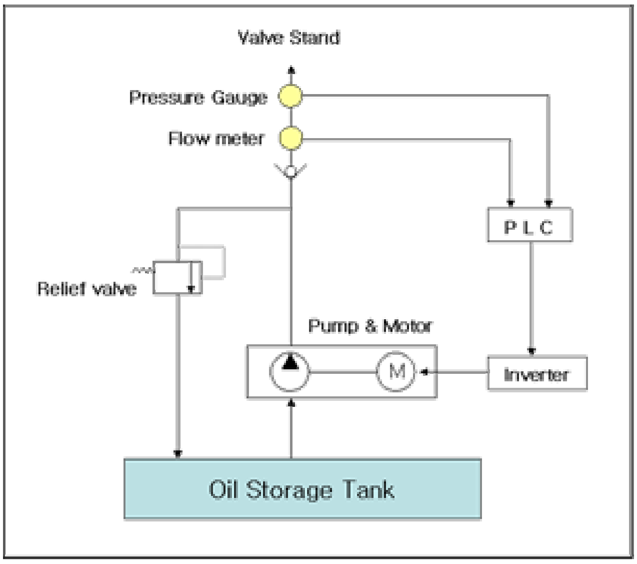

Fig.4 Pump unit diagram of using inverter

In order to use the optimal control technique for the pump, we have to make the model of pump. The pump model is (2.1).

$$x(k+1) = Ax(k) + Bu(k)$$
$$y(k) = Cx(k) \quad (2.1)$$

This model is discrete time model, and the states are the motor current, the pressure, and the flow rate of oil. The input is the motor torque, and output is pressure. In order to get the model parameter A, B, and C, we use system identification technique. Using above model, we design an optimal controller. In next part we explain the design of optimal controller when the constrained inputs exist.

3. OPTIMAL CONTROLLER DESIGN FOR PRESSURE MODEL [5]

Consider a linear discrete-time system

$$x(k+1) = Ax(k) + Bu(k) \quad (3.1)$$

We assume that the system is subject to input and/or state constraint represented by

$$Eu(k) \le e, \quad Gx(k) \le g, \ k = 1,2,\cdots \quad (3.2)$$

Without loss of generality, we assume that the origins are included in the set defined (2.105). Most common type of input constraint, for example, is given by

$$-u_{\min} \le u(k) \le u_{\max}, \quad k = 0,1,\cdots, \quad (3.3)$$

Where $u_{\max}$, $u_{\min}$ The constraint given in (3.3) can then be expressed as in (3.2) with

$$E = \begin{bmatrix} I \\ -I \end{bmatrix}, \quad e = \begin{bmatrix} u_{\max} \\ u_{\min} \end{bmatrix}$$

Cost function to be minimized in constrained LQR is given by

$$J_\infty = \sum_{k=0}^{\infty}[x^T(k)Qx(k) + u^T(k)Ru(k)]$$

Then constrained LQR problem is formulated as
Minimize J_∞ *subject to* (3.1) *and* (3.2)

Look over the concept of maximal output admissible set that related with constrained LQR. It is well-known that LQR for unconstrained system is given by
$u(k) = Kx(k)$

Where

$$K = -(R + B^T PB)^{-1} B^T PA \tag{3.4}$$

$$P = A^T PA - A^T PB\left(R + B^T PB\right)^{-1} B^T PA + Q \tag{3.5}$$

The closed loop system of (2.104) is represented by

$$x(k+1) = A_{cl}x(k)$$
$$y(k) = Cx(k)$$

Where $A_{cl} = A + BK$. Because the control $u(k) = Kx(k)$ is optimal in case that the system is unconstrained, it is not optimal for the actual system, which has input and (or) state constraint as in (3.2). However, if the initial state x_0, is in a certain region, the input and(or) state constraint will never be active and thus the control $u(k) = Kx(k)$ is optimal. We will obtain such a region for x_0 before moving to constrained LQR problem.

$$x(k+1) = A_{cl}x(k)$$
$$u(k) = Kx(k)$$

The input constraint is equivalently changed into state constraint as follows;
$Eu \le e \Leftrightarrow EKx \le e$

Then the total constraint is given by

$$\Phi x \le \phi, \quad where\ \Phi = \begin{bmatrix} EK \\ G \end{bmatrix}, \ \phi = \begin{bmatrix} e \\ g \end{bmatrix} \tag{3.6}$$

Then the constraint-satisfying region of x_0 is characterized by $\Omega_\infty(A_{cl}, \Phi, \phi)$, which can be obtained using algorithm presented previously.

Once again consider about LQR for constrained systems Note that the J_∞ can be decomposed as

$$J_\infty = \sum_{k=0}^{\infty}[x^T(k)Qx(k) + u^T(k)Ru(k)] + \sum_{i=0}^{\infty}[x^T(k)Qx(k) + u^T(k)Ru(k)]$$

Let's say that $x(N) \in \Omega_\infty$. Then $u(k) = Kx(k)$ is an optimal control satisfying all the given constraints and we have

$$\sum_{i=N}^{\infty}[x^T(k)Qx(k) + u^T(k)Ru(k)] = x^T(N)Px(N)$$

Where P is obtained using (3.5). Therefore, in a certain case, the cost J_∞ can be rewritten into

$$J_N = \sum_{k=0}^{N-1}[x^T(k)Qx(k) + u^T(k)Ru(k)] + x^T(N)Px(N) \tag{3 .7}$$

It is an important observation that the original infinite horizon cost J_∞ can also be equivalently replaced by a finite horizon cost J_N in (3.7)

Consider the following optimization problem with constraints
Minimize J_N *subject to*
$Eu(k) \le e, \ Gx(k) g, \quad k = 0,1,\cdots,N-1$

Note that the above optimization problem is finite-dimensional quadratic programming problem. Assume that the optimization problem is feasible. Let's denote the optimal control and resultant state by $u^*(k)$ and $x^*(k)$, respectively. We will use the control strategy

$$\begin{cases} u(k) = u^*(k), & k = 0,1,\cdots, N-1 \\ u(k) = Kx(k), & k = N, N+1,\cdots. \end{cases} \tag{3.8}$$

It is clear that $u(k)$ and $x(k)$, $k = 0,1,\cdots,N-1$, satisfy the given input and state constraint. However, it is not guaranteed that $u(k)$ for $k = N, N+1,\cdots$

Satisfy the given constraint. It was found out that if $u(N) \in \Omega_\infty(A_{cl}, \Phi, \phi)$, the control sequence in (3.8) constitute the LQR for constrained system.

4. SIMULATION RESULT

In this paper we induce a controller from chapter 3. This optimal controller has the constraint input condition and could save energy when the disturbance is come out. We apply this controller to following plant.

$$\dot{x} = Ax + B_u + B_W d$$
$$y = cx$$
(4.1)

Where "d " is the disturbance and input "u" has the following constraint condition

$$-u_{\min} \le u(k) \le u_{\max}, \qquad k = 0,1,\cdots, \qquad (4.2)$$

Following figures show the results.

Figure 5 is the disturbance. In the figure 6 and 7 illustrate the result that the state goes to zero by the optimal controller. In the figure 8, 9 and 10 show the change of input. If there is no constraint, the input change following dotted line but we have constraint so, the input change solid line. In these graphs we can see the optimal controller driven from chapter 3 is well stabilized the hydraulic system.

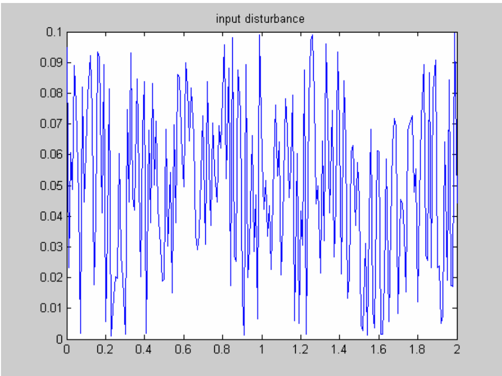

Fig.5

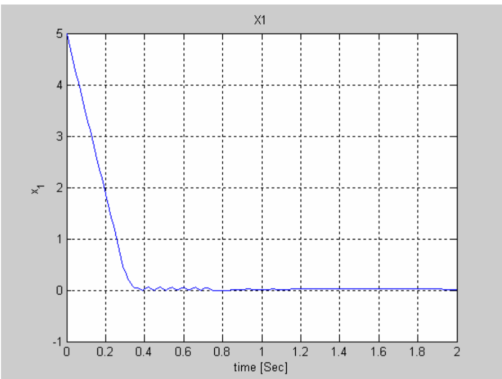

Fig.6

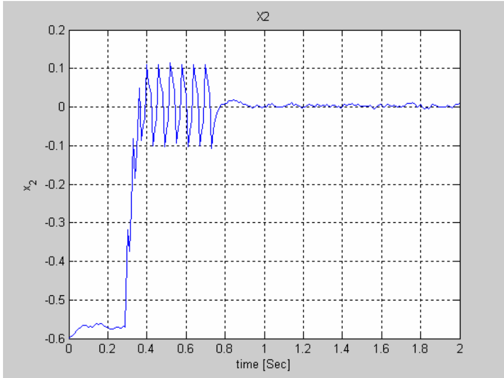

Fig.7

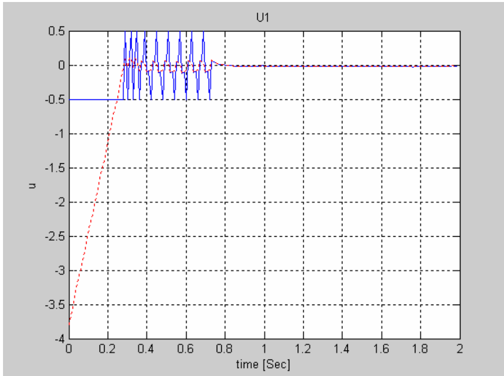

Fig.8

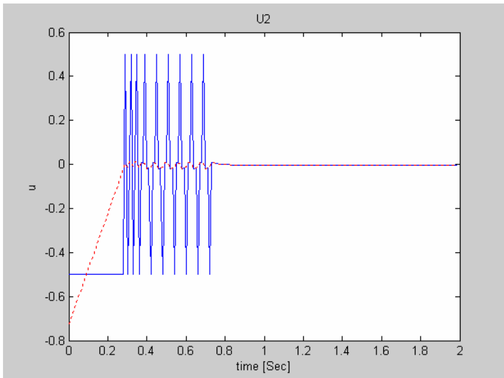

Fig.9

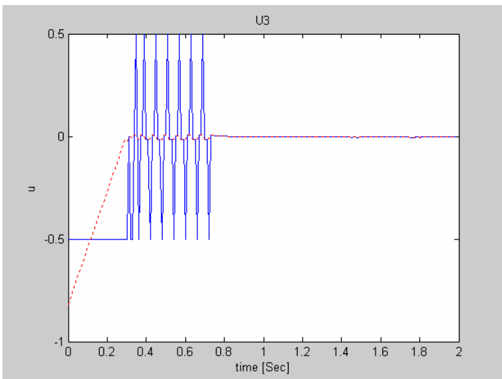

Fig.10

CONCLUSION

In this paper we found and simulated the optimal controller of hydraulic pump for energy saving in RCL plant. The multi input system is consisted through the parallel connection of hydraulic pump and the input of each pump has the constraint condition. We suppose that the system has the disturbance. In the results of simulation, we can find that the optimal controller for energy saving is well operated. But this simulation model is the very simple and implicated with several postulations. So, we need more realistic formulas and model for optimal controller that could save the energy of main hydraulic system.

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