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Comparing Constrained Controllers for Nonlinear Hydraulic Plant Using Matlab Interface

P. Bistak M. Huba I. Belai

* *Slovak University of Technology in Bratislava*
(e-mail: pavol.bistak, mikulas.huba@stuba.sk, igor.belai@stuba.sk)

Abstract: Controller design for hydraulic plants represents a task carried out frequently to demonstrate and compare properties of different nonlinear control approaches. The developed application demonstrates by simulation impact of several degrees of freedom in design of nonlinear model based methods: performance achievable by the dynamical feedforward, influence of different control constraints, of the parameter uncertainty, and of the closed loop dead time. The application can run locally as a simulation tool designed in Matlab/Simulink but also through the Internet as a virtual laboratory. Both approaches are described in the paper.

Keywords: PID control, nonlinear control, feedback linearization, robustness, dead time compensation, Matlab/Simulink, interactive tool, Internet application

1. INTRODUCTION

Hydraulic plants are frequently used to demonstrate features of nonlinear plant control, see e.g. Bistak and Huba [2014a,b], Bisták and Huba [2014], Belikov and Petlenkov [2014] and the references therein. Due to the process nonlinearity, the overall design process may be evaluated just experimentally - by simulation, or by real time control. In order to evaluate validity of the model used, it is recommended to combine and compare results of both these approaches. This paper introduces interactive application appropriate for the first phase of such a design process, but with the aim to continue later with real time experiments.

The paper is organized as follows. Section 2 discusses models of the hydraulic system. The next chapter briefly introduces performance criteria. Section 4 summarizes a constrained controller design together with a disturbance observer implementation. The developed application is described as an interactive simulation tool in Section 5. Section 6 is focused on an Internet version of the developed application and is followed by Conclusions.

2. NONLINEAR HYDRAULIC PLANT

The hydraulic plant represented by coupled tanks (Fig. 1) belongs to one of the most common examples of a nonlinear system. Besides of two tanks, the system consists of three valves and two pumps but in this paper only the first pump as a controlled input will be considered. The second pump may be used to produce disturbances. Each tank has its own outflow controlled by the respective valve. Moreover, an additional valve couples both tanks. The coupled tanks system variables and parameters are denoted according to Fig. 2. The liquid level in the first tank is denoted as x_1, with the liquid inflow u_1, tank cross-

Fig. 1. Coupled tanks laboratory system

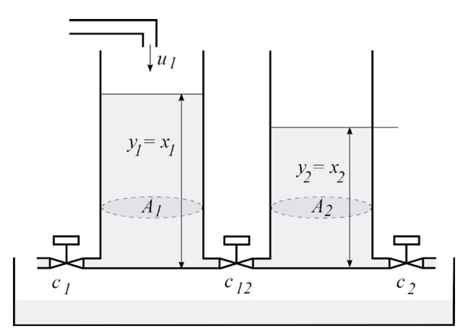

Fig. 2. Schematic drawing of Coupled tanks

section area A_1 and the valve outflow coefficient c_1. Similarly, for the second tank the liquid level is denoted as x_2, the cross-section area A_2, and the valve outflow coefficient c_2. Both tanks are coupled through the valve characterized by the coefficient c_{12}. The system can be modelled by differential equations derived via the application of the mass conservation law. It yields

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$$\dot{x}_1 = \frac{1}{A_1}u_1 - c_1\sqrt{x_1} - c_{12}\sqrt[\pm]{x_1 - x_2}$$
$$\dot{x}_2 = -c_2\sqrt{x_2} + c_{12}\sqrt[\pm]{x_1 - x_2} \tag{1}$$

where the symbol $\sqrt[\pm]{\cdot}$ stands for

$$\sqrt[\pm]{z} = \begin{cases} \sqrt{z} & \text{if } z \geq 0 \\ -\sqrt{-z} & \text{if } z < 0 \end{cases} \tag{2}$$

The coupled tanks can be easily converted to one-tank system when the valve between two tanks is closed ($c_{12} = 0$). In that case the output of the system is given by the hight of the level in the first tank

$$y_1 = x_1 \tag{3}$$

Otherwise it is considered that the outflow valve of the first tank is closed ($c_1 = 0$) that yields the two-tank configuration and in this case the second state variable is considered as the output

$$y_2 = x_2 \tag{4}$$

The input value u_1 is considered to be saturated $u_1 = sat(\cdot)$, i.e.

$$U_{r1} \leq u_1 \leq U_{r2} \tag{5}$$

3. PERFORMANCE MEASURES

Depending on the output of the system (one-tank or two-tanks) the aim of the control can be characterized by a number of control signal pulses [Huba and Šimunek, 2007]. Then the quality of control can be evaluated by several performance measures mentioned below.

Strong advantage of the hydraulic plants is given by the process visibility allowing a clear physical interpretation of control processes. Whereas the speed of transients may be evaluated by the integral of absolute error IAE, there are important also shape related performance measures based on requirement of monotonic transients at the output after a setpoint step change, monotonic return to the setpoint value after a deviation caused by a disturbance step, etc. Performance measures for such shape related evaluation may be based on relative total variance measures denoted as TV0, TV1, TV2,...

The later developed application provides a useful interactive tool to follow monotonic transients and number of pulses according to output and control time responses. It also offers all data necessary to evaluate performance criteria to compare the quality of control.

4. CONTROL OF HYDRAULIC PLANT

In this section two types of controllers will be designed for one and two-tank hydraulic systems. The first type is represented by a feedback controller that considers input constraints. Therefore it is called a constrained P-controller (for one-tank system) and a constrained PD-controller (for two-tank system). Also the second type of controllers respects input constraints but it is applied to the model of the hydraulic plant to produce a dynamical feedforward. Then as a feedback controller a simple P-controller is used to correct differences between the output of the model and of the controlled system. Alternatively, PD control may be considered in future modifications. Additionally, nonlinear disturbance observer will be included to suppress input disturbances. Possible control structures for both types of controllers are in Fig. 3 and Fig. 4 respectively.

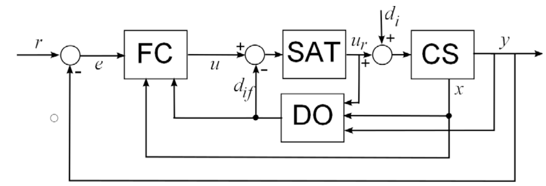

Fig. 3. Simplified constrained feedback control block diagram - feedback controller (FC), saturation (SAT), disturbance observer (DO), controlled system (CS)

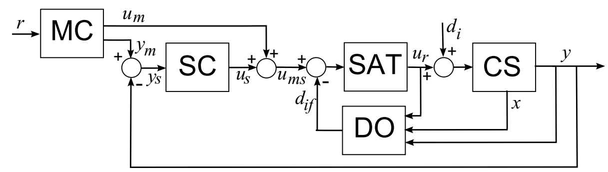

Fig. 4. Simplified model based dynamical feedforward control block diagram - model control (MC), stabilizing controller (SC), saturation (SAT), disturbance observer (DO), controlled system (CS)

4.1 Feedback control of one-tank system

In this case the output of the one-tank system is $y = x_1$ and (1) can be generally rewritten as

$$\frac{dy}{dt} = g(y)\,u - f(y) \tag{6}$$

After applying exact linearization [Isidori, 1995] the resulting feedback controller can be expressed in the form

$$u = sat(\frac{Ke + f(y)}{g(y)}) \tag{7}$$

where $e = r - y$ represents a control error, K is the P-controller gain after linearization, $f(y) = c_1\sqrt{y}$ and $g(y) = 1/A_1$. The feedback controller (7) is represented by the FC block in Fig. 3.

Note 1. For a chosen fixed point of linearization $y = y_p$ one can get a linear controller

$$u = sat(\frac{Ke + f(y_p)}{g(y_p)}) \tag{8}$$

representing a simple P-controller with a static feedforward. This can be considered for comparision.

4.2 Dynamical feedforward control of one-tank system

The dynamical feedforward control combines a feedforward control action u_m from the model control with a stabilizing control action u_s resulting from a simple feedback controller (Fig. 4). As a model controller the (7) can be exploited with the controlled system output y replaced by the model output y_m

$$u_m = sat(\frac{K_m e_m + f(y_m)}{g(y_m)}) \tag{9}$$

where $e_m = r - y_m$ is a model control error, K_m is the gain of the model P-controller, $f(y_m) = c_1\sqrt{y_m}$ and $g(y_m) = 1/A_1$. The model controller together with the model is represented by the MC block in the Fig. 4.

A difference between the output of the model y_m and the output of the controlled system y creates the stabilizing