Performance Analysis of the Level Control with Inverse Response by using Particle Swarm Optimization

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Abstract. Boiler is an important utility system to support operations in the industry. The control of water level in the steam drum is a complicated task due to the non-minimum phase (NMP), which possibly will cause instability to the controlled water level in the steam drum. Process identification and controller design are difficult tasks for the steam drum because of non-minimum phase. Following the previous literature, this paper proposed process identification to 3rd order transfer function and optimization of Proportional-Integral-Derivative (PID) tunings of the water level by using Particle Swarm Optimization (PSO). A Graphical User Interface (GUI) has been developed to provide a direct platform to deal with these tasks. The result of PSO is compared with other tuning methods in terms of performance indicator and index. An analysis of the performance curve in 3-dimension graphs is also presented to visualize the output performance of various proportional and integral gain settings. The study has concluded that PSO provided better PI tunings for the best control of the Heat Exchanger function in the LOOP-PRO software.

Keywords: Non-minimum phase, PID, Process Identification, Particle Swarm Optimization, Optimum Tuning.

1 Introduction

In the industry, boiler plant is widely used to support the process's operation. It provides heated and pressurized steam to rotate turbines for generating electricity as well as heated steam to many downstream processes. Controlling water level is the primary objective to ensure stable operations. However, rapid changes in the steam load and feedwater supply to the steam drum causes high volatility of the water level.

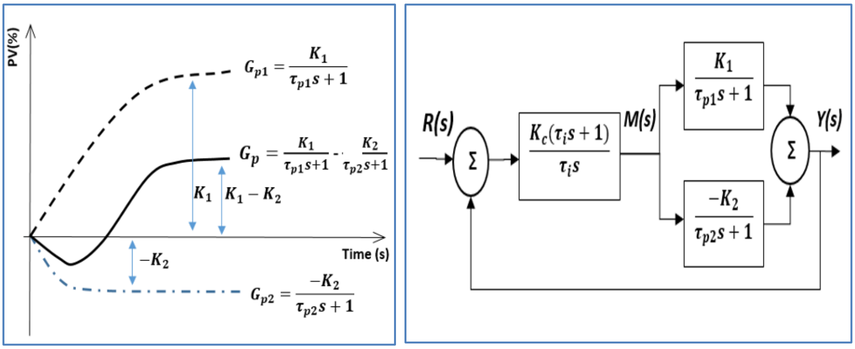
When steam load has decreased, the pressure in the steam drum is increased and thus, reduces the volume of the entrained vapour bubbles and thereby decreases the water level known as the shrink effect. Whereas, the increase of the steam load causing more volume of entrained vapour bubbles and creates the swell effect.

Apart from it, feedwater load also creates the swell and shrink effect in the steam boiler drum. The increment of feedwater load causes decreasing of water's temperature and reduced the volume of entrained bubbles [1]. With the constant heat supply, the water level will start the volume of entrained bubbles increases back to be a part of the

R. Alfred et al. (eds.), *Computational Science and Technology*,
Lecture Notes in Electrical Engineering 603,
https://doi.org/10.1007/978-981-15-0058-9_6

level measurement [2]. This is known as the shrink effect. In contrast, the swell effect will happen during the decrement of feedwater load.

The swell and shrink effect exhibits the inverse response that degrades control performance of water level in the steam drum [3]. The main characteristic of inverse response is reflected by a system with the process transfer function has a positive zero meaning zero in the right half plane [4], known as Non-minimum phase, *NMP*. The inverse response curve and the closed-loop diagram are shown in Fig. 1 (a) and (b).



(a) Inverse response (b) Closed-loop diagram model

Fig. 1. Inverse response curve and closed-loop diagram.

K_1 is the process gain of the initial first order system. K_2 is the process gain of the other first order system. τ_{p1} and τ_{p2} are the time constants of the two first order systems respectively. K_c and τ_i are the proportional gain and integral time constant. Besides, $Y(s)$ and $R(s)$ are the final output and step input respectively.

From Fig. 1 (b), $Y(s) = \left(\frac{K_1}{\tau_{p1}s+1} - \frac{K_2}{\tau_{p2}s+1}\right) u(s)$

$$Y(s) = \frac{(K_1\tau_{p2} - K_2\tau_{p1})s + (K_1 - K_2)}{(\tau_{p1}s+1)(\tau_{p2}s+1)} \tag{1}$$

When two opposing process models interact simultaneously, the inverse response appears due to competing effects of fast dynamic to provide opposite response initially until the slow dynamic that has higher gain has grown to prevail until the new steady-state value. The inverse response is preferable to maintain positive value for both numerator and denominator of the transfer function therefore in general, value of all parameters are summarized into (2).

$$\frac{\tau_2}{\tau_1} > \frac{K_2}{K_1} > 1 \tag{2}$$

Inverse response happens in many ways in real-life applications. Dealing with inverse response is a challenging task for the process engineers and requires additional analysis in the controller's tuning. It is due to the *NMP* characteristic that causes the controller to operate on wrong information in the initial time of the transient that drives the response to the opposite direction with respect to the ultimate steady state value.