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Novel transport delay problem solutions for gas plant inlet pressure control

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Abstract

The process of transferring the natural gas from the gas well to the gas separation plant encountered some delay time depending on the distance between this well and the factory, the cross section of the transport line, the geometry of this transport line, the well pressure and others. To control the factory inlet pressure by controlling the choke valve existing at the well head, the delay time makes the traditional control systems to fail. In this framework we aim to solve this problem by presenting a novel controller design and delay modeling technique. The presented technique is compared to the previous control system design and delay approximation techniques.

Keywords: PID controller; Control system design; State space; Transfer function

1. Literature review (introduction)

Controlling the gas plant inlet pressure by manipulating the choke valve existing at the well head is considered as one of the very important control systems in the oil and gas industry. The transport delay problem is one of the urgent problems in such control system. Many papers of the previous literature dealt with the delay problem but none of them hit the gas plant inlet pressure control directly. Although this problem is very important it has not been covered specifically in most of the previous literature. This paper fills this gap. Systems with delays are very common. Examples of time-delayed systems are communication networks, chemical processes, bio-systems, and so on. The presence of delays complicates the control design of the system. However, there are different approaches to model the delay such as Smith scheme and Pade approximation methods. Although Smith scheme was firstly introduced in

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late 1950s, it is still fundamental and basic tool for modeling systems with time delay (Furukawa and Shimemura, 1983). What makes Smith predictor so special is that it predicts outputs against time delays. The obtained systems after prediction can be treated as delay-free systems (Furukawa and Shimemura, 1983) (i.e. conventional design methods can be used). However, Smith predictor can be applied only to stable systems. Modified Smith can be applied to unstable systems with certain complex approximations (Furukawa and Shimemura, 1983). After modeling the delay, classical PID control can be used (Abe and Nobuyama, 2005). In state-space models, state predictor is used which is similar to modified Smith predictor, but it can also predict future states of the systems under consideration (Shinskey, 1967; Nobuyama and Abe, 2005; Kravaris and Wright, 1989). This paper developed a novel approach for dead-time compensation for nonlinear processes. The approach structure consisted of linearizing state feedback of a nonlinear system and developing Smith predictor to be used in state space to deal with systems with delay. To compensate for the dead-time linearized system, an open-loop state observer and a linear external controller have been added. Huang et al. (1990) presented a modified Smith predictor at low frequencies with an approximate inverse of dead time. Analysis and simulation results showed that the compensator had better disturbance rejection performance than the original Smith predictor. Hench et al. (1998) presented dampening controllers via a Riccati equation approach. The algorithm presented in this paper did not only introduce a stable solution for the system but also restrict the poles of the closed-pole system within predefined region in the left half plane. This had an effect of dampening the closed-loop system. This was accomplished by solving a damped algebraic Riccati equation and a degenerate Riccati equation. The solution to these equations was computed using numerically robust algorithms. Riccati can be expressed in the format of periodic Hamiltonian system. This periodic Hamiltonian system induced two damped Riccati equations with two different solutions (symmetric and skew symmetric solutions). These two solutions were valid. They produced different closed-loop eigenvalues and different controller gain. This increased the design flexibility by providing an alternative solution. Niculescu and Verriest (1998) presented a Riccati equation approach to solve delay-independent stability of linear neutral systems. This paper focused on the problem of asymptotic stability when the system has delay in the state of linear neutral systems. Sufficient conditions were given to ensure of the existence of symmetric and positive definite solutions of a continuous Riccati algebraic matrix equation coupled with a discrete Lyapunov equation. Syder et al. (2000) compared predictive compensation strategies with PID. A first-order system with delay was assumed to evaluate performance and robustness of predictive and PID compensation strategies. It was demonstrated that for a strong dominant delay, the predictive controllers had better performance than PID based controllers. In the case of less dominant delays, some of the PID controller gave comparable or even better performance than the predictive controllers. In non-dominant delay system, PID controller with filtered derivative gave better results than the predictive methods. Abe and Yamanaka (2003) presented the structure of Smith predictor control which was equivalent to Internal Model Control (IMC) in the sense that the delayed behavior of the plant was removed. The disturbance of the input channel can have a very long harmful effect when the system has slow modes. This can be avoided by adding disturbance compensator in the feedback path in the Smith predictor control. The integral error increases in the time delay period (as the output of the plant does not being affected from the input). This results on increasing the windup phenomena. To solve this problem, self conditioning anti-windup PI controller was proposed, which includes saturation model in PI controller. The saturation input reduces the integral error and therefore the extreme overshoot response is controlled.

2. The process model

The proposed gas process itself is a first order process. Before proceeding, it should be noted that the name of first order not only is the name describing such a process but it is also called as single capacity, first order lag process and lag process. This first order system can be modeled in Laplace domain as:

$$G_P(S) = \frac{K}{1 + \tau S} \quad \text{(delay free part)}$$

Note that K is the static part of the transfer function and $(1/(1 + \tau S))$ is the dynamic part of the transfer function where τ is the first time constant which indicates how quickly the process responds to the changes in the input signal. To determine this transfer function we have to determine K and τ.