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Control and Simulation of FOPDT Food Processes with Constraints using PI Controller

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Abstract**—**The most common type of controller being used in the industry is PI(D) controller which has been used since 1945 and is still being widely used due to its efficiency and simplicity. In most cases, the PI(D) controller was tuned without taking into consideration of the effect of actuator saturation. In real processes, the most common actuator which is valve will act as constraint and restrict the controller output. Since the controller is not designed to encounter saturation, the process may windup and consequently resulted in large oscillation or may become unstable. Usually, an antiwindup compensator is added to the feedback control loop to reduce the deterioration effect of integral windup. This research aims to specifically control processes with constraints. The proposed method was applied to two different types of food processes, which are blending and spray drying. Simulations were done using MATLAB and the performances of the proposed method were compared with other conventional methods. The proposed technique was able to control the processes and avoid saturation such that no anti windup compensator is needed.

Keywords**—**constraints, food process control, first order plus dead time process, PI

I. INTRODUCTION

PID controller has become the most widely used controller since the last six decades, and is still being used nowadays due to its simplicity and flexibility. All real processes involve constraints that may appear in actuator saturation, for instance. More complex control strategies were usually applied for processes with saturation [1][2]. Saturation will cause windup which will cause performance deterioration such as large overshoot, large settling time and may even become unstable [2][3].In order to compensate this, anti windup compensator is usually added to the control feedback loop [3][4]. As an alternative, this research investigates the possibility to tune the PI controller when the system is under saturation without using anti-windup.

II. MATERIALS AND METHODS

This research emphasised on applying the methods of controlling a food processes with constraints. A simple method of tuning a PI controller that takes into consideration of the actuator saturation was developed. Focus was given on the first order plus dead time (FOPDT) model and the method was based on direct synthesis method. Typically, PI control is sufficient to apply in a large number of control processes, especially when the design requirements are not rigorous for the dominant first (second) order process dynamics [5]. The method was then applied to two different types of food processing and the performances were evaluated. Two different processes were modelled empirically and mathematically. They are the milk spray drying process and blending process. Both processes can be represented by first order plus dead time (FOPDT). The models are shown in Eq 1 and Eq 2 respectively where G_P = Process transfer function,

Process 1: Blending

$$G_p = \frac{0.01e^{-4s}}{10s+1} \tag{1}$$

Process 2: Spray drying

$$G_p = \frac{2e^{-3.5s}}{7.8s+1} \tag{2}$$

The method, M1 was based on direct synthesis method. In direct synthesis tuning method, there is a parameter λ that needs to be selected and is usually chosen to be half of the process time constant [6]. Simulations were done to find the relationship between lambda, λ and saturation level, *U*. This was done to ensure saturation can be avoided therefore no antiwindup is needed. Simulations were done to assess the performance of the proposed method, M1 with the existing tuning methods. Comparisons were made for processes with and without antiwindup compensator.

III. RESULTS AND DISCUSSIONS

Three existing different tuning methods were applied on PI controller; the Ziegler- Nichols method (ZN), Cohen-Coon methods (CC), Abbas method (AA) and the performances were compared to the newly developed method, M1. Simulations were done for processes without saturation, with saturation and with antiwindup. Figure 1 shows the control signals given by PI controller tuned using the 4 different methods for Process 1. PI controller tuned using the CC methods gave rise to the highest control signal, which indicates that it is easily saturated. On the contrary, the control signal obtained using M1 tuned controller was the lowest, which means that saturation is highly unlikely.

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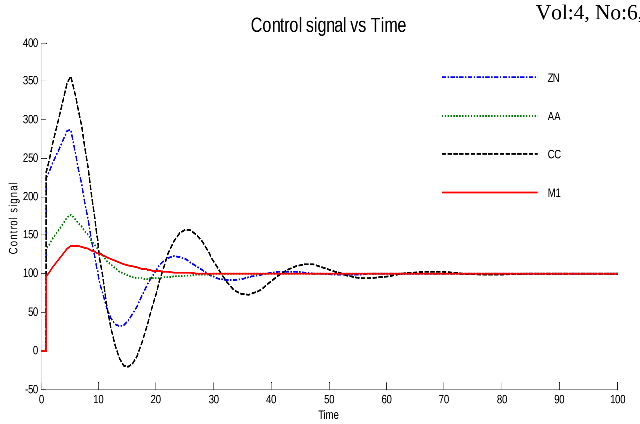

Fig. 1 Control signal for system without saturation (Process 1)

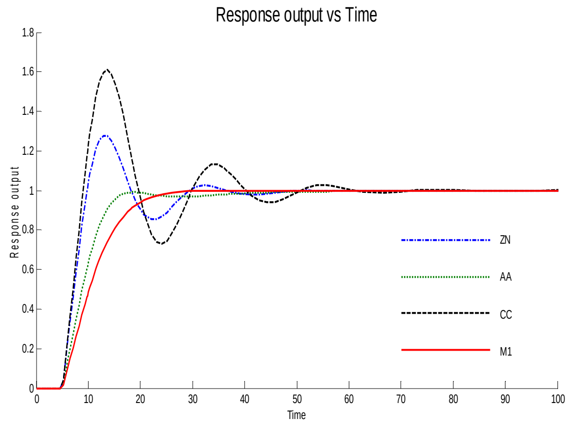

Fig. 2 Output response for system without saturation (Process 1)

Fig. 2 shows the corresponding output response. The response output of CC exhibited an active, aggressive and higher degree of oscillation and overshoot. As can be expected, controller tuned using CC method showed more aggressive and oscillatory response while M1 tuning methods resulted in more conservative and overdamped response. Figure 3 and 4 shows the control signal and output response for processes when saturation is considered for Process 1. When saturation is applied, the control signals were saturated, except the controller tuned using M1 methods. This because this method has already taken into consideration input constraints and thereore saturation can be avoided.

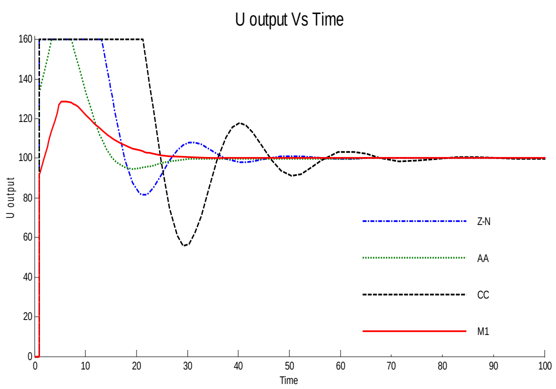

Fig. 3 Control signal for system with saturation (Process 1)

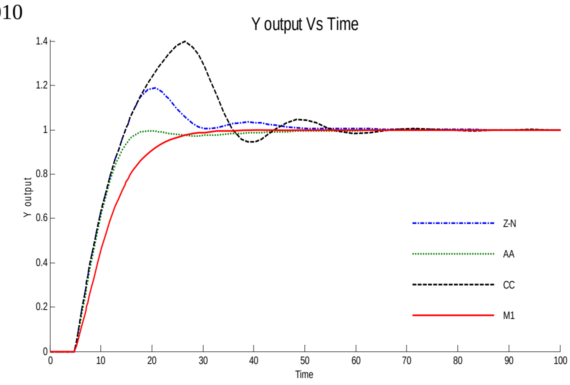

Fig. 4 Output response for system without saturation (Process 1)

As for the output response, the other existing tuning methods were affected by saturation. The process took longer time to reach steady state value, contributing to the increament of integral absolute error (IAE) where PI tuned using ZN method showed the largest increament of 16.7% followed by CC method which gave rise to 8.3% increase in IAE. Figure 5 shows the output response when anti windup compensator was applied. It was evident that anti-windup improved the performance of processes using ZN and CC tuned methods by reducing the level of oscillations. The process controlled using PI tuned by CC and ZN methods gained the most benefit by having the antiwindup compensator in which the IAE values were reduced by 36% and 26%, respectively. Note that the output response given by PI tuned using M1 method remained the same, with and without anti windup.

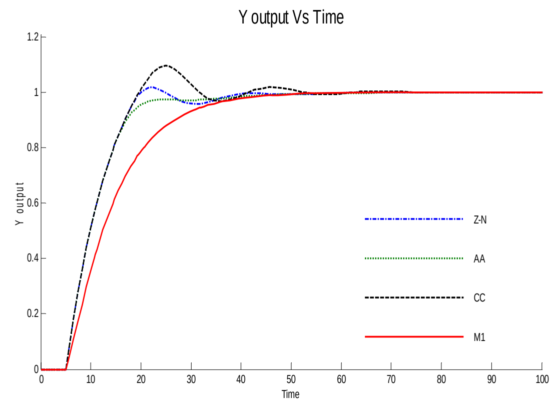

Fig. 5 Output response for saturation with antiwindup (Process 1)

Simulations were done on other spray drying model (Process 2). The model is still FOPDT but with a higher process gain and smaller process time constant and the results corroborate the results obtained for the blending process (Process 1). For Process 1, the highest rise time value for with and without saturation was AA method, but for Process 2, controller tuned using M1 method had highest rise time value for both system with and without saturation as shown in Figure 6 and 7. It was evident that overshoot for process controlled using ZN and CC method decreased when saturation occurred. The proposed method, M1 showed a more conservative response with no overshoot for both cases.

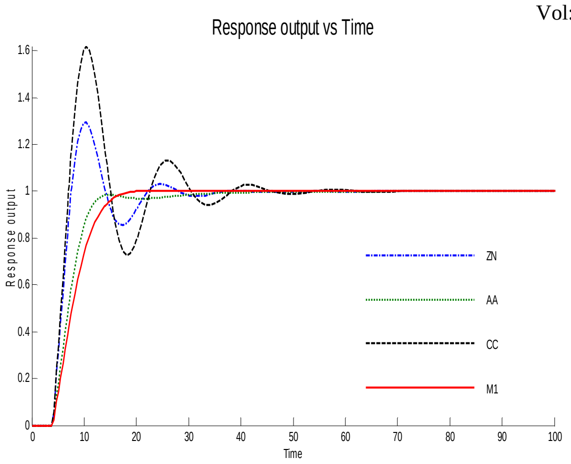

Fig. 6 Output response for system without saturation (Process 2)

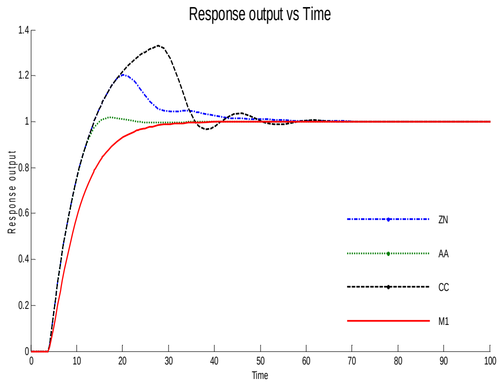

Fig. 7 Output response for saturation without antiwindup (Process 2)

IV. CONCLUSIONS

In this study, results showed that the M1 method and can be used to control processes with constraints and avoid saturations. Therefore, by applying this method, no antiwindup compensator is needed and therefore no additional feedback loop is required in the control loop.

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