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Servo Mechanism Technique based Anti-Reset Windup PI Controller for Pressure Process Station

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Abstract

Background/Objectives: In this paper a new architecture is followed which is based on manipulating feedback structure for pressure process. **Methods/Statistical Analysis:** This work copes with the research based on anti-reset windup mechanism. Mathematical Modeling of pressure station is carried out using two-point method. Windup action is being complication in FOPDT process, therefore designing a controller for such problem is always a big challenge for control engineers. As a part of controller design direct synthesis method has been used. Apart from controller design, architecture of system will also influence the system performance. Tending towards architectural manipulationa new structure has been followed. **Findings:** Result shows the significance and positive approach towards the proposed model for pressure process in both simulation and real time. Controller action can be optimized in a reliable way and energy utilization of actuator gradually reduced. **Applications/Improvements:** In some real time nonlinear processes windup action manipulates plant process more than required limit, where process leads to saturation. In such scenarios the proposed approach provide plant to regain its position and act within limits of its boundary.

Keywords: Anti-Reset Windup, Architecture Manipulation, FOPDT, PID Tuning, Pressure Station, Servo Mechanism

1. Introduction

Classical PID control is being used in industries from last few decades and continuing the usage is because of its simplicity in designing and easily understandable architecture, however for most complex industrial problems the classical controller alone cannot be recommended for better performance and stability requirements. Hence there comes the need to develop advanced controller for nonlinearity, robustness and optimality etc. In real time or industrial processes almost all process will be limited to their control action, so the controllers used will be within the setup. Hence user won't be having the access to manipulate the control parameters. The problem arises for such kind of process is when it need any manipulation or the external parameters influence the process. In such scenarios the process reaches saturation or there will be mismatch in process parameters. Considering this constraint, researchers following different approaches to overcome and improve the performance in dynamic process. In this paper a different approach is followed to overcome reset-windup issue by considering pressure process which is FOPDT model[1].

The block diagram of control system including saturation nonlinearity is shown in Figure 1 where *'r'* is reference input, *'y'* is output, *'e'* is error (difference of between output (y) and reference input (r), *'C'* and *'P'* are controller and Process plant respectively.'u_{max}' *and* 'u_{min}' are higher and lower limits of saturation. *'u'* is input and *'u^*'* is output of the saturation.

Conditions for saturation is given by

$$u^* = +u_{sat} u > +u_{sat} \tag{1}$$

$$u^* = u - u_{sat} \leq u \leq +u_{sat} \tag{2}$$

$$u^* = -u_{sat} u < +u_{sat} \tag{3}$$

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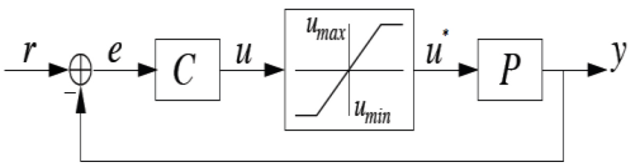

Figure 1. General block diagram with saturation.

2. Overview of Integral Windup

Windup problem in the system occurs when the controller output saturates or the controller output is more than the limit of final control element (actuator) when subjected to transient response. Usually the reset windup occurs when the reference signal is applied rather than load disturbance. Furthermore, the most important effect of integral windup is considered when the order of the plant transfer function is low, which means that the value of dead time is lower than the time constant (τ). In order to run the plant in controlled region, its important reduce or eliminate the actuator saturation. The control action of reset windup can be considered in two ways. Firstly considering nonlinearity from the initial stage and designing the controller accordingly or designing nominal PID controller and noting the effect of nonlinearity on plant and applying compensation to it. In cases where nonlinearity exists in/out of the plant avoiding or limiting saturation makes the system to gain its stability. This can be done by smoothening set-point changes or detuning the controller (by selecting more sluggish controller), which is not advisable in practical cases. Reset windup is one of the issue to be considered in such scenarios. There are different advanced and controller design techniques being used when windup problemsarise[2–4].

3. Modelling Pressure Station

In this paper the plant is modelled by using two point method in which operating conditions were based on linear characteristics and the FCE saturation limit of the flow process. The plant can be modelled by considering step response. The selected points for modelling are 23.8 and 63.2 from the step response curve. The standard FOPDT model and response curve as follows[5]

$$Q(s)=\frac{k_p}{\tau s+1}e^{-t_d s} \tag{4}$$

The selection of different process variables from Figure 2 is given by

$$k_p=\frac{Y_F-Y_I}{U_F-U_I} \tag{5}$$

$$\tau=1.5(t_2-t_1) \tag{6}$$

$$t_d=1.5\left[(t_1-t_0)-\frac{1}{3}(t_2-t_0)\right] \tag{7}$$

Figure 3 depicts the real time model of pressure plant and process plant equation followed in the Equation (8) through substituting Equations (5), (6) and (7) in (4).

$$Q(s)=\frac{k}{Ts+1}e^{-t_d s}=\frac{1.649}{8.309s+1}e^{-0.89s} \tag{8}$$

4. Architectural Model

Usually in real time process based on requirement of output the process the dynamics vary from time to time. As the dynamics of plant changes the tuned controller values may not show good effect on the plant. As the closed loop built-in controller will be fixed in its gain the response will be poor. Here comes the need of dynamic change in tuning with respect to process plant[6]. In this proposed architecture there exists two loops as shown in

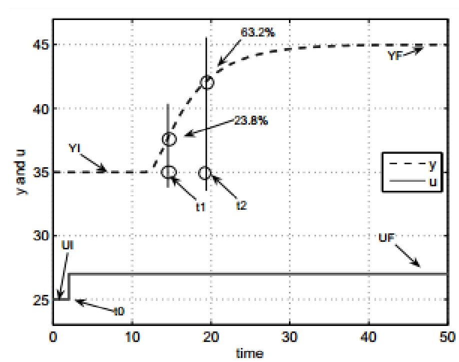

Figure 2. Selection of variables from step response.

Figure 3. Real-time pressure process station.

the Figure 4, in which one loop feuded to controller $\bar{G}_c$ and $G_{c1.}$ Here $\bar{G}_c = \frac{K_i}{s}$ and $G_{c1} = K_p$

The block diagram as follows

The dynamic controller in this paper is $\bar{G}_c$. The conditions for selecting $\bar{G}_c$ is given by

$$e = \begin{Bmatrix} (r-y)\, if\, \delta < \bar{e} < \sigma \\ 0 \quad otherwise \end{Bmatrix} \tag{9}$$

Where $\bar{e} = y - \bar{G}$, $\sigma = \frac{U_{max}}{k_p}$, and $\delta = \frac{U_{min}}{k_p}$

Figure 5 shows the plant model incorporated with anti-reset windup mechanism. U_{max} and U_{min} are selected as saturation limits. Therefore the controller value K_i is selected as a function of feedback loop error $\bar{e}$ and hence the integral gain will be always varying with respect to error $\bar{e}$.

5. Controller Design

Even though there are many tuning methods exists for designing PID parameters, due to simplicity and flexible in design, direct synthesis is the method of tuning has been used in this paper. The same values are used both in conventional structure and proposed model also, the proportional gain K_c and integral gain K_i is given by[7]

$$K_c = \frac{\tau_p}{k_p(\tau_c + \theta)} \tag{10}$$

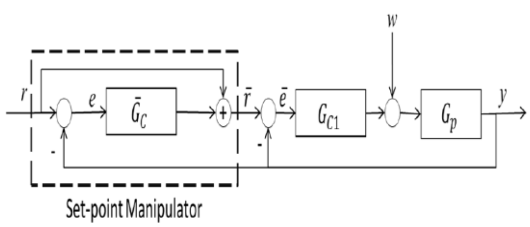

Figure 4. Servo manipulation block diagram.

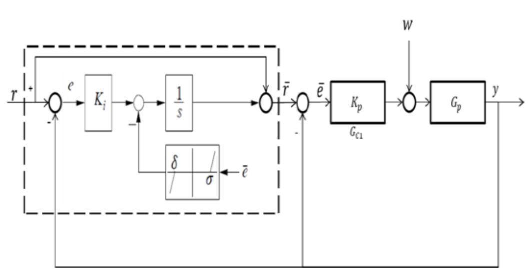

Figure 5. Model incorporated with anti-reset windup.

$$T_i = \tau_p \tag{11}$$

Where K_p is process gain τ_p, is time constant and θ is time delay and τ_c is usually selected as settling time of closed loop response. Table 1 represents proportional gain (K_c) and integral gain (K_i).

Therefore by calculating Equation (10) and (11)

6. Results and Comparison

Below mentioned results clearly distinguish the comparison of conventional control effect and anti-reset windup controller effect on process station. Figure 6 shows simulation response of direct synthesis method with anti-reset windup. As the integral action is completely dependent on process response, even the changes occurred in the process as disturbance (load) and reference, the controller action will be performed with respect to those changes. Figure 7 shows the performance of plant process with respect to setpoint change and comparison is

Table 1. Controller parameters

K_c	5.1
K_i	0.61

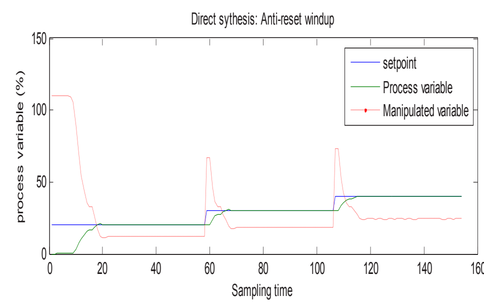

Figure 6. Simulation response of direct synthesis method with anti-reset windup.

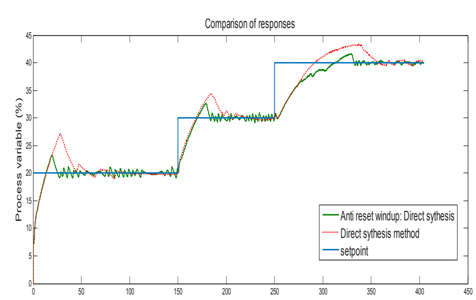

Figure 7. Comparison of process variable: Direct synthesis method with and without anti reset windup.

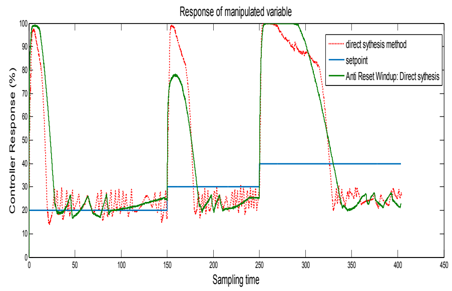

Figure 8. Comparison of manipulated variable: Direct synthesis method with and without anti reset windup.

Table 2. Comparison of system charateristics (with and without Anti Reset windup)

Methods	Peak time (sampling time)	Rise time (sampling time)	Peak Over-shoot (%)	Settling time (sampling time)
Conventational	28.1	10.61	35.25	57.5
Servo Mechanism Technique	19.6	10.4	16.5	28.3

made to enable the difference between convention control and the controller with anti-reset windup. It can be clearly shown that the performance with anti-reset windup has better response than conventional process. Figure 8 shows the controller action comparison in which controller with anti-reset windup has very smooth controller action compared with conventional process.

6.1 Results Comparison Table

System charateristics of first step change of (20%)

The Table 2 provides the comparison of system characteristics like peak time, rise time, peak over-shoot and settling time of response with and without anti-reset windup.

7. Conclusion

In this paper, Pressure station is considered as process plant, modelling of plant has been carried out by using two point method. A new approach of architecture designing in process flow is followed in which the controller parameters acts as function of error and the integral gain (Ki) will be auto tuned with respect to the process error. Direct synthesis method is used for tuning and experimental tests has been performed in simulation as well as real time. The results clearly shows that the process with anti-reset windup give better performance compared with conventional method. Energy utilized by the controller is drastically reduced with respect to conventional method.

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