Tuning of a PIDF Controller Used With a Highly Oscillating Second Order Process

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Abstract--- High oscillation in industrial processes is something undesired and controller tuning has to solve this problems. PDF and PIDF are controller modes which are expected to overcome this problem. This research work has proven that the PIDF is the genuine solution for the high level process oscillation.

A second order process of 85.45 % maximum overshoot and 8 seconds settling time is controlled using a PIDF controller (through simulation). The controller is tuned by minimizing the sum of absolute error of the control system using MATLAB. A functional constrains is imposed on the maximum percentage overshoot. The result was cancelling completely the process oscillation with a zero overshoot and a 0.62 seconds settling time. The performance of the PIDF controller is compared with the classical PID controller with the same process.

Keywords—PDF controller, PIDF controller, overshoot, maximum overshoot, gain, and settling time.

II. PROCESS

The process is a second order process having the parameters:
- Natural frequency: \( \omega_n = 10 \text{ rad/s} \)
- Damping ratio: \( \zeta = 0.05 \)

The process has the transfer function:
\[
M_p(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}
\]  
(1)

The time response of this process to a unit step input is shown in Fig. 1 as generated by MATLAB:

![Fig.1 Step response of the uncontrolled process.](image-url)
The severity of the process oscillations is measured by its maximum percentage overshoot. It has a maximum overshoot of 85.4% and an 6 seconds settling time.

III. CONTROLLER

The controller used in this study is a proportional + integral + derivative + filter (PIDF) controller. The filter is a low pass type. There are different configurations for the PIDF controller:

(a) The filter is associated with the derivative part of the filter [Bertini].
(b) The filter is associated with the proportional mode of the PID controller [Ruel].
(c) The filter is a part of a complex configuration [MTS & Airouche]:

- The proportional and integral modes work on the system error.
- The derivative mode works on the output signal of the system.
- A filter gain works on the command signal.
- The filter (F) input is the output of the P and I modes and the filter gain mode.
- The PIDF controller output is the sum of the F and I modes outputs.

Only the first configuration for the PIDF controller is used in the present study.

The PIDF controller of type (a) has a transfer function given by [10]:

\[ G_c(s) = K_p + (K_i/s) + K_f/s \left(1 + T_f s\right) \]

Where:
- \( K_p \) = controller proportional gain
- \( K_i \) = controller integral gain
- \( K_f \) = controller derivative gain
- \( T_f \) = filter time constant

IV. CONTROL SYSTEM TRANSFER FUNCTION

Assuming that the control system is a unit feedback one, its transfer function becomes:

\[ M(s) = \frac{a_4s^4 + a_3s^3 + a_2s^2 + a_1s + a_0}{b_4s^4 + b_3s^3 + b_2s^2 + b_1s + b_0} \]

The MATLAB command "fmincon" is used to minimize the optimization objective function given by Eq.4 subjected to the functional inequality constraints given by Eqs. 5 and 6 to provide the controller parameters subjected to the limits mentioned in section 6. The results are as follows:

Controller parameters:
- \( K_p = 1.29723 \), \( K_i = 8.19745 \)
- \( K_d = 0.20717 \), \( T_f = 0.01085 \ s \)

The performance of the control system is controlled using two functional constraints:

(a) The maximum percentage overshoot, \( OS_{max} \):

\[ C_1 = OS_{max} = 100(c_{ss} - c_{ns}) / c_{ss} \]

(b) The settling time, \( T_s \):

\[ C_2 = T_s \]

Where \( c_{ss} \) is the steady state of the system.

A lower limit of 0.01 is set for the controller parameters: \( K_p \), \( K_i \), \( K_d \) and \( T_f \).

A 1% upper limit is set for the controller parameters.

A 1 second upper limit is set for the control system maximum overshoot.

A 1 second upper limit is set for the control system settling time.

VIII. TUNING RESULTS

The MATLAB command "fmincon" is used to minimize the optimization objective function given by Eq.4 subjected to the functional inequality constraints given by Eqs. 5 and 6 to provide the controller parameters subjected to the limits mentioned in section 6. The results are as follows:

Controller parameters:
- \( K_p = 1.29723 \), \( K_i = 8.19745 \)
- \( K_d = 0.20717 \), \( T_f = 0.01085 \ s \)

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Time response to a unit step input: Fig. 2.
International Journal of Emerging Technology and Advanced Engineering


Fig.2 Step response of the PIDF controlled second order process.

Characteristics of the control system using the tuned PIDF controller:
- Maximum percentage overshoot: 0%
- Settling time: 0.62 s

IX. COMPARISON WITH PID CONTROLLER

In the analysis presented in this paper, the term $T_f$ is dropped from all the equations, we end up with the situation of using a PID controller to control the process. The tuning procedure using the IAE objective function yields the following results as produced using the MATLAB optimization toolbox:

$$K_p = 1.3808, \quad K_i = 5.3405 \quad K_d = 0.0900$$

The time response of the system is shown in Fig.3:

Fig.3 Step response of the PID controlled second order process.

Characteristics of the control system using the tuned PID controller:
- Maximum percentage overshoot: 1%
- Settling time: 0.94 s
- The system response exhibits some oscillations (about 4) before settling at $c_{ss}=1$ after about 1.5 s.

X. DISCUSSIONS

- It is possible to suppress higher oscillations in processes through using PID or PIDF controllers.
- Through using a PIDF controller it was possible to cancel completely the 85% maximum overshoot of the uncontrolled process.
- Through using a PIDF controller it was possible to reduce the settling time from about 6 seconds to about 0.6 seconds indicating the fast settlement of the controlled process.
- The PID controller could not reduce the maximum percentage overshoot than 1% compared with zero for the PIDF controller.
- The PID controller could not reduce the settling time than 0.94 seconds compared with 0.62 seconds for the PIDF controller.

REFERENCES