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Novel PDI-F Controller for Underdamped Second Order-Like Processes

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Abstract:

This research paper aims at investigating the use of a novel PDI-F controller to control a second order-like process of 10 rad/s natural frequency and 0.1 damping ratio. The proposed controller is tuned based on using MATLAB control and optimization toolboxes. Using the suggested tuning technique, it is possible to eliminate completely the kick characteristic associated with PID controllers and improve the speed of the time response of the control system.

Keywords — Underdamped second order process, novel PDI-F controller, controller tuning.

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I. INTRODUCTION

The author investigated the application of a new series of controllers and compensators for control of second and third order processes. This research aimed at replacing the first generation of the PID controllers by new ones (the second generation) providing better performance of the control systems and providing better robustness and better capability of disturbance rejection. The proposed controller is entirely new and it is expected to solve some of the disadvantages of PID controllers and opens new prospective for its application in control engineering.

Hassaan (2014, 2015) presented a number of new controllers to control a highly oscillating second order process including an I-PD controller [1], PPI controller [2], PI-P controller [3], 2DOF controller [4], PI-PD controller [5] and a PD-PI controller [6]. Hassaan (2018) studied the control of second-order-like processes using a novel PD-I controller. He covered processes having natural frequency from 5 to 15 rad/s and damping ratio from 0.1 to 0.95 [7].

II. PROCESS

The controlled process is second-order-like process having the transfer function, $G_p(s)$:

$$G_p(s) = (\omega_n^2 / (s^2 + 2\zeta\omega_n s + \omega_n^2) \qquad (1)$$

Where:

ω_n = process natural frequency = 10 rad/s.
ζ = process damping ratio = 0.10

The unit step time response of the process is shown in Fig.1 as generated by the MATLAB program.

It has the following time based specifications:

- Maximum percentage overshoot: 72.9 %
- Maximum percentage undershoot: 54.0 %
- Settling time (± 2 % band): 3.8 s

III. CONTROLLER

The PD-I controller was proposed by the author in 2018 where it has a proportional part (P-action) connected in parallel with the derivative part (D-action) with their outputs added together through a summer circuit having an output fed to the integral part (I-action) [7]. The block diagram of the proposed controller is shown in Fig.2.

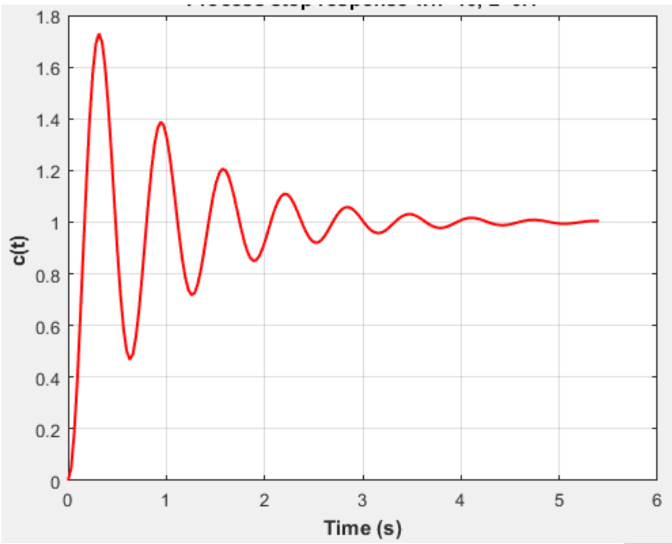

Fig.1 Unit step time response of the process.

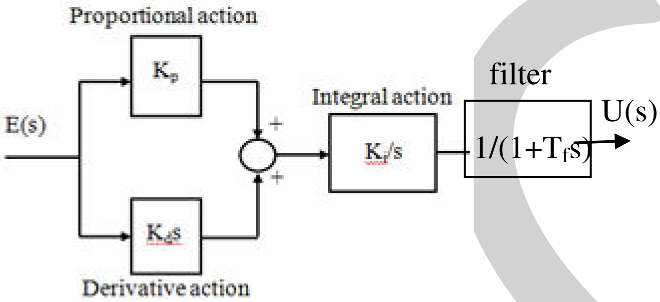

Fig.2 Block diagram of a PDI with filter controller.

The proportional gain of the PD-I controller is K_{pc} , its derivative gain is K_d and its integral gain is K_i. The modified PD-I controller (PDI-F controller) has one more controller parameter which is the time constant T_f. The transfer function of the PDI_F controller using the block diagram of Fig.2, $G_c(s)$ is:

$$G_c(s) = [K_dK_is + K_{pc}K_i] / [T_fs^2 + s] \quad (2)$$

IV. CONTROL SYSTEM TRANSFER FUNCTION

The block diagram of the closed-loop control system comprising the PDI-F controller and the second order process is shown Fig.3 with R(s) as the reference input, E(s) is the error, U(s) is the control signal and C(s) is the process output.

Using the block diagram of Fig.3 and the process and controller transfer functions given by Eqs.1 and 2, the closed loop transfer function of the control system to a reference input, C(s)/R(s) is given by:

$$C(s)/R(s) = (b_0s+b_1) / [a_0s^3 + a_1s^2+a_2s + a_3] \quad (3)$$

Where:

$b_0 = K_dK_i\omega_n^2$
$b_1 = K_{pc}K_i\omega_n^2$
$a_0 = T_f$
$a_1 = 1+2\zeta\omega_nT_f$
$a_2 = \omega_n^2T_f + 2\zeta\omega_n$
$a_3 = K_dK_i\ \omega_n^2 + \omega_n^2$
$a_4 = K_{pc}K_i\omega_n^2$

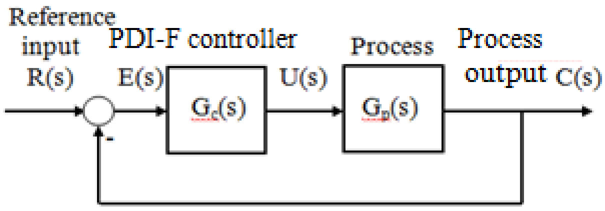

Fig.3 Control system block diagram.

V. CONTROLLER TUNING AND SYTEM TIME RESPONSE

The controller has four parameters: K_{pc}, K_d, K_i and T_f. The controller parameters are tuned as follows:

- The control and optimization toolboxes of MATLAB are used to assign the three parameters of the controller (K_{pc} , K_d and K_i) [8].
- The integral of absolute error (IAE), integral of square error (ISE), integral of time multiplied by absolute error (ITAE), integral of time multiplied by square error (ITSE) and integral of square time multiplied by square error (ISTSE) are tried as objective functions for the optimization process. Then, the best one providing the best performance of the closed loop control system is chosen.
- The step response of the closed-loop control system is plotted using the command '*step*' of MATLAB [9].
- The time-based specifications of the control system are extracted using the MATLAB command '*stepinfo*' [10].

The application of the above procedure to tune the PDI-F controller used to control the highly oscillating second order process defined by Eq.1 revealed ISTSE as the best objective function and a tuned controller parameters given by:

$K_{pc} = 0.34078$
$K_d = 0.649187$
$K_i = 0.313612$
$T_f = 4.74377$

For sake of comparison with the unfiltered PDI controller, the same tuning procedure was applied where it revealed the ISE as the best objective function and the following tuned controller parameters:

$K_{pc} = 0.506245$
$K_d = 0.365778$
$K_i = 0.131957$

The unit step time response of the control system for both tuned PDI and PDI-F controllers when used to control the process of Eq.1 is shown in Fig.4.

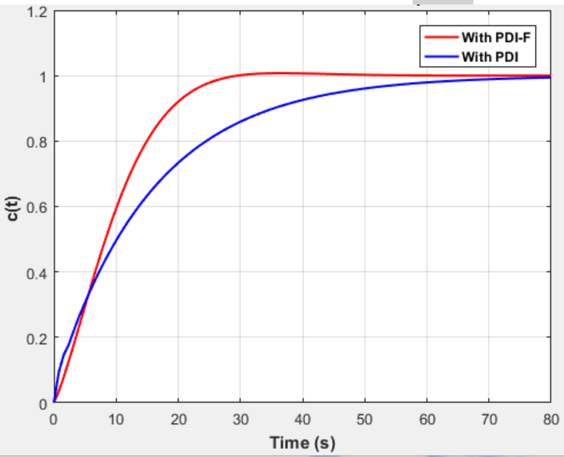

Fig.4 Unit step time response of the control system using PDI and PDI-F controllers.

The control system has the following time-based specifications:

- Settling time:
  - 46.2 s when using PDI controller.
  - 25.2 s when using PDI-F controller
- Maximum percentage overshoot:
  - 0 when using PDI controller.
  - 0.75 % when using PDI-F controller

To examine the effectiveness of the proposed PDI-F controller, it will be compared with the conventional PID controller when used to control the same second order process. A tuned PID controller when used to control a second order process with ωn = 10 rad/s and ζ = 0.1 has the parameters [11]:

$K_{pc} = 9.9948$
\ $K_i = 9.0056$
$K_d = 0.9773$

The closed loop control system comprising the tuned PID controller and the second order process has the unit step time response shown in Fig.5. It has the time based-specifications:

- Settling time: 1.885 s
- Maximum percentage overshoot: 2.94 %
- Kick time: 0.048 s

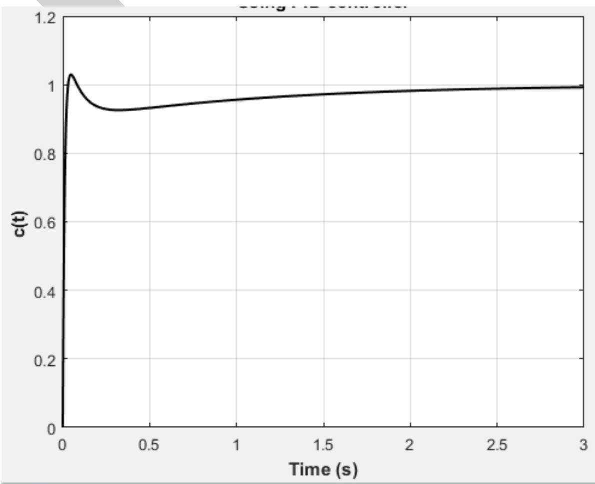

Fig.5 Unit step time response of the control system using PID controller.

VI. CONCLUSION

- A novel PDI-F controller was proposed to control highly oscillating second order-like processes.
- The proposed controller had a filter added in series with a PDI controller proposed by the author in 2018.
- The new controller had four parameters to be tuned.
- The best tuning was achieved by using an ISTSE objective function minimized using MATLAB optimization toolbox.
- The settling time was reduced from 46.2 s with PDI controller to 25.2 s with PDI-F controller.

- The overshoot was increased from zeo with PDI controller to 0.75 % with PDI-F controller.
- Both PDI and PDI-F controllers had zero kick characteristic.
- The conventional PID controller provided a closed loop control system with better settling time (1.885 s) and more maximum percentage overshoot (2.94 %).
- The PID controller has the disadvantage of the kick phenomenon at 0.048 s for the closed loop control system step response.

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BIOGRAPHY

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- Member of the Editorial Board of some International Journals.
- Reviewer in some international journals.