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Robustness of Feed forward 2/2 Second-Order Compensators used with Second-Order-Like Processes

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Abstract— **Robustness is one of the requirements used in controllers and compensators design. The objective of this paper is to investigate the robustness of a feedforward 2/2 second-order compensator used to control second-order-like processes against uncertainty in the process parameters.**

A variation of ± 20 % in process parameters is considered through simulation to study its effect on the system performance parameters using the tuned compensators. The study shows that this variation in process parameters has a little effect on the parameters of the control system performance. The variation in process damping ratio has no effect on the control system performance. The variation of the process natural frequency affects the performance of the closed-loop control system using this type of compensators. The steady-state error changes in the range 0.007 to 0.0138, the settling time changes in the range 0.127 to 0.35 seconds, the maximum percentage overshoot changes in the range 0 to 1.64 % and the phase margin changes in the range 70 to 81 degrees. Therefore, this type of compensators is completely robust when used with second-order-like processes having bad dynamics.

Index Terms—**Compensator robustness , 2/2 second-order feedforward compensator, second-order processes , variation of process parameters , bad dynamics processes.**

I. INTRODUCTION

Processes are subject to uncertainty in their parameters during operation. Therefore, it is worth to investigate the effectiveness of the used controllers or compensators with such certainty.

Hu, Chang, Yeh and Kwatny (2000) used the H∞ approximate I/O linearization formulation and μ-synthesis to design a nonlinear controller for an aircraft longitudinal flight control problem and address tracking, regulation and robustness issues [1]. Gong and Yao (2001) generalized a neural network adaptive robust control design to synthesize performance oriented control laws for a class of nonlinear systems in semi-strict feedback forms through the incorporation of backstepping design techniques [2]. Lee and Na (2002) designed a robust controller for a nuclear power control system. They used the Kharitonov and edge theorem in the determination of the controller which was simpler than that obtained by the H∞ [3]. Arvanitis, Syrkos, Stellas and Sigrimis (2003) analyzed PDF controllers designed and tuned to control integrator plus dead time processes in terms of robustness. They performed the robustness analysis in terms of structured parametric uncertainty description [4]. Lhommeau, Hardouin, Cottenceau and Laulin (2004) discussed the existence and the computation of a robust controller set for uncertain systems described by parametric models with unknown parameters assumed to vary between known bounds [5]. Dechanupaprittha, Hongesombut, Watanabe, Mitani and Ngammroo (2005) proposed the design of robust superconducting magnetic energy storage controller in a multimachine power system by using hybrid tabu search and evolutionary programming. The objective function of the optimization problem considered the disturbance attenuation performance and robust stability index [6].

Chin, Lau, Low and Seet (2006) proposed a robust PID controller based on actuated dynamics and an unactuated dynamics shown to be global …….. bounded by the Sordalen lemma giving the necessary sufficient condition to guarantee the global asymptotic stability of the URV system [7]. Vagja and Tzes (2007) designed a robust PID controller coupled into a Feedforward compensator for set point regulation of an electrostatic micromechanical actuator. They tuned the PID controller using the LMI-approach for robustness against the switching nature of the linearized system dynamics [8]. Fiorentini and Bolender (2008) described the design of a nonlinear robust/adaptive controller for an air-breathing hypersonic vehicle model. They adapted a nonlinear sequential loop-closure approach to design a dynamic state-feedback control for stable tracking of velocity and altitude reference trajectories [9]. Labibi, Marquez and Chen (2009) presented a scheme to design decentralized robust PI controllers for uncertain LTI multi-variable systems. They obtained sufficient conditions for closed-loop stability of multi-variable systems and robust performance of the overall system [10]. Matusu, Vanekova, Porkop and Bakosova (2010) presented a possible approach to design simple PI robust controllers and demonstrate their applicability during control of a laboratory model with uncertain parameters through PLC [11].

Kada and Ghazzawi (2011) described the structures and design of a robust PID controller for higher order systems. They presented a design scheme combining deadbeat response, robust control and model reduction techniques to enhance the performance and robustness of the PID controller [12]. Surjan (2012) applied the genetic algorithm for the design of the structure specified optimal robust controllers. The parameters of the chosen controller were obtained by solving the nonlinear constrained optimization problem using IAE, ISE, ITAE and ITSE performance indices. He used constraints on the frequency domain performances with robust stability and disturbance rejection [13]. Jiao, Jin and Wang (2013) analyzed the robustness of a double PID

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controller for a missile system by changing the aerodynamic coefficients. They viewed the dynamic characteristics as a two-loop system and designed an adaptive PID control strategy for the pitch channel linear model of supersonic missile [14]. Hassaan (2014) studied the robustness of some new controllers and compensators used with second-order and third-order-like processes [15-17].

II. PROCESS

The process considered in this analysis has the transfer function, $G_p(s)$:

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

The process parameters depend on the dynamics of the controlled process. For a second-order-like process having high oscillations (bad dynamics), the process parameters are:

ω_n = process natural frequency = 10 rad/s.
ζ = process damping ratio = 0.05

For a second-order-like process having a very slow response (bad dynamics too), the process parameters are:

ω_n = process natural frequency = 0.4472 rad/s.
ζ = process damping ratio = 11.203

III. ROBUSTNESS OF A FEEDFORWARD 2/2 COMPENSATOR CONTROLLING A HIGHLY OSCILLATING SECOND-ORDER-LIKE PROCESS

The author presented a tuning approach to tune a 2/2 second-order compensator when used with a highly oscillating second order process using a novel approach based on solving a set of nonlinear equations in some of the performance parameters of the control system [18].

The compensator parameters and the system performace measures are:

K = 4.792
ω_{nc2} = 2.202
ζ_{c2} = 9.531
Maximum percentage overshoot = 0
Settling time = 0.20 s
Gain margin = ∞
Phase margin = 75.8 degrees

The robustrness investigation procedure is applied on the resulting control system for process variation in the range ± 20 % from the nominal values. The results are as follows:

- The control system is stable for all the studied change in process parameters (-20 % to 20 %).
- The maximum increase in the steady-state error of the closed-loop control system is 56 % corresponding to – 20 % change in the process natural frequency.
- The maximum change in settling time is 75 % corresponding to – 20 % change in the process natural frequency.
- The maximum percentage overshoot increases from 0 to a maximum value of 1.6 % at a 20 % change in process natural frequency.
- The phase margin decreases by 7.5 % for the positive maximum change change in process natural frequency (20 %).
- The change in the process damping ratio does not affect the performance of the closed-loop control system.

Fig.1 shows the effect of the natural frequency and damping ratio change on the system steady-state error.

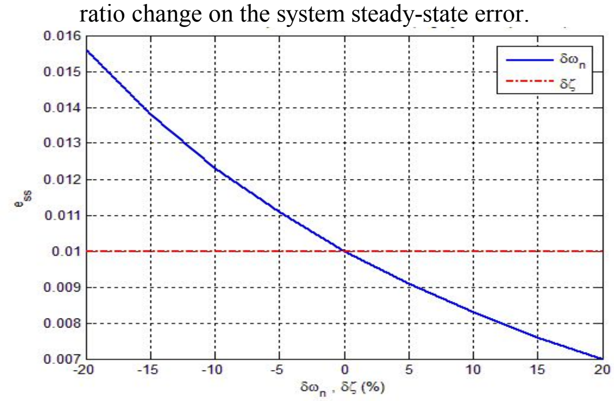

Fig.1 Effect of process parameters change on system steady-state error (2/2 second-order compensator – highly oscillating process).

Fig.2 shows the effect of the natural frequency and damping ratio change on the system settling time.

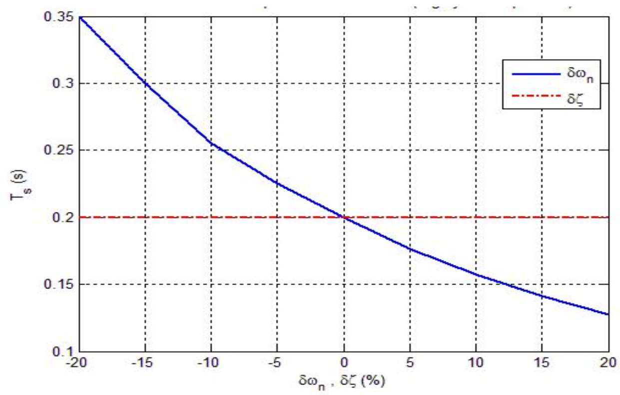

Fig.2 Effect of process parameters change on system settling time (2/2 second-order compensator– highly oscillating process).

Fig.3 shows the effect of the natural frequency and damping ratio change on the system maximum percentage overshoot.

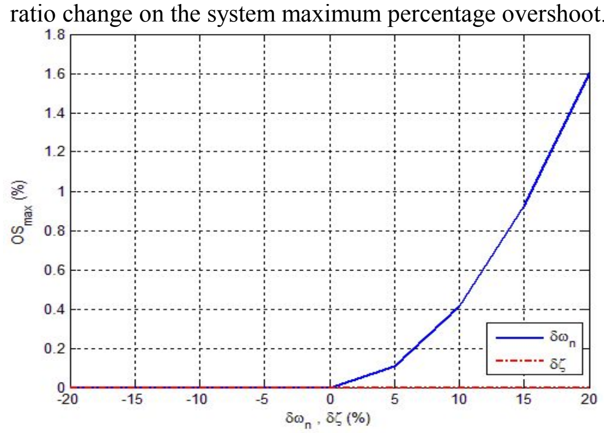

Fig.3 Effect of process parameters change on system maximum percentage overshoot (2/2 second-order compensator– highly oscillating process).

Fig.4 shows the effect of the natural frequency and damping ratio change on the system phase margin.

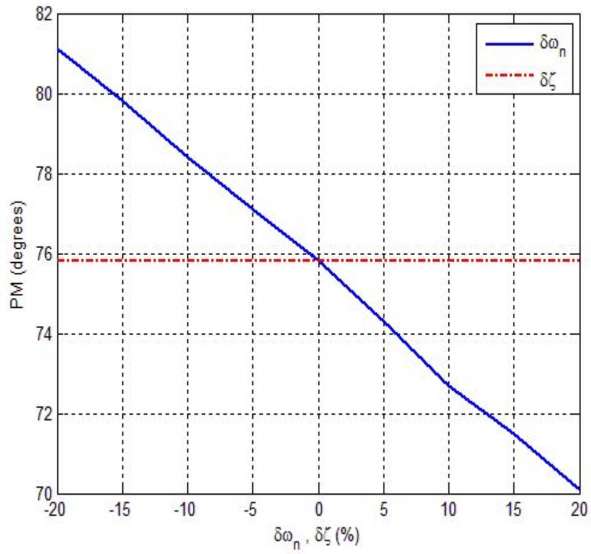

Fig.4 Effect of process parameters change on system phase margin (2/2 second-order compensator – highly oscillating process).

IV. ROBUSTNESS OF A FEEDFORWARD 2/2 COMPENSATOR CONTROLLING A VERY SLOW SECOND-ORDER-LIKE PROCESS

The author presented a tuning approach to tune a 2/2 second-order compensator when used with a very slow second order-like process using a novel approach based on solving a set of nonlinear equations in some of the performance parameters of the control system [19].

The compensator parameters and the system performace measures are:

$K = 2386.2$
$\omega_{nc2} = 2.2$
$\zeta_{c2} = 9.5$

Maximum percentage overshoot = 0
Settling time = 0.22 s
Gain margin = ∞
Phase margin = 75.7 degrees

The robustrness investigation procedure is applied on the resulting control system for process variation in the range ± 20 % from the nominal values. The results are as follows:

- The idea of the 2/2 second-order compensator is to cancel the bad poles resulting in the bad dynamics of the process.
- Those bad poles aree replaced by good poles defined by any suitable optimization technique or by solving a set of nonlinear equations governing the performance of the closed-loop control system.
- The good poles in both cases of process with high oscillations or very slow response are almost the same.
- This reveals almost the same robustness analysis presented for the higly oscillating second-order process.

Conclusion

- Variation in second-order process parameters within ± 20 % was considered.
- The judgment on the robustness condition of a controller is based on an accepted range of both gain margin and phase margin of the closed-loop control system.
- According to Ogata [20], a recommended range is: GM ≥ 6 dB and 30 ≤ PM ≤ 60 degrees.
- According to Lei and Man [21], the phase margin range can be widened to be:
- 30 ≤ PM ≤ 90 degrees.
- The gain margin of the control system is infinity.
- The phase margin (PM) is affected only by the change in the process natural frequency. It varied in the range: 70.1 ≤ PM ≤ 81.1 degrees). It is within the range assigned by Lei and Man [21].
- The tuned 2/2 second-order compensators used to control a highly oscillating and very slow second order processes are robust for the ± 20 % change in the process parameters.
- The steady-state error of the closed-loop control system due to the ± 20 % change in process natural frequency did not exceed 0.0156.
- The maximum percentage overshoot due to the ± 20 % change in process natural frequency did not exceed 1.64 %.
- The settling time due to the ± 20 % change in process natural frequency did not exceed 0.35 seconds.
- The change in the process damping ratio had no effect on the performance parameters of the closed loop control system.

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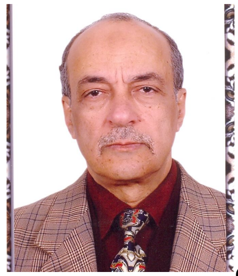
BIOGRAPHY



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