Gain-Scheduling Control Solutions for a Strip Winding System with Variable Moment of Inertia

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Abstract: This paper presents four design methods for the speed control of a mechatronics application characterized by variable parameters: variable reference, variable load disturbance and variable moment of inertia. The variations of the operating conditions and also the variations of the process parameters require the development of advanced control solutions. In this context the development of advanced control solutions will be influenced and justified significantly by the knowledge of a detailed mathematical model of the process and its parameters. In order to obtain high performance speed control for the electric drive system, referred to as the strip winding system, four proportional-integral (PI) gain-scheduling control solutions are developed and tested: (1) a PI Switching-I Gain-Scheduling version with bump-less switching between three control algorithms (PI-SIGS), (2) a PI Switching-II Gain-Scheduling version with a switching logic based on Euclidean distance metric (PI-SIIGS); (3) a PI Gain-Scheduling version with a switching logic based on a generalization of the monovariable case of the Lagrange interpolating parameter value method (PI-LGS), and (4) a PI Gain-Scheduling version with a switching logic based on a Cauchy kernel distance metric (PI-CGS). The continuous-time speed controllers are tuned by the Modulus Optimum method (MO-m) and are discretized using Tustin's method. The proposed and developed control solutions were embedded in a conventional control structure (CCS) which involves the switching between different digital control algorithms and are validated by means of simulation results. The strip winding system is discussed in this paper due to its applicability as a controlled plant in the field of mechatronics systems.

Keywords: proportional-integral controllers, gain-scheduling techniques, conventional control structure, switching logic, strip winding system, variable moment of inertia.

1. INTRODUCTION

The mechatronics system considered in this paper is the strip winding system (SWS), which is a complex and nonlinear mechanism that wraps a brass strip on a reel. The overall system behaviours and the plant parameters are changed due to the wrapping of the strip which actually determines the increase of the reel radius, which in turn leads to the modification of the moment of inertia. The main goal of the control, in order to avoid the breaking of the strip, is to keep constant the resistance force of the material (f_{rs}) and also the linear velocity of the reel (v_l). So, in order to ensure good control performance it is necessary to provide bump-less switching between several algorithms and at the same time it is necessary to recalculate the controller parameters (Stinean et al., 2013a; Stinean et al., 2013b). Well justified relations are required in order to recalculate the controller parameters. The conditions for calculating the controller parameters and the choice of the number of control algorithms are problems which need to be solved by the designer.

The fact that the linear controllers can only function in certain vicinities of a single operating point, determines the gain-scheduling (GS) technique to be one of the most common ones for nonlinear control systems design. Its increasing popularity in many engineering applications results from the fact that the scheduling variable should have a slow variation and should capture the nonlinearities of the plant (Shamma and Athans, 1990; Veselý and Ilka, 2013; Fozo et al., 2017). In the last three decades, representative gain-scheduling control solutions have been proposed for different processes and some of them will be briefly analyzed as follows. An analysis for two types of nonlinear gain-scheduled control systems and the conditions which guarantee stability, robustness, and performance properties of these designs are presented in (Shamma and Athans, 1990). Based on the physical significance of the equilibrium manifold linearization model and the self-feedback mechanism of shock motion, a gain-scheduling controller for nonlinear shock motion is developed in (Tao et al., 2007). In (Michino et al., 2009) a high gain adaptive output feedback controller for a magnetic levitation system is designed by introducing two different virtual filters and using back stepping strategy. A design methodology of gain scheduled controllers for wind turbines is proposed in (Bianchia et al., 2012) to deal with multi-variable and high order models as those produced by high fidelity aeroelastic simulators. A robust gain-scheduling Smith proportional-integral-derivative (PID) controller with pole placement constraints for second order linear parameter varying systems with time varying delay is discussed in (Puig et al., 2012). An adaptive fuzzy gain-scheduling sliding mode control approach for attitude regulation of unmanned quadrotors is suggested in (Yang and Yan, 2016). The design of adaptive fuzzy gain-scheduling of PI controller for wind energy conversion systems based on doubly fed induction generator is investigated in (Bedoud et al., 2016). A theoretical study on the dynamic shape control problem of deployable mesh reflectors via feedback approaches using gain-scheduling method is given in (Xie et al., 2016). Other gain-scheduling control solutions for interesting experimental applications are presented in (Dounis et al., 2013; Veselý and Ilka, 2013; Bojan-Dragos et al., 2016).

The paper is focused on the design and implementation of four PI gain-scheduling control solutions meant for controlling the angular speed of the SWS. These solutions include PI controllers, because, as shown in (Åström and Hägglund, 2005), even if the controller has a simple structure, the I component determines a zero steady-state control error. In addition, the PI controllers can be subjected to the design of advanced and efficient control structures that include fuzzy logic, sliding mode and robust control. The controller design is carried out in terms of the following steps: (i) a detailed preliminary study of the process is done with focus on the parameters' variability, (ii) the nonlinear mathematical model (MM) is derived under the condition that the thickness of the strip that is wrapped on the reel is sufficiently small, (iii) only in the design step, the transfer function (t.f.) of the plant is accepted as linearized equivalent second-order benchmark-type t.f. connected to certain parameter values, and (iv) the designed control solutions are tested with respect to the performance specifications and using the detailed (nonlinear) MM.

The paper offers four new contributions: 1. the interpretation of the extended nonlinear model as second-order benchmark type MM, 2. the design and implementation of four GS control techniques, 3. the digital validation of the gain-scheduled structures with PI controllers dedicated to the speed control of the SWS with continuously variable parameters, and 4. the comparative analysis of all adaptive gain-scheduling control techniques to highlight the achieving of the specified control system performance.

The paper is divided into the following topics: the conventional control structure (CCS) and simplified MMs are presented in Section 2. The design and the implementation of the four proposed gain-scheduling control techniques are given in Section 3. Section 4 presents a comparative analysis of all adaptive control solutions and digital simulation results concerning the proposed control solutions developed for the speed control of a mechatronics application. The main conclusions are pointed out in Section 5.

2. STRIP WINDING SYSTEM

The mechatronics application that is controlled in this paper consists of an electric drive system with continuously variable parameters (namely reference, load disturbance and moment of inertia), rigid coupling and a strip rolling reel. The SWS presents two specific features in operation: (1) due to the wrapping of the strip, the moment of inertia of the rolling reel (J_r) will increase over time; (2) in order to avoid the breaking of the strip, the resistance force of the material (f_{rs}) and also the linear velocity of the reel (v_l) must remain constant:

$$f_{rs}(t) = \text{const}, \quad v_l(t) = v_r(t) = \text{const} \cdot \tag{1}$$

Taking into account these aspects, the total moment of inertia, the reel radius variation and the angular speed reference input can be expressed as

$$\begin{aligned} & J_{tot}(t) = J_0 + a^2 \cdot J_r(t), \\ & a = \frac{\omega_r}{\omega}, \quad J_0 = J_m + J_{empty\_drum}, \quad J_r(t) = \frac{\rho \cdot \pi \cdot l \cdot [r(t) - r_0]^4}{2}, \\ & \frac{dr(t)}{dt} = \frac{h}{2\pi} \cdot \omega_r(t) = \frac{h}{2\pi} \cdot a \cdot \omega(t), \\ & \omega_{ref}(t) = \frac{v_{ref}}{r(t)}, \end{aligned} \tag{2}$$

where: $J_{tot}(t)$ – the total moment of inertia of the system [kgm^2], J_m – the moment of inertia of the direct current motor [kgm^2], $J_r(t)$ – the moment of inertia of the winding reel [kgm^2], a – the transmission parameter which characterizes the speed reduction unit, ω – the angular speed of the motor [rad/s], ω_r – the angular speed of the winding reel [rad/s], $r(t)$ – the reel radius with material on it [m], r_0 – the initial radius of the reel [m], h – the thickness of the strip, l – the reel width, ρ – the density of the material, ω_{ref} – the angular speed reference input [rad/s], v_{ref} – the linear speed reference input [m/s]. The CCS is illustrated in Fig. 1.

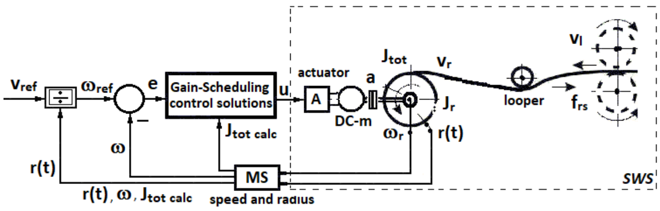

Fig. 1. Conventional control structure with gain-scheduling techniques.

The nonlinear MM of the SWS and the numerical values of system parameters used in the CCS design are given in (Stinean et al., 2013a; Stinean et al., 2013b). The achieved mathematical models are simplified, in the form of, for instance, second-order benchmark-type t.f.s

$$H_{CP}(s) = \frac{k_{CP}}{(1 + sT_\Sigma)(1 + sT_m)}, \tag{3}$$

where: k_{CP} – the controlled process gain, T_Σ – the small time constant, T_m – the mechanical time constant and $T_\Sigma << T_m$. Relying on this benchmark-type t.f., speed control structures and controller designs can be applied.

3. COMPARATIVE STUDY OF FOUR PI GAIN-SCHEDULING CONTROLLERS

The continuously variable parameters of the SWS determine the occurrence of modifications in the controllers. Consequently, the solutions that employ a switching logic among several control algorithms (c.a.s) offer a good option. A correlation and connection between the switching conditions and the changes of the plant must be ensured. The adaptive controllers offer an additional benefit by taking into account these changes and by retuning their parameters. If needed, using Kharitonov's method in the linear case or Liapunov's method in the nonlinear case, a stability analysis test can be performed for the adjacent domains (Precup et al., 2013; Blažič et al., 2014).

Using (3), the design of the proposed GS controller versions starts with the design and tuning of the following continuous-time PI control algorithms with the t.f.

$$H_C(s)=\frac{k_C}{s\cdot T_i}\cdot(1+s\cdot T_i)=\frac{k_c}{s}\cdot(1+s\cdot T_i), \tag{4}$$

where: k_C – the controller gain and T_i – the integral time constant, $k_c=k_C/T_i$. The control algorithms are designed and tuned by the MO-m referred in (Åström and Hägglund, 2005). Each of these PI controllers has fixed parameter values tuned for three values of J_{tot}: $J_{tot}^{(j)}$, $j\in\{1,2,3\}$, obtained for three significant values of the reel radius: R_{01}=0.01375 m, R_{02}=0.02875 m and R_{03}=0.05 m.

The continuous-time PI controllers are discretized using Tustin's method with the sampling period T_s=0.00025 s, resulting three discrete-time PI controllers with the t.f.s

$$H_C(z^{-1})=\frac{q_0+q_1z^{-1}}{1-z^{-1}}, \tag{5}$$

where z^{-1} represents the backward shift operator. The parameters of the digital control algorithms are

$$q_0=k_C+k_C\cdot T_e/(2\cdot T_i),\ q_1=-[k_C-k_C\cdot T_e/(2\cdot T_i)]. \tag{6}$$

After the design of the discrete-time PI controllers for three values of J_{tot}, four GS control solutions, namely Switching-I GS, Switching-II GS, Lagrange GS, Cauchy GS, are developed in order to improve the control system performance with the following c.a.:

$$u(k)=u(k-1)+q_0(k)e(k)+q_1(k)e(k-1), \tag{7}$$

where k is the discrete time argument, $e(k)=\omega_{ref}(k)-\omega(k)$ is the control error sequence, $\omega(k)$ is the process output sequence, $\omega_{ref}(k)$ is the reference input sequence, $q_i(k)$, $i\in\{0,1\}$ are the discrete-time PI tuning parameters designed in the next subsections according to the proposed GS control version. In the last three versions — Switching-II GS, Lagrange GS, Cauchy GS — the discrete-time PI tuning parameters are extended with a first-order lag filter:

$$q_i(k)=\beta\cdot q_{i,GS}(k-1)+q_{i,GS}(k), \tag{8}$$

where the parameter $\beta\in\{0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8\}$ controls the transition speed between controller parameters and $q_{i,GS}(k)$ are regarded as reference inputs calculated as shown next for each of the four proposed GS versions.

3.1 Switching-I Gain-Scheduling Controller

The Switching-I GS (SIGS) controller is based on the c.a. (7), where the discrete-time PI tuning parameters

$$q_i(k)=q_{i,SIGS}^{(j)}(k),\ i\in\{0,1\},\ j=\overline{1,3} \tag{9}$$

are obtained based on the switching between three PI c.a.s according to

$$\begin{aligned}&\text{IF } ((r>r_0)\text{ and }(r\le r_1))\text{ THEN } && \{q_{0,SIGS}^{(1)},q_{1,SIGS}^{(1)}\}\Leftrightarrow r_0<r\le r_1\\ &\text{ELSE IF } (r\le r_2)\text{ THEN } && \{q_{0,SIGS}^{(2)},q_{1,SIGS}^{(2)}\}\Leftrightarrow r_1<r\le r_2\\ &\text{ELSE} && \{q_{0,SIGS}^{(3)},q_{1,SIGS}^{(3)}\}\Leftrightarrow r_2<r\le r_3\end{aligned} \tag{10}$$

For the electric drive system with variable parameters the switching logic is realised according to Fig. 2 (a).

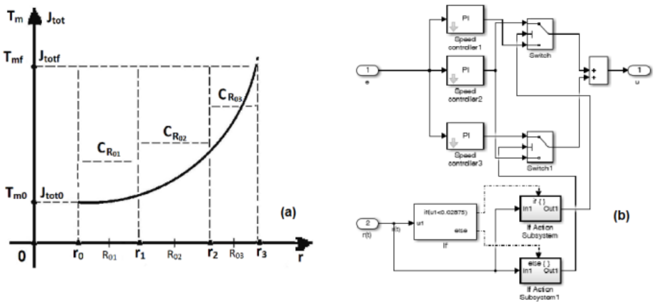

Fig. 2. The mechanical time constant and total moment of inertia variation as function of reel radius (a) and detailed block diagram of controller switching (SIGS version).

The modification of the mechanical time constant ($T_m=f(J_{tot}(t))$) and the modification of the total moment of inertia (J_{tot}) versus the reel ($r(t)$), are detailed in Fig. 2 (a), where: r – the variable parameter which imposes the switching condition, r_1, r_2 –the switching values (included in the switching conditions), r_0, r_3 – the initial value, respectively final value of r and R_{01}, R_{02}, R_{03} – the values for which the controllers are developed. The block diagram of the controller is given in Fig. 2 (b).

3.2 Switching-II Gain-Scheduling Controller

The Switching-II GS (SIIGS) controller is based on the switching between three PI controllers, and during the digital simulation the PI controller parameters correspond to the nearest moment of inertia, which are selected based on the Euclidean distance metric:

$$q_{i,SIIGS}=\sum_{j=1}^{3}[\alpha_{SIIGS}^{(j)}/(\sum_{j=1}^{n}\alpha_{SIIGS}^{(j)})\cdot q_i^{(j)}],\ i\in\{0,1\}, \tag{11}$$

where

$$q_{i,SIIGS}=q_i^{(j^*)},\quad j^*=\arg\min_{j=1,3}(J_{tot}-J_{tot}^{(j)})^2,\quad i\in\{0,1\}, \tag{12}$$

SIIGS stands out for Switching-II Gain-Scheduling version, J_{tot} represents the current total inertia, and $(J_{tot}-J_{tot}^{(j)})^2$ are the square Euclidean distances between the current J_{tot} and the nearest total inertia $J_{tot}^{(j)}$. The three total inertia values are specified in Section 4. Taking into account these aspects, the logic for SIIGS is included in the pseudo-code form

$$\begin{aligned}&d_{\min}=\inf;\\&\text{FOR } j=1:3\\&\quad d=\text{norm}(J_{\text{tot}}-J_{\text{tot}}^{(j)});\\&\quad \text{IF } d<d_{\min}\ \text{THEN}\ d_{\min}=d;\\&\quad \text{END}\\&\text{END}\end{aligned} \tag{13}$$

where inf indicates the largest positive number stored in the computer.

3.3 Lagrange Gain-Scheduling Controller

The Lagrange GS (LGS) controller is based on the monovariable case, also given in (Tao et al., 2007), of the Lagrange interpolating parameter value method as follows:

$$q_{i,LGS} = \sum_{j=1}^{3}[\alpha_{LGS}^{(j)} / (\sum_{j=1}^{n}\alpha_{LGS}^{(j)}) \cdot q_i^{(j)}],\ i \in \{0,1\}, \quad (14)$$

where

$$\alpha_{LGS}^{(j)} = \prod_{l=1, l \neq j}^{3}[(J_{tot} - J_{tot}^{(l)}) / (J_{tot}^{(j)} - J_{tot}^{(l)})]^2, \quad (15)$$

the superscripts j denote different total inertia values, and all coefficients $\alpha_{LGS}^{(j)}$ in the first summation in (14) are normalized to add up to 1.

3.4 Cauchy Gain-Scheduling Controller

The Cauchy GS (CGS) controller is based on a Cauchy kernel distance metric resulting in the Cauchy GS control solution. This approach directly takes into account all previous data samples:

$$q_{i,CGS} = \sum_{j=1}^{3}[\alpha_{CGS}^{(j)} / (\sum_{j=1}^{n}\alpha_{CGS}^{(j)}) \cdot q_i^{(j)}],\ i \in \{0,1\}, \quad (16)$$

where

$$\alpha_{CGS}^{(j)} = \sum_{j=1}^{3}\{1/[1 + (J_{tot} - J_{tot}^{(j)})^2]\}. \quad (17)$$

The last three GS versions, SIIGS, LGS and CGS, are detailed in the block diagram given in Fig. 3.

4. SIMULATION RESULTS

The CCS was developed and tested on the SWS with variable moment of inertia in the framework of four proposed speed control solutions. The PI controllers were designed for three fixed values of the total moment of inertia, $J_{tot}^{(1)}=0.1833 \cdot 10^{-4}$ kgm^2, $J_{tot}^{(2)}=0.2439 \cdot 10^{-4}$ kgm^2 and $J_{tot}^{(3)}=0.7652 \cdot 10^{-4}$ kgm^2. The second-order benchmark t.f.s and the parameters of the digital c.a.s are given in Table 1. The system's response to an appropriate change of the reference input that causes an increased reel radius and leads to a moment of inertia variation for the electrical drive system with variable parameters is illustrated in Fig. 4, Fig. 5 and Fig. 6.

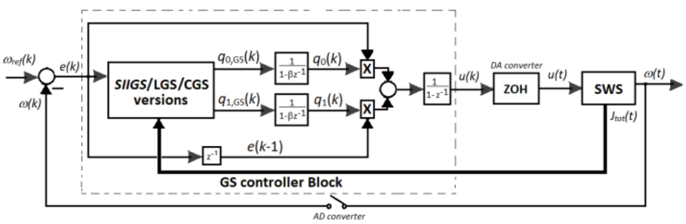

Fig. 3. Detailed block diagram of the last three GS versions (SIIGS, LGS and CGS).

A performance comparison between the analyzed control solutions is carried out in terms of the mean square error (MSE) values included in Table 2. The values of the MSE, which cumulate the control errors over the time horizon of m sampling intervals, considered as a global performance index, between the model outputs $\omega_{ref,k}$ and the real-world system outputs ω_k, are defined as:

$$MSE = \frac{1}{m}\sum_{k=1}^{m}(\omega_{ref,k} - \omega_k)^2, \quad (18)$$

Table 1. Controlled process t.f.s and numerical values of PI controllers parameters

Moment of inertia	Controlled process t.f.s $H_{CP}(s)$	Parameters of PI controllers	
		$q_0^{(j)}$	$q_1^{(j)}$
$J_{tot}^{(1)}$	$\frac{161.8}{(1+0.001s)(1+0.02483s)}$	0.0771	-0.0763
$J_{tot}^{(2)}$	$\frac{161.8}{(1+0.001s)(1+0.03303s)}$	0.1025	-0.1017
$J_{tot}^{(3)}$	$\frac{161.8}{(1+0.001s)(1+0.10363s)}$	0.3207	-0.3199

Table 2. MSE values obtained with respect to four GS techniques

β	SIGS	SIIGS	LGS	CGS
0	0.1232	0.5198	0.4546	0.2295
0.1	0.1232	0.4286	0.3745	0.1883
0.2	0.1232	0.3453	0.3015	0.1511
0.3	0.1232	0.2704	0.2359	0.1179
0.4	0.1232	0.2045	0.1783	0.0892
0.5	0.1232	0.1485	0.1296	0.0656
0.6	0.1232	0.1042	0.0914	0.0483
0.7	0.1232	0.0732	0.0652	0.0376
0.8	0.1232	0.0551	0.0501	0.0326

Taking into account the graphs illustrated in Figs. 4-6 (for $\beta \in \{0, 0.4, 0.8\}$) and the MSE values presented in Table 2 following conclusions can be drawn: (1) the justification for employing PI controllers in combination with switching controllers is given by the variation of the parameters and by the existence of the process nonlinearities; (2) the results given in Figs. 4-6 (c) and (d) point out that no substantial differences are observed in terms of reel radius and total moment of inertia for all GS techniques; (3) the MSE values for SIGS version will always be the same, due to the fact that the switching between the three PI c.a.s is according to relation (10) and also because the discrete-time PI tuning parameters do not depend on β; (4) the SIIGS version is less effective in comparison with the SIGS version because more than 60% of the MSE values are greater than the MSE value for SIGS version; (5) the LGS version is more effective in comparison with the SIIGS version because all the MSE values are smaller than the SIIGS MSE values; (6) the results given in Table 2 point out that the best performances have been achieved by the CGS version due to the fact that more than 60% of the MSE values are smaller than the MSE value for SIGS version and (7) based on the comparative analysis of the four adaptive control solutions it can be highlighted that the proposed control solutions - SIGS, SIIGS, LGS and CGS - proved viable and ensure a good reference tracking ability.

5. CONCLUSIONS

This paper has provided details regarding the design and implementation of four GS techniques aiming to control the speed for a mechatronics system with variable parameters. The proposed GS versions were embedded in a CCS which involves the switching between different digital c.a.s and are validated by means of simulation results.

The design of the PI controllers was made on the basis of second-order benchmark-type t.f.s connected to certain parameter values. The extended nonlinear MM was used in testing the proposed control solution, due to the fact that this model is closer to the real-world system behaviour.

The motivation to use PI controllers is to obtain a zero steady-state control error. The motivation for the design of PI controllers in the variant with switching controllers is justified by the presence of the process nonlinearities, the overall system behaviours and by the parameters variation. All GS techniques are transparent, relatively simple to understand and to implement and based on simulation results it can be concluded that these control solutions proved viable and ensure a good reference tracking ability.

The methodical selection of parameters for the PI GS control will constitute the goal of future research by certifying the optimal tuning in terms of employing classical and modern optimization and artificial intelligence techniques (Sánchez Boza et al., 2011; Haidegger et al., 2012; Pozna et al., 2012; Arsene et al., 2015; Xu and Vilanova, 2015; Tran and Vang, 2017) dealing with various applications (Filip, 2008; Vaščák and Hirota, 2011; Fioriti and Chinnici, 2017; Kovács, 2017; Mac et al., 2017; Padula et al., 2017; Vrkalovic et al., 2017). In the future, the design and development of control structures with neural network-based and fuzzy logic GS controllers as well as hybrid structures to ensure increased performance, will be the focus of research.

ACKNOWLEDGEMENTS

This work was supported (partial supported) by a grant of the Politehnica University of Timisoara, Romania, project number PCD-TC-UPT-2017.

REFERENCES

Arsene, O., Dumitrache, I., and Mihu, I. (2015). Expert system for medicine diagnosis using software agents. *Expert Systems with Applications*, 42 (4), 1825-1834.

Åström, K.J. and Hägglund, T. (2005). *Advanced PID Control*. Instrumentation, Systems, and Automation Society, Research Triangle Park.

Bedoud, K., Ali-rachedi, M., Bahid, T., and Lakel, R. (2016). Adaptive fuzzy gain scheduling of PI controller for control of the wind energy conversion systems. *Energy Procedia*, 74, 211-225.

Bianchia, F.D., Sánchez-Peña, R.S., and Guadayol, M. (2012). Gain scheduled control based on high fidelity local wind turbine models. *Renewable Energy*, 37 (1), 233-240.

Blažič, S., Škrjanc, I., and Matko, D. (2014). A robust fuzzy adaptive law for evolving control systems. E*volving Systems*, 5 (1), 3-10.

Bojan-Dragos, C.-A., Precup, R.-E., Preitl, S., Hergane, S., Hughiet, E.G., and Szedlak-Stinean, A.-I. (2016). Proportional-integral gain-scheduling control of a magnetic levitation system. *Proceedings of 20th International Conference on System Theory, Control and Computing*, Sinaia, Romania, 1-6.

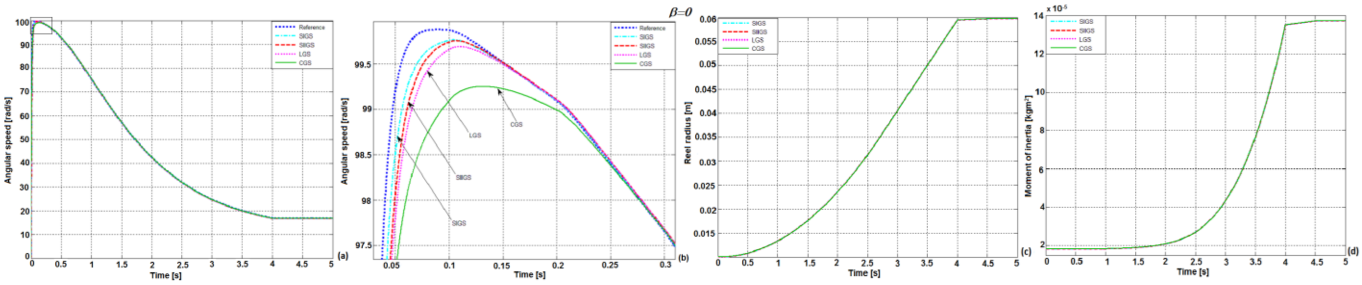

Fig. 4. Simulation results for the SWS with variable parameters for β=0: angular speed versus time (a), detail of angular speed versus time (b), reel radius versus time (c), moment of inertia versus time.

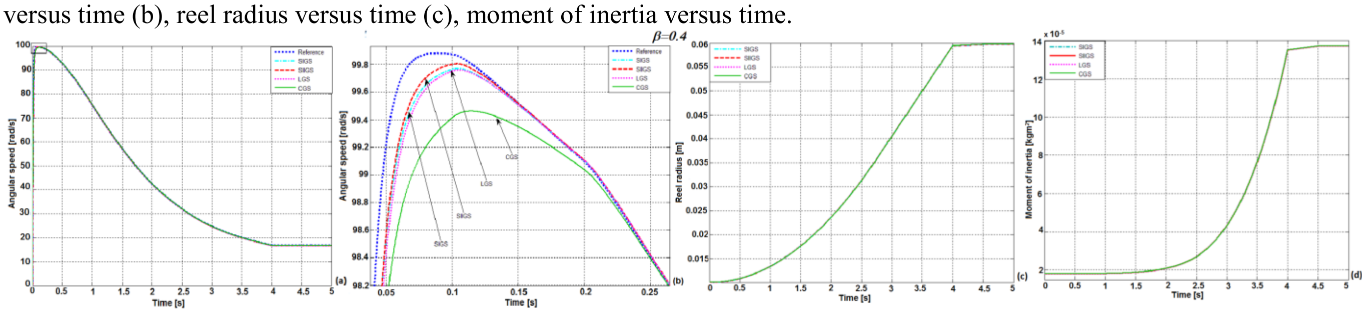

Fig. 5. Simulation results for the SWS with variable parameters for β=0.4: angular speed versus time (a), detail of angular speed versus time (b), reel radius versus time (c), moment of inertia versus time (d).

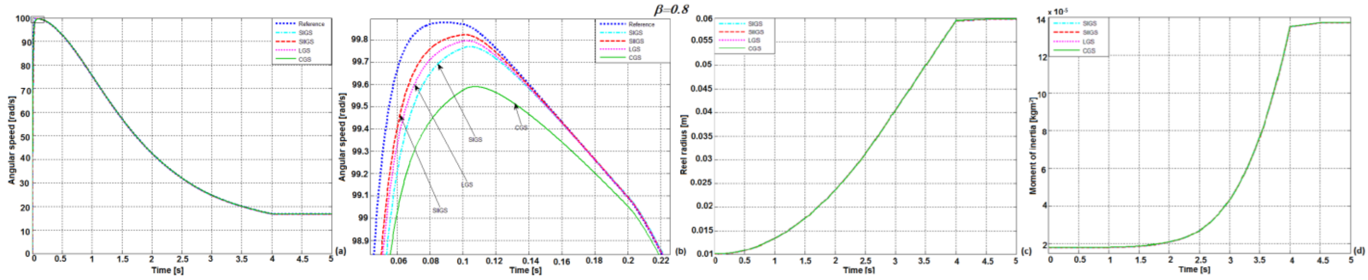

Fig. 6. Simulation results for the SWS with variable parameters for β=0.8: angular speed versus time (a), detail of angular speed versus time (b), reel radius versus time (c), moment of inertia versus time.

Dounis, A.I., Kofinas, P., Alafodimos, C., and Tseles, D. (2013). Adaptive fuzzy gain scheduling PID controller for maximum power point tracking of photovoltaic system. *Renewable Energy*, 60, 202-214.

Filip, F.G. (2008). Decision support and control for large-scale complex systems. *Annual Rev. Control*, 32 (1), 61-70.

Fioriti V. and Chinnici, M. (2017). Node seniority ranking in networks. *Studies in Informatics and Control*, 26 (4), 397-402.

Fozo, L., Andoga, R., Beneda, K., and Kolesár, J. (2017). Effect of operating point selection on non-linear experimental identification of iSTC-21v and TKT-1 small turbojet engines, *Periodica Polyt. TE*, 45 (3), 141-147.

Haidegger, T., Kovács, L., Precup, R.-E., Benyó, B., Benyó, Z., and Preitl, S. (2012). Simulation and control for telerobots in space medicine. *Acta Astronautica*, 181 (1), 390-402.

Kovács, L. (2017). Linear parameter varying (LPV) based robust control of type-I diabetes driven for real patient data. *Knowledge-Based Systems*, 122, 199-213.

Mac, T.T., Copot, C., Duc, T.T., De Keyser, R. (2017). A hierarchical global path planning approach for mobile robots based on multi-objective particle swarm optimization. *Applied Soft Computing*, 59, 68-76.

Michino, R., Tanaka, H., and Mizumoto, I. (2009). Application of high gain adaptive output feedback control to a magnetic levitation system. *Proceedings of ICROS-SICE International Joint Conference*, Fukuoka, Japan, 970-975.

Padula, F., Ionescu, C.M., Latronico, N., Paltenghi, M., Visioli, A., and Vivacqua, G. (2017). Optimized PID control of depth of hypnosis in anesthesia. *Computer Methods and Programs in Biomedicine*, 144, 21-35.

Pozna, C., Minculete, N., Precup, R.-E., Kóczy, L.T., and Ballagi, Á. (2012). Signatures: Definitions, operators and applications to fuzzy modelling. *Fuzzy Sets and Systems*, 201, 86-104.

Precup, R.-E., Tomescu, M.L., Preitl, S., Petriu, E.M., Fodor, J., Pozna, C. (2013). Stability analysis and design of a class of MIMO fuzzy control systems *Journal of Intelligent and Fuzzy Systems*, 25 (1), 145-155.

Puig, V., Bolea, Y., and Blesa, J. (2012). Robust gain-scheduled Smith PID controllers for second order LPV systems with time varying delay. *IFAC Proceedings Volumes*, 45(3), 199-204.

Sánchez Boza, A., Haber Guerra, R., and Gajate, A. (2011). Artificial cognitive control system based on the shared circuits model of sociocognitive capacities. A first approach. *Engineering Applications of Artificial Intelligence*, 24 (2), 209-219.

Shamma, J.S. and Athans, M. (1990). Analysis of gain scheduled control for nonlinear plants. *IEEE Transactions on Automatic Control*, 35 (8), 898-907.

Stinean, A.-I., Preitl, S., Precup, R.-E., Dragos, C.-A., Radac, M.-B., and Petriu, E.M. (2013a). Modeling and control of an electric drive system with continuously variable reference, moment of inertia and load disturbance. *Proceedings of 9th Asian Control Conference*, Istanbul, Turkey, 1-6.

Stinean, A.-I., Preitl, S., Precup, R.-E., Dragos, C.-A., Radac, M.-B., and Petriu, E.M. (2013b). Low-cost neuro-fuzzy control solution for servo systems with variable parameters. *Proceedings of 2013 IEEE International Conference on Comput. Intell. and Virtual Environments for Measurement Syst. and App.*, Milano, Italy, 156-161.

Veselý, V. and Ilka, A. (2013). Gain-scheduled PID controller design. *Journal of Process Control*, 23 (8), 1141-1148.

Xie, Y.-M., Shi, H., Alleyne, A., and Yang, B.-G. (2016). Feedback shape control for deployable mesh reflectors using gain scheduling method. *Acta Astronautica*, 121, 241-255.

Yang, Y.-N. and Yan, Y. (2016). Attitude regulation for unmanned quadrotors using adaptive fuzzy gain-scheduling sliding mode control. *Aerospace Science and Technology*, 54, 208-217.

Tao, C., Daren, Y., Wen, B., and Yongbin, Y. (2007). Gain scheduling control of nonlinear shock motion based on equilibrium manifold linearization model. *Chinese Journal of Aeronautics*, 20(6), 481-487.

Tran, T.V. and Wang, Y.N. (2017). Artificial chemical reaction optimization algorithm and neural network based adaptive control for robot manipulator. *Control Engineering and Applied Informatics*, 19 (2), 61-70.

Vaščák, J. and Hirota, K. (2011). Integrated decision-making system for robot soccer. *Journal of Advanced Computational Intelligence and Intelligent Informatics*, 15 (2), 156-163.

Vrkalovic, S., Teban, T.-A., and Borlea, I.-D. (2017). Stable Takagi-Sugeno fuzzy control designed by optimization. *International Journal of Artificial Intelligence*, 15 (2), 17-29.

Xu, H.-Y. and Vilanova, R. (2015). PI and fuzzy control for P-removal in wastewater treatment plant. *International Journal of Computers, Communic. Control*, 10, 936-951.