Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 69 (2014) 323 – 332

Procedia Engineering

www.elsevier.com/locate/procedia

24th DAAAM International Symposium on Intelligent Manufacturing and Automation, 2013

Adaptive LMS Filter using in Flexible Mechatronics System with Variable Parameter Control

Martin Juhas*, Bohuslava Juhasova, Igor Halenar

Institute of AIAM FMST SUT in Trnava, Hajdoczyho 1, Trnava 917 24, Slovakia

Abstract

The analysis of negative impact of flexible mechatronics system time variable parameter and its reduction or complete elimination possibility is presented in this contribution. The LMS adaptive filter is proposed to use for reduction of double notch filter insufficient effect, which was initially integrated into system for flexible joint parasitic frequencies elimination. Simulation experiments results - step response and control quality analysis confirmed the correctness of suggestion of LMS adaptive filter using.

Keywords: flexible mechatronics system control; variable flexibility; adaptive LMS filter

1. Introduction

This contribution deals with special case of flexible mechatronics system – DC motor with flexible joint containing in-time variable parameter affecting the coupling properties. A DC motor angular velocity controller was designed by standard method of controller design - Modulus Optimum Method. A flexible connection is characterized by undesirable frequencies occurrence. In case of time invariable joint parameters in relation to this control design method, a double notch filter was used and enough to eliminate these parasitic resonant and antiresonant frequencies. Because of static character of double notch filter, variability of flexible joint key parameters can result in filter efficiency reduction. In case of joint variable parameter occurrence, an additional LMS adaptive filter is proposed to use together with simplified model of rigid connection system for generating of desired signal for LMS algorithm.

* Corresponding author. Tel.: +421 906 068 731.
E-mail address: martin_juhas@stuba.sk

doi:10.1016/j.proeng.2014.02.239

2. Flexible mechatronics system model

The DC motor (DCM) with flexible coupling as analysed mechatronics system is chosen. A special type of drive – torque motor was analysed. This type of drive is characterized by high torsion moment at relatively low speed.

If the inertia of the transmission mechanisms is small compared to the motor and load, the flexible coupling between the motor and load can be treated as a two-mass motor/load system [1], [5] described with mathematical model in form of algebraic differential equations system (1)…(6) [11].

The electric subsystem [4] is represented by equations:

$$U_a = R_a I_a + L_a \frac{dI_a}{dt} + U_i \tag{1}$$

$$U_i = c\varphi\,\omega_M \tag{2}$$

$$T_E = c\varphi\, I_a \tag{3}$$

The mechanical subsystem [4] is represented by equations:

$$J_M \frac{d\omega_M}{dt} + b_{12}(\omega_M - \omega_L) + T_{12} - T_E = 0 \tag{4}$$

$$\frac{dT_{12}}{dt} - d_{12}(\omega_M - \omega_L) = 0 \tag{5}$$

$$J_L \frac{d\omega_L}{dt} - b_{12}(\omega_M - \omega_L) - T_{12} + T_L = 0 \tag{6}$$

Table 1. Analysed system parameters.

Parameter	Unit	Description	Value
R_a	Ω	armature current	0.02
L_a	mH	resistance and inductance of armature winding	100
$c\Phi$	Nm/A	torque constant	0.3
J_M	kg/m^2	inertia of the motor rotor	10
J_L	kg/m^2	inertia of the load	60
b_{12}	Nms	damping of the transmission	0.1
d_{12}	Nm	spring constant of the transmission	4

A coupling flexibility is a source of the antiresonant and resonant frequencies, which can lead up to whole system instability. A double notch filter for this spurious frequencies elimination is chosen. The filter is represented as a subsystem, whose transfer function contains complex conjugate poles and zeros. These conjugate poles and zeros induce resonant and antiresonant frequencies in the logarithmic frequency characteristics (LFCh). The filter coefficients are set up to compensate system antiresonant frequency by filter resonant frequency and conversely, that system resonant frequency was compensated by filter antiresonant frequency [2].

The numerator and denominator of filter transfer function are defined as:

$$num\_filter = \left(\frac{1}{\omega_r}\right)^2 s^2 + \frac{2\xi_r}{\omega_r} s + 1 \tag{7}$$

$$den\_filter = \left(\frac{1}{\omega_a}\right)^2 s^2 + \frac{2\xi_a}{\omega_a} s + 1 \tag{8}$$

where:

$$\omega_r = \sqrt{d_{12}\frac{J_M + J_L}{J_M J_L}}$$

$$\xi_r = \frac{b_{12}}{2}\sqrt{\frac{J_M + J_L}{d_{12} J_M J_L}}$$

$$\omega_a = \sqrt{\frac{d_{12}}{J_L}}$$

$$\xi_a = \frac{b_{12}}{2\sqrt{d_{12} J_L}} \tag{9}$$

In (9) are characteristic parameters of two-mass system with flexible joint (FJ):

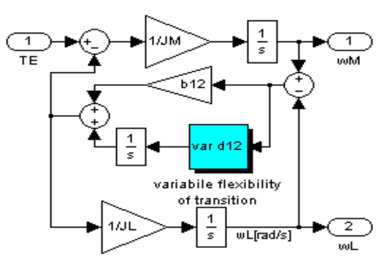
- ω_r system resonant frequency
- ω_a system antiresonant frequency
- ξ_r damping coefficient of system resonant frequency
- ξ_a damping coefficient of system antiresonant frequency

The aim of this paper is to focus on the case where one (or more) parameter of flexible joint is time variable. Let's assume that parameter d_{12}, which represents a flexibility of transition, is varying in time. Because of resonant and antiresonant frequencies of whole system depends on coefficient d_{12} (9), we assume that this variation can affect a control quality of this mechatronics system. For best observability of this variability influence, the variation function is set in form:

$$d_{12}(t) = 0.6 * d_{12} * \boldsymbol{sin}(t\,\pi/20) + d_{12} \tag{10}$$

which means that joint flexibility is varying between 60% with frequency reflecting the whole system dynamics. Simulation model of flexible joint with variable flexibility [9] was created in form as shown in Fig. 1.

a



b

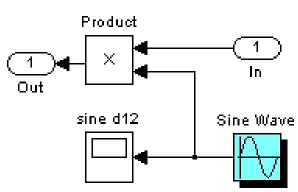


Fig. 1. Simulation model of analysed system: (a) variable flexible joint; (b) variation function for d_{12} variation.

An influence of flexibility variability was analysed by Matlab linearization tool using open loop models of DCM with flexible joint, double notch filter and DCM+FJ with double notch filter together as is shown in Fig. 2 with parameters specified in Table 1, based on system logarithmic amplitude-frequency characteristic (LAFCh).

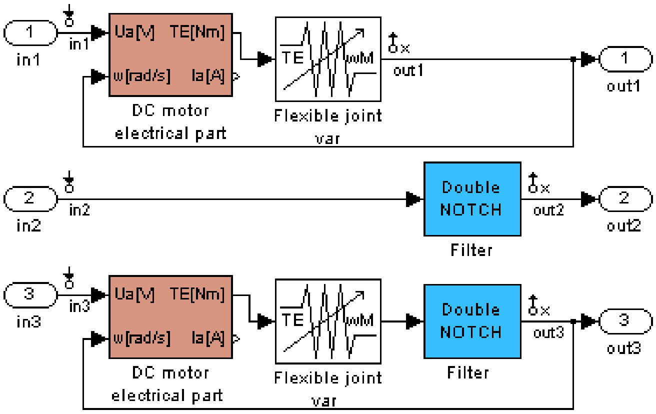


Fig. 2. Simulation model for LAFCh analysis.

The analysis was performed using Matlab script (Fig. 3) in which a loop was used for simulation of joint flexibility variation during monitored time period.

```
d12t=0:step:200;
variance=0.6;
d12v=variance*d12*sin(d12t*pi/20)+d12;
system='DCM_FJ_md102';
load_system(system);
io=getlinio(system);
d12_orig=d12;
for xx=1:length(d12v)
  d12=d12v(xx);
  sys=linearize(system,io);
  sig=sigma(sys(3,1),w);
  sigdb_sys(xx,:)=20*log10(sig); %#ok<*SAGROW>
  sigdb=20*log10(sig);
  a_rez(xx)=sigdb(find(sigdb==max(sigdb),1,'first'));
  f_rez(xx)=w(find(sigdb==max(sigdb),1,'first'));
  a_arez(xx)=sigdb(find(sigdb==min(sigdb),1,'first'));
  f_arez(xx)=w(find(sigdb==min(sigdb),1,'first'));
  %notch
  sig=sigma(sys(1,2),w);
  sigdb_notch(xx,:)=20*log10(sig);
  %sys+notch
  sig=sigma(sys(2,3),w);
  sigdb_sys_notch(xx,:)=20*log10(sig);
end
```

Fig. 3. Matlab script for variation of coupling flexibility analysis.

Based on the results shown in Fig. 5 is evident, that flexibility variation causes reduction of double notch filter positive influence in resonant and antiresonant frequencies elimination because of moving these frequencies across frequency spectrum (Fig. 4).

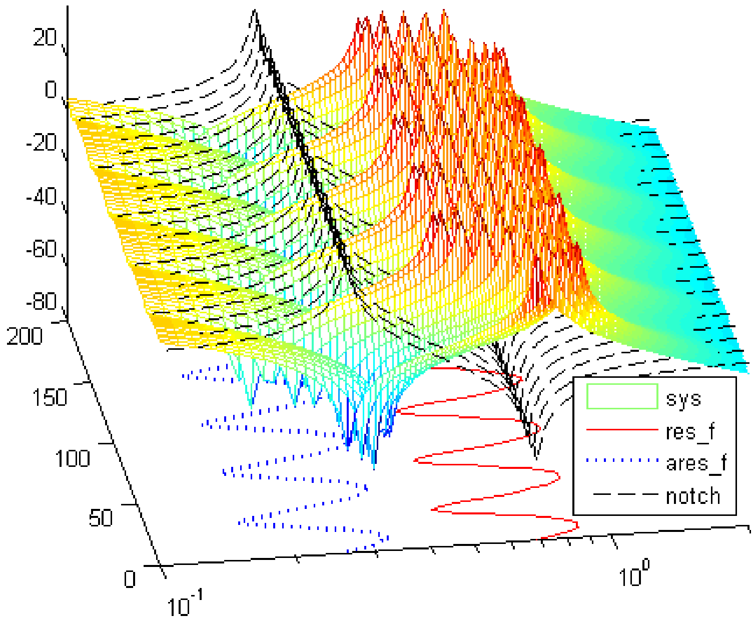


Fig. 4. LAFCh of mechatronics system and notch filter independently.

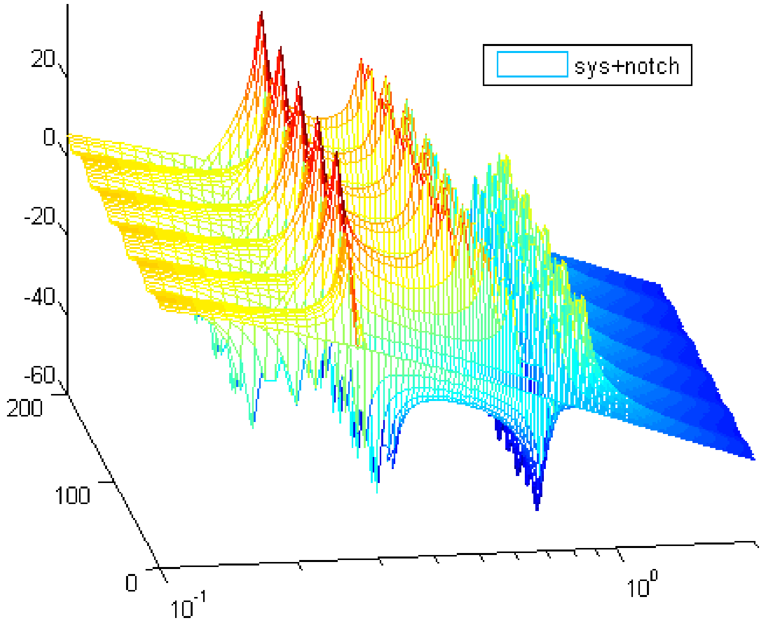


Fig. 5. LAFCh of system and notch filter together.

3. Control system design

The control system design was based on idealized condition where the infinitely rigid connection was considered instead of flexible connection between actuator and a load. This condition is described as:

$$J = J_M + J_L \tag{11}$$

Oversimplified model of system as transfer function of this adjusted mechatronics system has a form:

$$G_{DCMFJ}(s) = \frac{c\varphi}{(J_M + J_L)L_a s^2 + (J_M + J_L)R_a s + c\varphi^2} \tag{12}$$

The Modulus Optimum Method for PID controller design was used from a large number of existing known methods [3], [8], [7].

For controller of PID type in form:

$$G_R(s) = r_0 + \frac{r_{-1}}{s} + r_1 s \tag{13}$$

has an opened control loop form:

$$Go(s) = \frac{0.3r_1 s^2 + 0.3r_0 s + 0.3r_{-1}}{7s^3 + 1.4s^2 + 0.09s} \tag{14}$$

Following an assumption that ideal closed control system transfer function has a value approaching to one, the equation involving real part of open control loop frequency response has form:

$$Go(s) = \frac{\omega^4(0.42r_1 - 2.1r_0) + \omega^2(0.027r_0 - 0.42r_{-1})}{49\omega^6 + 0.7\omega^4 + 0.0081\omega^2}$$

$$Go(s) = -0.5 \tag{15}$$

The coefficients of PID controller are solved based on equations system in matrix form solution:

$$\begin{bmatrix} -0.42 & 0.027 & 0 \\ 0 & -2.1 & 0.42 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} r_{-1} \\ r_0 \\ r_1 \end{bmatrix} = -0.5 \begin{bmatrix} 0.0081 \\ 0.7 \\ 49 \end{bmatrix} \tag{16}$$

The coefficients of PID controller designed by Modulus Optimum Method are in Table 2.

Table 2. PID (MOM) controller parameters.

Parameter	Value
r_0	0.1602
r_{-1}	0.0199

r_1	–0.0323

The simulation was performed as a feedback control of angular velocity by simulation model (Fig. 6) that consists of:

- controlled system – actuator electrical part and flexible connection of actuator with load (with static and variable flexibility)
- controller $G_R(s)$
- double notch filter
- control quality measurement subsystem (Fig. 9)

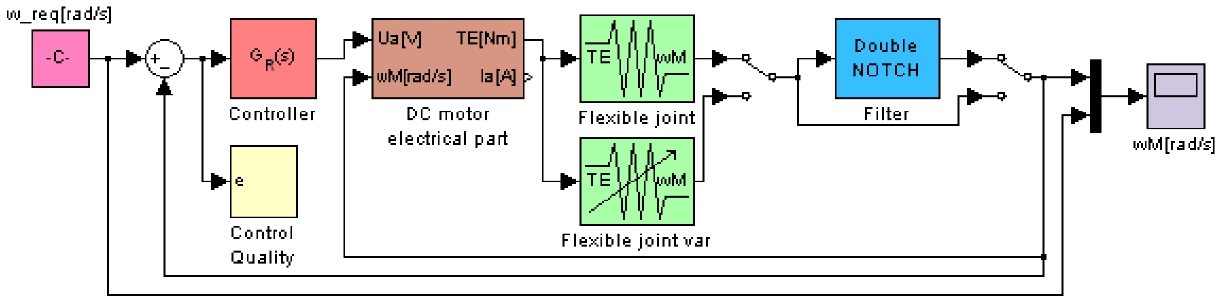


Fig. 6. Simulation model of angular velocity feedback control.

Transmission parameter (d_{12}) variability implies deterioration of control process quality because of notch filter efficiency reduction, which is evident from the closed loop step response (Fig. 7).

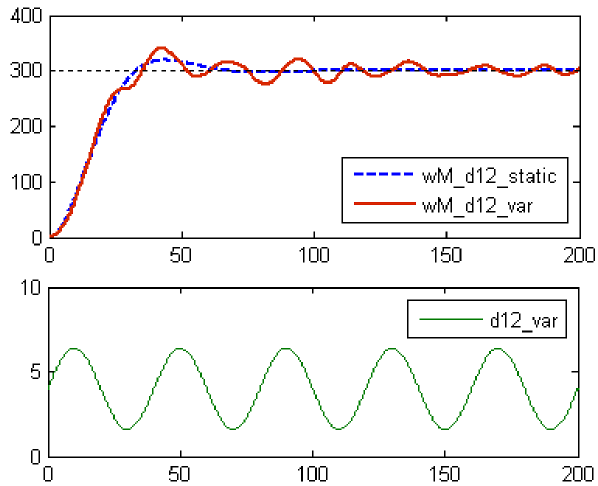


Fig. 7. Actuator angular velocity in static flexibility vs. variable flexibility system.

The proposal for elimination of flexibility variability negative influence is an adaptive LMS filter using. The LMS filter is represented in Matlab as LMS Filter block using the least mean-square (LMS) algorithm [6], [10]. This algorithm is defined by the following equations:

$$y(n) = \mathbf{w}^T(n-1)\,\mathbf{u}(n)$$
$$e(n) = d(n) - y(n) \qquad (17)$$
$$\mathbf{w}(n) = \alpha\,\mathbf{w}(n-1) + f(\mathbf{u}(n), e(n), \mu)$$

The weight update function for the LMS adaptive filter algorithm is defined as:

$$f(\mathbf{u}(n), e(n), \mu) = \mu e(n)\,\mathbf{u}^*(n) \qquad (18)$$

The variables are as follows:

- n the current time index
- $\mathbf{u}(n)$ the vector of buffered input samples at step n
- $\mathbf{u}^*(n)$ the complex conjugate of the vector of buffered input samples at step n
- $\mathbf{w}(n)$ the vector of filter weight estimates at step n
- $y(n)$ the filtered output at step n
- $e(n)$ the estimation error at step n
- $d(n)$ the desired response at step n
- μ the adaptation step size

As a desired signal for LMS filtering a signal from simplified control loop with infinitely rigid connection was used.

The resulting suggested closed loop circuit (Fig. 8) designed for quality analysis consists of:

- control loop with flexible mechatronics system with variable flexibility, notch filter and adaptive LMS filter
- simplified control loop with infinitely rigid connection (for desired signal generation for LMS filter)
- control loop with flexible mechatronics system with static flexibility and notch filter (for simplified control loop using verification)
- control loop with flexible mechatronics system with variable flexibility and notch filter (for LMS filter using efficiency analysis)

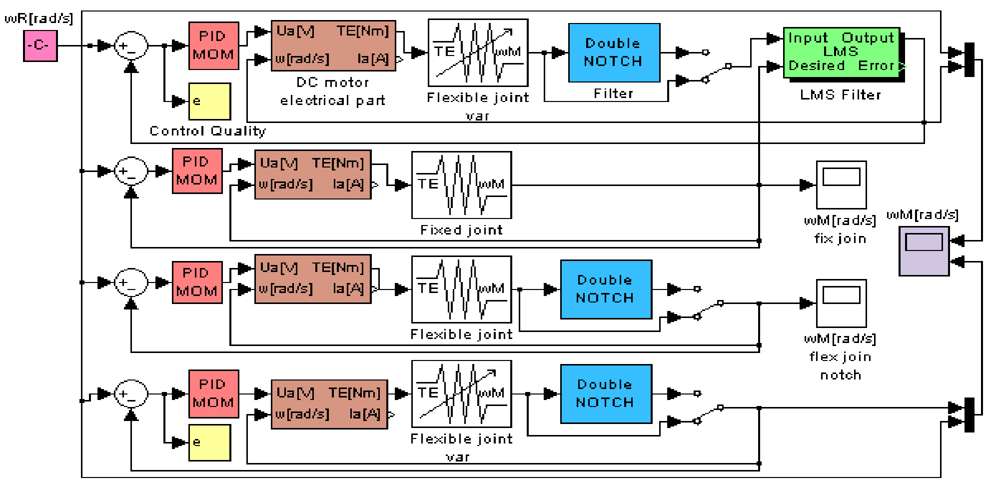


Fig. 8. The complex simulation model for quality analysis.

4. Control quality analysis

The quality of control process has been evaluated based on integral criteria of quality for control error space, acquired through the simulation subsystem shown in Fig. 9 and consists of:

- Integral Square Error (ISE)
- Integral Time Square Error (ITSE)
- Integral Absolute Error (IAE)
- Integral Time Absolute Error (ITAE)

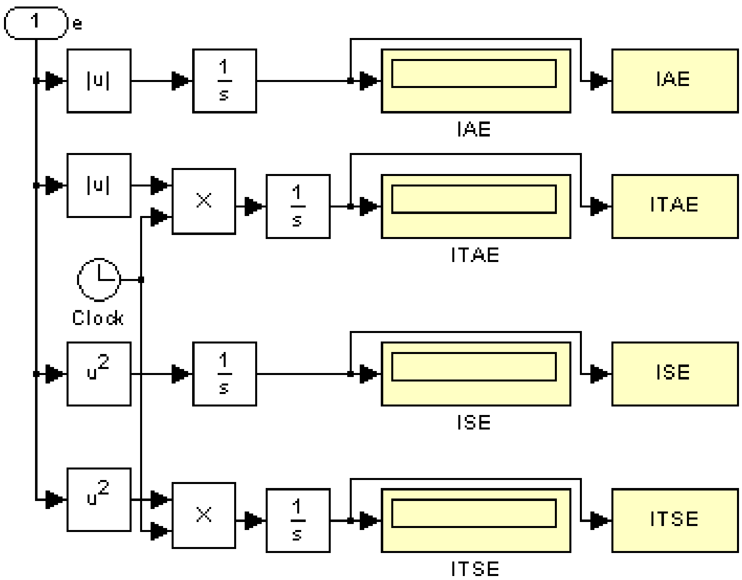


Fig. 9. The simulation subsystem for integral criteria measurement.

A set of several runs of simulation experiments was realized with different parameters settings of LMS filter. A combination of LMS filter with and without notch filter using was analysed too. Obtained simulation results confirm assumption, that LMS filter using can positive affect control process in case of flexible joint of mechatronics system flexibility variability occurrence in both simulated scenarios – with or without notch filter using, as is shown in Table 3 as a control quality comparison and in Fig. 10 as a shape of motor angular velocity characteristics.

Table 3. Simulation experiments results.

quality criterion	using LMS		without LMS	
	using notch	without notch	using notch	without notch
IAE	5.32E+03	*5.30E+03*	6.63E+03	6.08E+03
ITAE	7.40E+04	*7.33E+04*	2.16E+05	1.21E+05
ISE	1.06E+06	*1.05E+06*	1.09E+06	1.07E+06
ITSE	*8.11E+06*	8.19E+06	1.01E+07	9.67E+06

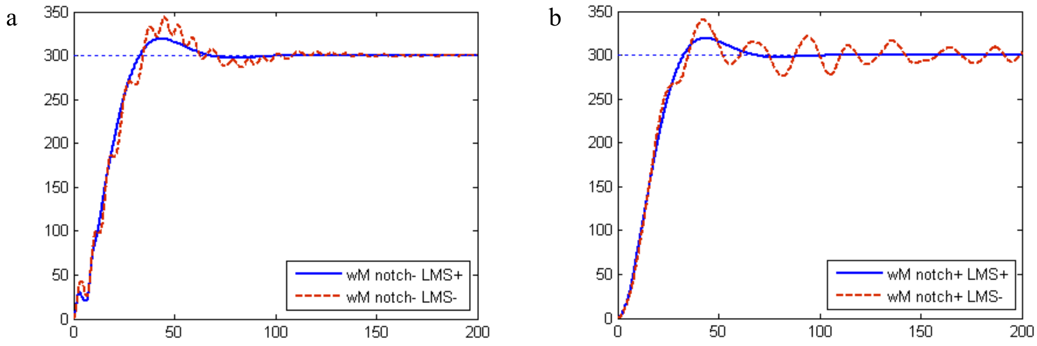


Fig. 10. Motor angular velocity in variable flexibility system: (a) without notch filter; (b) with notch filter.

5. Conclusion

In this contribution a special case of flexible mechatronics system, containing in-time variable parameter affecting the coupling flexibility, was analysed. This variable flexibility has significant negative influence to control quality, while speed controller was designed by Modulus Optimum Method for PID controller design. In case of constant flexibility in relation to this standard method of control design, a double notch filter is enough to eliminate parasitic resonant and antiresonant frequencies. In case of variable flexibility, additional LMS adaptive filter is proposed to use together with simplified model of rigid connection system for generating of desired signal for LMS algorithm. A set of different simulation experiments was realized with different LMS filter parameters settings. A combination of LMS filter with and without notch filter using was analysed too. Simulation experiments results - step response and control quality analysis confirmed the correctness of LMS adaptive filter using suggestion, while correctly configured adaptive LMS filter is by IAE, ITAE and ISE criteria capable to replace double notch filter as originally used correcting element.

Acknowledgment

This contribution was written with a financial support VEGA agency in the frame of the project 1/0463/13 „Study of flexible mechatronics system variable parameters influence on its control“.

References

[1] S. Vukosavic, M. Stojic, “Suppression of Torsional Oscillations in a High-Performance Speed Servo Drive,” IEEE Trans. on Industrial Electronics, vol. 45, Jan. 1998, pp 108-117.

[2] G. Ellis, “Control system design guide,” San Diego: Elsevier Academic Press, 2004, pp 464.

[3] M. Vítečková, A. Víteček, “Modulus optimum for digital controllers,” Acta Montanistica Slovaca, vol. 8, no. 4, 2003, pp 214-216.

[4] J. Kalous, C. Kratochvíl and P. Heriban, “Dynamics of Rotary Electromechanical Drives,” ÚT AVČR – Centrum mechatroniky, Brno, 2007.

[5] J. Vittek, P. Briš, P. Makyš, M. Štulrajter and V. Vavruš, “Control of Flexible Drive with PMSM employing Forced Dynamics,” 13th EPE-PEMC 2008, pp. 2219-2226. IEEE 978-1-4244-1742-1.

[6] MathWorks. (2013, June). Adaptive Filters in Simulink [Online]. Available: http://www.mathworks.com/help/dsp/ug/adaptive-filters-in-simulink.html.

[7] M. Juhás, B. Juhásová and P. Mydlo, “The Mechatronics System Control Quality Analysis Using Simulink and GUI in Matlab,” in Lecture Notes in Engineering and Computer Science. WCECS 2012. Vol. II. : World Congress on Engineering and Computer Science 2012. Proceedings IAENG & IET. San Francisco, USA, 24-26 October, 2012. Hong Kong : International Association of Engineers, 2012, pp. 1228-1232.

[8] J. Jovankovič, M. Žalman, “Mechatronické pohybové systémy (2),” AT&P journal, vol. XIII, no. 3, 2006, pp 73 – 74.

[9] M. Foltin, “MATLAB SIMULINK - simulačné prostredie pre Matlab (2),” AT&P Journal. vol. 15, no. 4, 2008, pp 53-54.

[10] H.J. Butterweck, “Steady-state analysis of the long LMS adaptive filter,” Signal Processing, vol. 91, iss. 4, April 2011, pp 690-701.

[11] A.A.A.Emhemed, R.B. Mamat, “Modelling and Simulation for Industrial DC Motor Using Intelligent Control,” Procedia Engineering, vol. 41, 2012, pp 420-425.