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UTILIZATION OF ADVANCED METHODS IN THE CONTROL OF A MECHATRONIC SYSTEM WITH FLEXIBLE ELEMENTS

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Abstract

Analysis of the negative impact of a mechatronic system with the flexible elements parameter error and the possibilities of impact reduction are presented in this contribution. Two advanced methods – the Model Predictive Control method and the inclusion of an LMS filter into the control process are proposed for the reduction of the insufficient effect of a double notch filter, which was initially integrated into the system for elimination of two-mass flexible joint parasitic frequencies. Simulation experiments results – response of system angular velocity and control process quality analysis confirmed the correctness of the proposition for the usage of these progressive control elements.

Key words

Mechatronic system control, Model Predictive Control, LMS filter, Control quality

INTRODUCTION

This contribution deals with the special case of a mechatronic system – torque DC motor with flexible elements in motor-to-load coupling containing static or in-time variable parameter error affecting the coupling properties. A DC motor angular velocity controller was designed by the standard method of controller design – Modulus Optimum Method. A flexible connection is characterized by undesirable frequencies (resonant, anti-resonant) occurrence. A double notch filter was used and is enough to eliminate these parasitic frequencies. Because of the static character of a double notch filter, the error of flexible joint key parameters can result in filter efficiency reduction. In the case of parameter error occurrence, two advanced methods: Model Predictive Control (MPC) and LMS adaptive filter are proposed for the elimination of this deficiency.

PROBLEM DEFINITION

The direct current motor (DCM) with a drive-to-load coupling, containing a flexible element, was chosen as the analyzed mechatronic system for the research. A special type of drive – torque motor was set as a subject of the analysis. This type of drive is characterized by high torsion moment at a relatively low speed.

If the inertia of the transmission mechanism is small compared to the motor and load, the coupling between the motor and load can be treated as a two-mass motor/load system (1, 4 and 5). The analyzed controlled object with a transfer function of the flexible joints of two masses 0] is represented by the simulation model depicted in Fig. 1, Fig. 2 and Fig. 3.

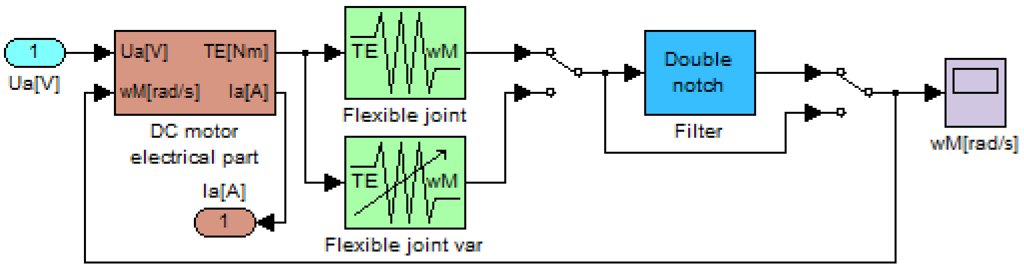

Fig. 1 *Controlled system model*

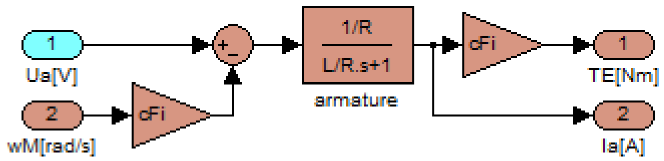

Fig. 2 *Model of the system electrical part*

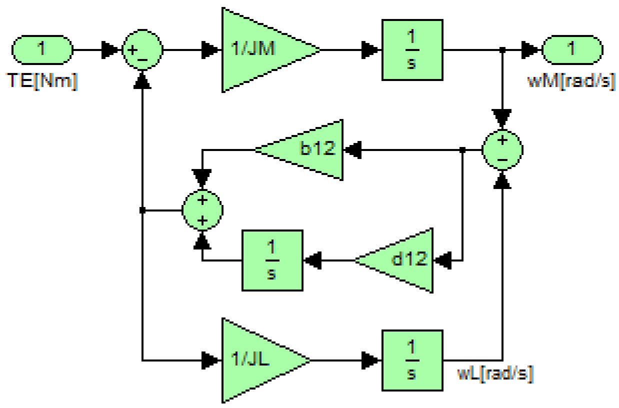

Fig. 3 *Model of two masses flexible joint*

The transfer function of a flexible joint of two masses depicted in Fig. 3 is:

$$G_{FJ}(s) = \frac{J_L s^2 + b_{12} s + d_{12}}{J_M J_L s^3 + b_{12}(J_M + J_L)s^2 + d_{12}(J_M + J_L)s} \; . \qquad [1]$$

The control system was designed based on idealized conditions where an infinitely rigid connection was considered instead of a flexible connection between actuator and a load.

Table 1 Analyzed system parameters

Parameter	Unit	Description	Value
R_a	Ω	armature current	0.02
L_a	mH	resistance and inductance of armature winding	100
$c\Phi$	N.m/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}	N.m.s/rad	torsion damping	0.1
d_{12}	N.m/rad	torsion stiffness	4

The Modulus Optimum Method for PID controller design was used from a large number of existing known methods (2, 3, 4 and 6). The coefficients of the PID controller, designed by the Modulus Optimum Method, are listed in Table 2 and were calculated based on the analyzed mechatronic system defined in Table 1.

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 the simulation model depicted in Fig. 4 based on a set of simulation experiments.

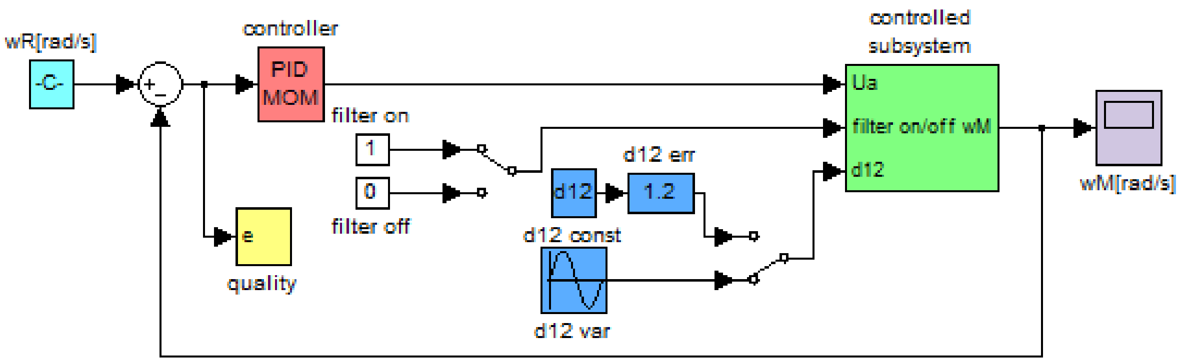

Fig. 4 *Simulation model of the system with PID controller*

The aim of this paper is to focus on the case where a time invariant or a time variable error of the chosen parameter of the coupling occurs. Because the resonant and anti-resonant frequencies of the analyzed system depends on coefficient d_{12}, it is clear that this error can affect a control quality of this mechatronic system. This negative impact is caused by moving these frequencies across the frequency spectrum as is shown in Fig. 5.

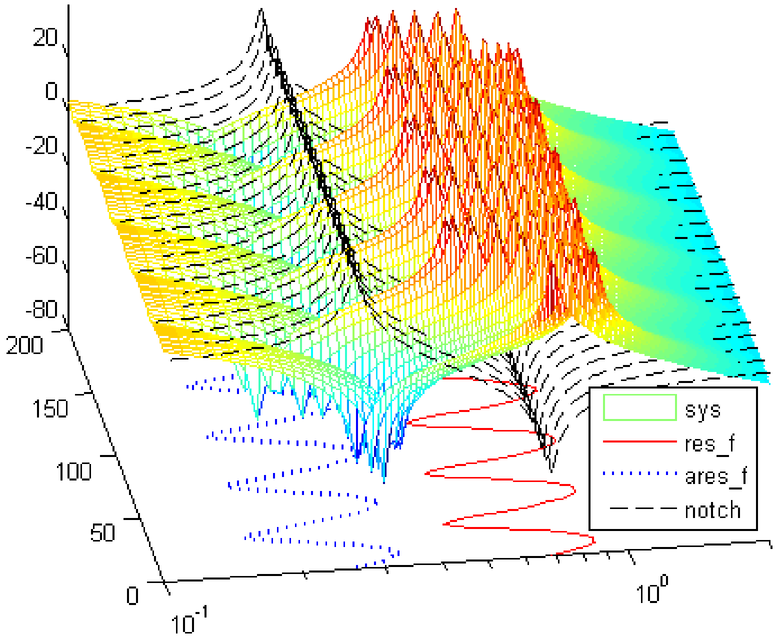

Fig. 5 *LAFCh of mechatronic system and double notch filter independently.*

MODEL PREDICTIVE CONTROL

The first proposal to eliminate the negative effects of the combination of the filter use and the existence of the elastic coupling parameter error is the use of the predictive control method called Model predictive control (MPC) (7, 8, 9 and 10).

An additional part – the control system with MPC controller was added (Fig. 6) to the original control system with PID controller (Fig. 4) for the purpose of assessing the MPC control versus PID control use.

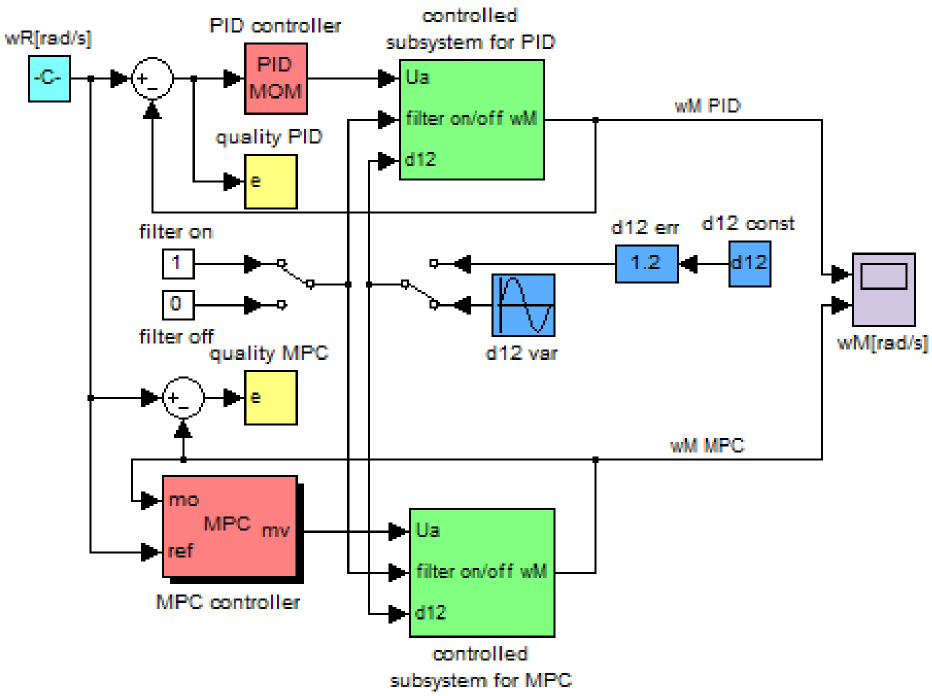

Fig. 6 *Simulation model of the system with PID and MPC controllers*

The cases of high negative impact of filter use with the d_{12} parameter error occurrence were analyzed based on fine tuning of the MPC controller, which was initially set up by Matlab Model Predictive Control Toolbox. The simulation was performed by the simulation model depicted in Fig. 6 based on a set of simulation experiments.

The obtained results of the simulation experiments were processed in graphical form wherein a response of ω_M and the control process quality based on Integral Time Absolute Error (ITAE) and Integral Time Square Error (ITSE) were observed. The functionality of the control process quality on the parameter weight tuning of the MPC controller within range <+0.13; +0.22> is displayed in Fig. 7 and Fig. 8 and it can be very helpful in the analysis process for final MPC controller setting.

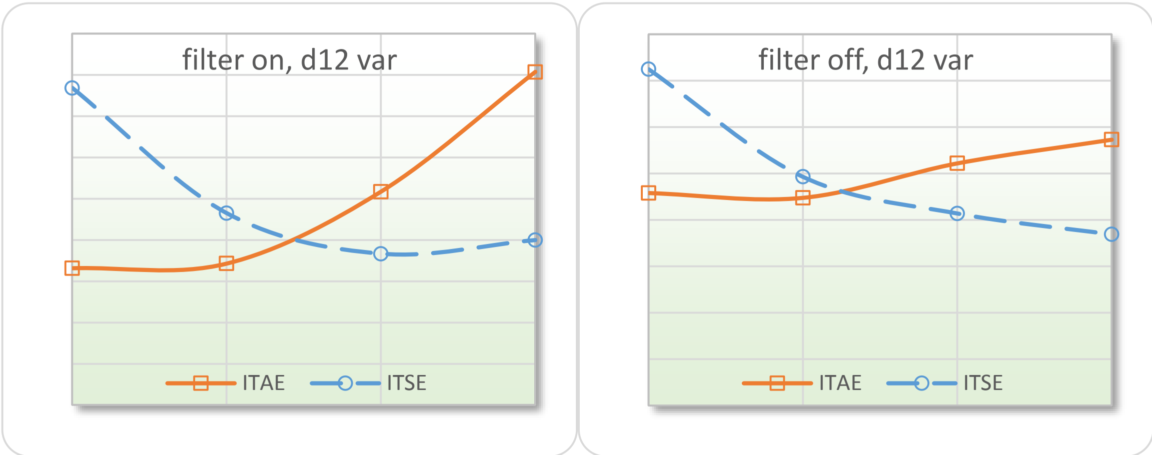

Fig. 7 *Quality of the control process of the system with MPC controller and variable* d_{12}

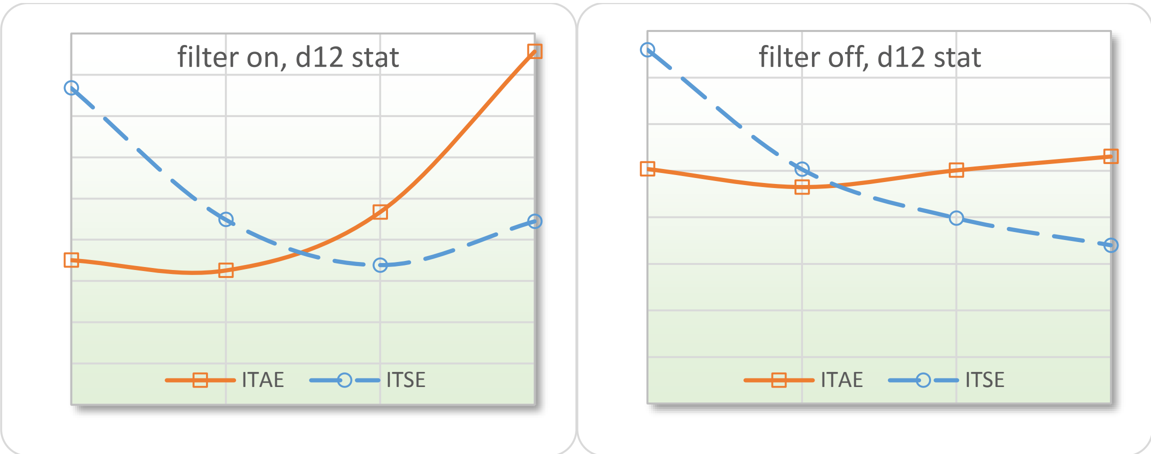

Fig. 8 *Quality of the control process of the system with MPC controller and static* d_{12} *with +20% error*

LMS FILTER

The second proposal for elimination of the coupling parameter error negative influence is the use of an adaptive LMS filter. The LMS filter is represented in the simulation model as an LMS Filter subsystem, which uses the least mean-square (LMS) algorithm (11). As a desired signal for LMS filtering, a signal from the simplified control loop with an infinitely rigid connection between drive and load was used. The resulting suggested complex closed loop circuit designed for quality analysis is shown in Fig. 9 and consists of:

- a control loop with a mechatronic system with variable flexibility, double notch filter and adaptive LMS filter
- a simplified control loop with infinitely rigid connection (for desired signal generation for LMS filter)
- a control loop with a mechatronic system with invariable flexibility and double notch filter (for verification of simplified control loop using)
- a control loop with a mechatronic system with variable flexibility and double notch filter (for LMS filter using efficiency analysis).

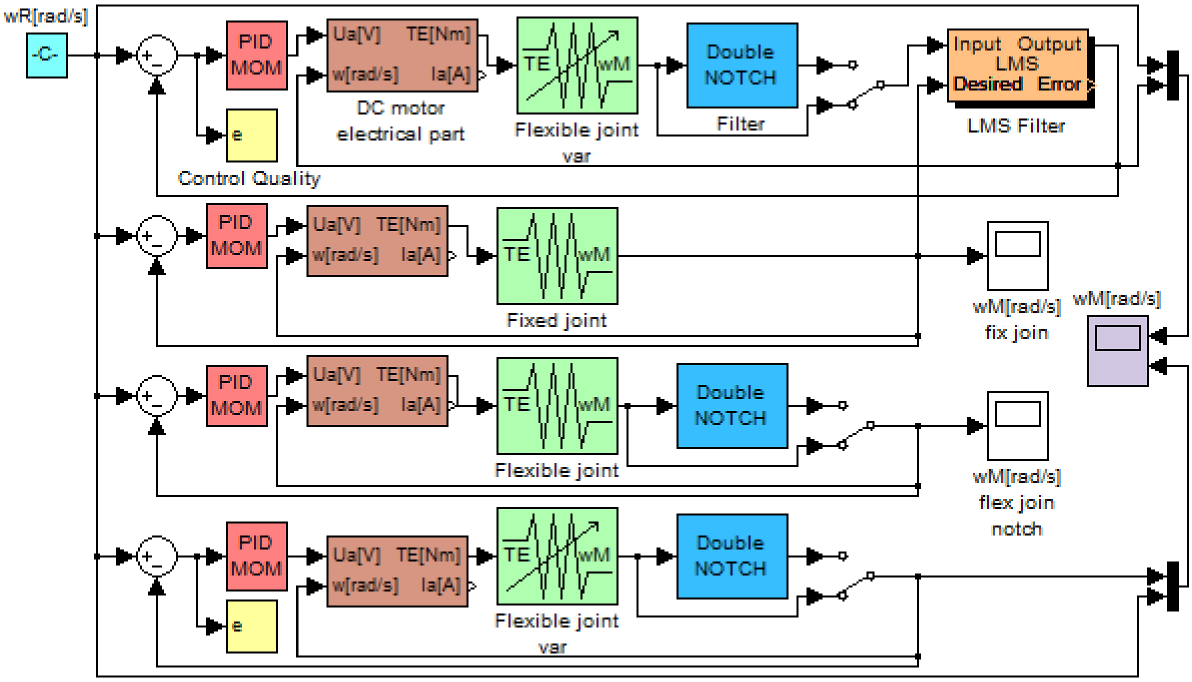

Fig. 9 The complex simulation model for quality analysis

A set of several simulation experiments were conducted with different parameters settings of LMS filter. A combination of LMS filter with and without double notch filter use was analyzed too. The obtained simulation results confirm an assumption, that the LMS filter usage can positively affect the whole control process in the case of a mechatronic system part parameter error occurrence in both simulated scenarios – with or without double notch filter use, as is shown in Table 3 as a control quality comparison.

Table 3 Simulation experiments results

quality criterion	**using LMS**		**without LMS**	
	using double notch	**without double notch**	**using double notch**	**without double 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

CONCLUSION

In this contribution, analysis was conducted of a special case mechatronic system with flexible coupling elements containing static or in-time variable parameter error affecting the coupling flexibility. This ambiguity in the system properties definition has a significant negative influence on the control process quality, while the PID speed controller was designed by Modulus Optimum Method. In the case of non-error parameters, in relation to this standard control design method, a double notch filter is enough to eliminate parasitic resonant and anti-resonant frequencies. In the case of system parameter error occurrence, two advanced methods – Model Predictive Control and LMS filter are proposed to be used for the purpose of elimination of this deficiency. A set of different simulation experiments were conducted with different parameters settings of the proposed methods components. The obtained results of the simulation experiments based on control process quality analysis, clearly confirmed the correctness of using either the MPC controller or LMS filter, while the correctly configured MPC controller as well as the LMS filter are capable to replace the double notch filter that was originally used as a correcting element.

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