WIKTOR HUDY
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Testing the impact of input signals disturbances of PI controllers in a field-oriented control system with an induction motor

The paper discusses the qualitative impact of disturbances which affect input signals of PI controllers in a field-oriented control system. An induction motor is an object for rotational speed control. The settings of PI controllers were calculated with the use of an evolutionary algorithm. The dynamics of the system was tested by a computer method, with the use of the MATLAB/Simulink software.

key words: *drive systems, induction motor, reactive power compensation, control system*

1. INTRODUCTION

Modern drive systems are constructed with the use of controllers which have programs for vector control of the rotational speed of motors. At present, there are two vector-control methods used: field-oriented control (FOC) and direct torque control (DTC) [1, 2, 3, 5, 6, 7, 8]. The key task of control is to make the system work as efficiently as possible. This is done by parametrical optimization of the control system. For further analysis conducted in the paper, the authors chose the FOC system with a bigger number of parameters to optimize. In its basic configuration the system has 5 PI controllers (two current controllers, torque controller, electromagnetic flux controller, rotational speed controller) In the parametrical optimization process there are 10 parameters to calculate (controllers boosting parameters and coefficients dependent on integral action times). Out of many different configurations of the FOC system, the authors selected the direct field-oriented control system (DFOC) [2, 3, 5, 6, 8], presented in Fig. 1.

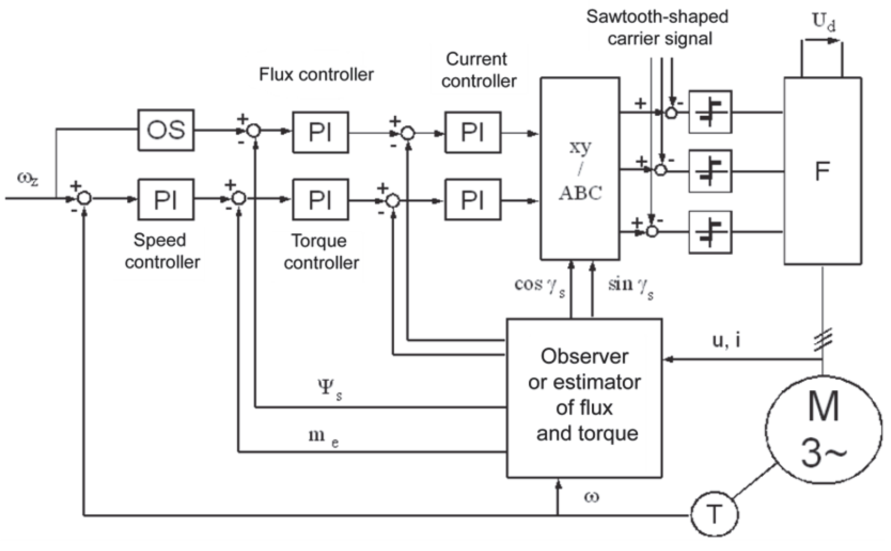

Fig. 1. Direct field-oriented control system (DFOC) [3, 6, 8]

DFOC can be executed in two ways which differ from each other in terms of the applied PWM inwerter current controller [3, 6, 8]. For further analysis the authors selected a system with linear controllers of inverter current.

2. TESTED CONTROL SYSTEM

The DFOC system was presented in Fig. 1.

Symbols in the figure stand for the following:
ω_z – set rotational speed of the controlled induction motor,
OS– electromagnetic flux weakening module,
PI – linear PI controllers,
F – inverter,
U_d – reference voltage of the F inverter,
u, i– voltages and phase currents of the induction motor,
cos γ_s, sin γ_s – cosinus and sinus of the angle needed for the transformation from the xy to the ABC system,
ω – current value of the rotational speed of the induction motor,
Ψ_s – estimated value of the magnetic flux of the induction motor,
m_e – estimated value of the electromagnetic torque of the motor,
M – low power induction motor (Tamel SG90L-6),
T – tachogenerator – measuring the rotational speed of the induction motor.

What is characteristic of this system is the γ_s angle, the knowledge about which is necessary to transform the equations. The value of this angle is determined based on the measurements of phase currents and voltages and based on the mathematical model of the induction motor (the mathematical model parameters of the induction motor, being an object of control, were defined earlier with the use of revolutionary methods [3, 6, 8]).

For the purposes of this paper, the process of parametric optimization was conducted with the use of a numerical method with an evolutionary algorithm which was written on the basis of the mathematical model of this control system. The calculations of parameters required for the controllers were made [2, 3]. The results of these calculations can be seen in Table 1.

Table 1.
Calculated settings of PI controllers of the DFOC system, with the use of an evolutionary algorithm

$K_{p,1}$	$K_{p,2}$	$K_{p,3}$	$K_{p,4}$	$K_{p,5}$	$T_{p,1}$	$T_{p,2}$	$T_{p,3}$	$T_{p,4}$	$T_{p,5}$	F [rotations /min]
13.2	14.9	11.9	0.20	1.91	3.04	2.01	3.96	0.49	8.8	$7.43 \cdot 10^5$

Symbols used in the table:

$K_{p,1}$; $K_{p,2}$; $K_{p,3}$; $K_{p,4}$; $K_{p,5}$ – boosting of controllers, respectively: current controller in the control loop of the magnetic flux, current controller in the control loop of the speed controller, magnetic flux controller, electromagnetic torque controller, and rotational speed controller,

$T_{p,1}$; $T_{p,2}$; $T_{p,3}$; $T_{p,4}$; $T_{p,5}$ – coefficients dependent on integral action times of the controllers in the control loop, as above.

F – quality criterion which is a total of modules of differences in the value of rotational speed generated on the basis of current settings of controllers and the value of rotational speed set to the control system in discrete moments of time (simulation time – 5 s, simulation time step – 0.001 s).

The processes set for the described control system were the following:
- step change of rotational speed which is to execute the system,
- step change of load torque after the rotational speed sets in.

The processes which are set and executed by the control system were presented in Fig. 2. Simulation time was 5 [s]. In the first second the set speed was step-changed from 0 [rpm] to 800 [rpm]. After the next two seconds the drive shaft of the motor was step-loaded from 0 [Nm] to 10 [Nm].

So far the calculations have been focused mainly on proper and sub-optimal calculation of settings of PI controllers [2, 3, 9]. Different configurations of the field-oriented control system were examined along with the impact of different parameters of the evolutionary algorithm on the obtained results. Further in this work, the described system was tested in terms of its resistance to additive disturbances of signals with white noise [4]. These tests were based on simulations carried out with the use of MATLAB/Simulink.

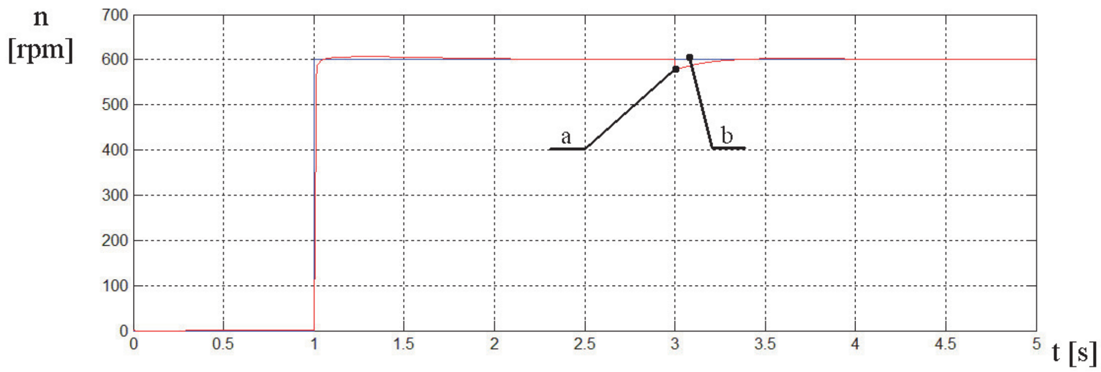

Fig. 2. Processes: the set process (b) and the process executed by the control system based on the calculated parameters of PI controllers (a) [authors' own elaboration]

3. TESTING FOC RESISTANCE TO WHITE NOISE DISTURBANCES

The impact of such disturbances on the system dynamics (Fig. 3) was tested with the use of random disturbances in the form of white noise as an additive component of the controller input signal.

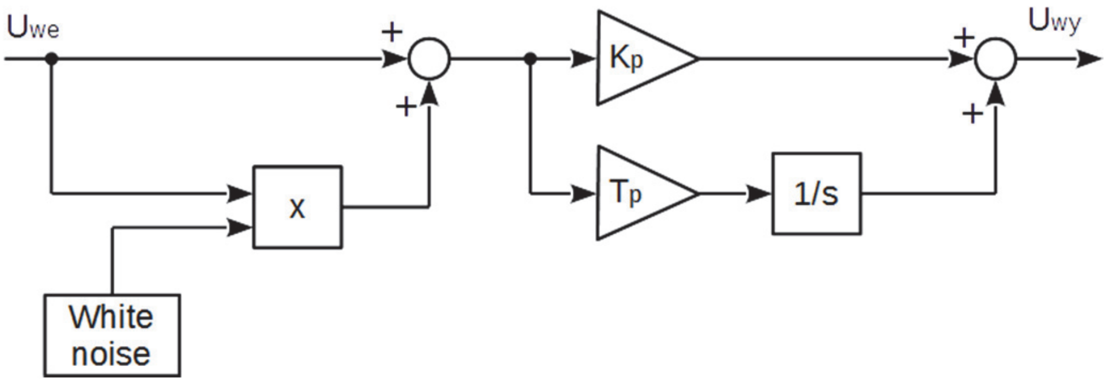

Fig. 3. Diagram of the controller with white noise in the input signal [authors' own elaboration]
where: U_{we} – input signal of the controller, U_{wy} – output signal of the controller, K_p – controller boosting, T_p – coefficient dependent on integral action times.

The system was tested in the following manner:
- white noise was introduced to each controller separately and output rotational speed was observed,
- white noise was introduced to all controllers simultaneously and rotational speed was observed.

The output measure is the mean absolute percentage error (MAPE) expressed by a commonly known formula:

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{x_{zi}-x_i}{x_{zi}}\right|100\% \qquad (1)$$

where:

$MAPE$ – value of mean absolute percentage error,
n – number of moments of time in which the values of errors were calculated (n = 5000, t = 5 s, Δt = 0,001 s),
x_{zi} – set value of rotational speed measured in the successive i-th moment of time,
x_i – output value of the FOC control system in the successive moment of time i.

The calculation results were presented in Table 2.

Table 2.

Values of mean absolute percentage error for particular controllers

Controllers on whose inputs white noise was introduced	MAPE values of input signal	MAPE values of rotational speed
No disturbances introduced	0%	0.6601%
White noise introduced at the input of the current controller in the magnetic flux channel	1%	0.6601%
	2%	0.6601%
	5%	0.6602%
	10%	0.6602%
	20%	0.6604%
	25%	0.6605%
	50%	0.6611%
	100%	0.6639%
White noise introduced at the input of the current controller in the rotational speed channel	1%	0.6601%
	2%	0.6603%
	5%	0.6640%
	10%	0.6788%
	20%	0.7316%
	25%	0.7611%
	50%	0.9889%
	100%	1.7637%
White noise introduced at the input of the magnetic flux controller	1%	0.6601%
	2%	0.6600%
	5%	0.6598%
	10%	0.6595%
	20%	0.6589%
	25%	0.6588%
	50%	0.6590%
	100%	0.6648%
White noise introduced at the input of the electromagnetic torque controller	1%	0.6601%
	2%	0.6601%
	5%	0.6600%
	10%	0.6601%
	20%	0.6605%
	25%	0.6609%
	50%	0.6659%
	100%	0.6988%
White noise introduced at the input of the rotational speed controller	1%	0.6602%
	2%	0.6602%
	5%	0.6604%
	10%	0.6608%
	20%	0.6616%
	25%	0.6621%
	50%	0.6676%
	100%	0.6933%
White noise introduced at the inputs of all controllers	1%	0.6600%
	2%	0.6602%
	5%	0.6632%
	10%	0.6757%
	20%	0.7239%
	25%	0.7569%
	50%	0.9717%
	100%	1.6833%

Fig. 4 features the process of the rotational speed of the motor at disturbed inputs of the controller and a disturbed load torque signal.

Mean value of these noises is equal to 100% of the amplitude of the signal which sets rotational speed and load torque.

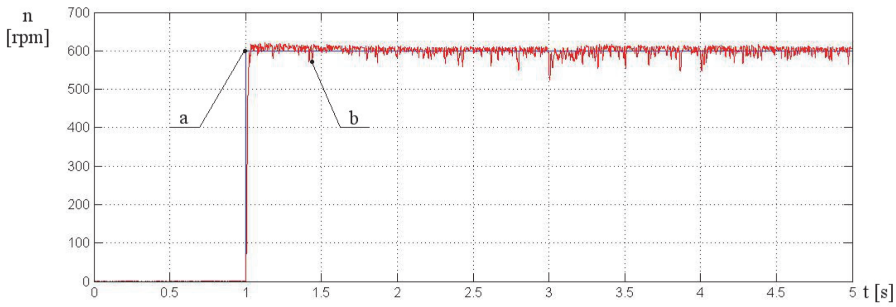

Fig. 4. Rotational speed processes: set speed (a) and calculated speed which is the response of the control system (with noises introduced at all inputs on the level of 100%) to a single step change of rotational speed and the step change of load (b) [authors' own elaboration]

4. CONCLUSIONS

A non-zero value of mean absolute percentage error of the system output, with no disturbances introduced, results from the fact that the set value of rotational speed is not equal to the rotational speed executed by the control system. In the case of the control system without disturbances, there is a readjustment and the process is characterized by a long control time (Fig. 2). In addition, in the third second of the simulation the induction motor was step-loaded. Due to differences in the processes a and b in Fig. 2, the value of the MAPE coefficient is non-zero.

When white noise was introduced at the input of the magnetic flux controller, the value of the MAPE coefficient was smaller than in the case without disturbances. When white noise was introduced at the input of the current controller in the rotational speed channel, the observed value of the MAPE coefficient was the biggest, yet acceptable. As it was mentioned before, these settings were calculated by an evolutionary algorithm. At first the results of this algorithm are assumed to be non-optimal and differ in 5% from optimal values. The value of disturbances, added to a non-disturbed signal, had an amplitude equal to the non-disturbed signal amplitude, for all controllers.

Figure 4 shows that such a big disturbance of the controllers input signals has a disadvantageous impact on the process of rotational speed executed by the control system. This may cause strong vibrations of the whole system and, indirectly, its quicker wear. When the settings of the controllers are property selected, the system has high resistance to disturbances and is stable.

References

1. Głowacz A., Głowacz Z.: *Diagnostics of induction motor based on analysis of acoustic signals with application of FFT and classifier based on words — Diagnostyka silnika indukcyjnego oparta na analizie sygnałów akustycznych z zastosowaniem FFT i klasyfikatora opartego na Archives of Metallurgy and Materials*, Polish Academy of Sciences, Committee of Metallurgy, Institute of Metallurgy and Materials Science, ISSN 1733-3490, 2010, vol. 55, iss. 3, pp. 707-712.
2. Hudy W.: *Analysis of parametric optimization of field-oriented control of 3-Phase induction motor with using evolutionary algorithm*, Transactions of the VŠB, Technical University of Ostrava, "Mechanical Series", No. 2, vol. LIX, article No. 1959, Ostrava 2013.
3. Hudy W., Jaracz K.: *Evolutionary operators impact on results of evolutionary parametric optimization of FOC system with induction motor (Wpływ operatorów ewolucyjnych na wyniki ewolucyjnej optymalizacji parametrycznej układu FOC z silnikiem indukcyjnym)*, 39. Konferencja Automatyka Telekomunikacja Informatyka ATI 2013, Zakopane, 30 september – 2 october 2013 (in Polish).
4. Jaracz K.: *Rozszerzone modele wrażliwości maszyn prądu stałego przy zakłóceniach niezdeterminowanych*, Wydawnictwo naukowe WSP, Kraków 1998.
5. Kaźmierkowski M.P.: *Porównanie metody sterowania polowozorientowanego z metodą bezpośredniej regulacji momentu silnika klatkowego*. „Przegląd Elektrotechniczny", 1998, No 4.
6. Leonard W.: *Control of Electrical Drives*, Springer Verlag, Berlin 1985.
7. Miksiewicz R.: *Maszyny elektryczne*, Wydawnictwo Politechniki Śląskiej, Gliwice 2000.
8. Orłowska-Kowalska T., *Control systems of the induction motors without sensors*, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2003.
9. Vítečková M., Víteček A.: *Vybrané metody seřizování regulátorů*, VŠB-TU Ostrava, Fakulta strojní, Ostrava 2011, ISBN 978-80-248-2503-8, 230.

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