

# Nonlinearity compensation for two-zone energy-shaping control systems of DC drive

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**Abstract – DC machines are the keystone of world industry. Working in second zone they behave as nonlinear objects. One of the newest methods of control system design for such machine as a part of electromechanical systems are energy-based approaches. Energy-shaping control systems based on simplified model don't work in second zone and the use of accurate model leads to many complications. This article contains description and comparative researches of proposed nonlinearity compensators that allows to use simplified control system. It was shown that reference signal corrector provides highly effective control, but there are still many possibilities to increase energy-shaping system's efficiency.**

Keywords – DC motor, nonlinear control, two-zone control, energy-based approach, energy-shaping control system, port-controlled Hamiltonian system.

## I. Introduction

DC machines are the keystone of world industry. Simplicity in exploitation and regulating, as well as in control systems building, allows to get high quality properties of response, static precision, durability and reliability of synthesized control systems [1], and also the setup simplicity for most of them. Generally, these machines are considered as linear objects. In order to extend its regulation possibilities, the control in excitation loop is used. In this case they became nonlinear systems and are treated respectfully. All this transforms DC machine into perfect testing sample for different control systems and control approaches.

Nowadays there are numerous control systems developed for DC motors. Among them, one of the most perspective methods of control system design are physical control theory approaches. Exactly such are energy-based approaches, which are based on physical laws of energy transfer and conversion [2]. In order to simplify such energy-shaping control system (ESCS) synthesis procedure, control object as well, as automatic control system itself are representing as port-controlled Hamiltonian system (PCHs) [3].

By the method, given in [4], the ESCS regulator for DCM, based on simplified model, has been got:

$$\begin{cases} u_a = i_{a0}R_a + (i_{a0} - i_a)r_{11} + Ci_{ex0}w_0L_{ex} \\ u_{ex} = i_{ex0}R_{ex} + (i_a w_0 - i_{a0}w)(CL_{ex}) + (i_{ex0} - i_{ex})r_{33} \\ i_{a0} = [T_s - (w - w_0)r_{22}] / Ci_{ex0}L_{ex} \end{cases}, \quad (1)$$

where  $u_a$  and  $u_{ex}$  – armature and excitation voltages;  $i_{a0}$  and  $i_{ex0}$  – desired armature and excitation currents;  $i_a$  and  $i_{ex}$  – armature and excitation currents;  $R_a$  and  $R_{ex}$  –

armature and excitation circuits resistance;  $r_{11}$ ,  $r_{22}$  and  $r_{33}$  – electrical (armature), mechanical and excitation damping coefficients;  $L_{ex}$  – excitation circuit inductance,  $C$  – feedback EMF coefficient;  $\omega_0$  – reference speed;  $\omega$  – actual speed;  $T_s$  – static torque.

In case of excitation regulation, when DC behave as nonlinear system with magnetization characteristics and excitation winding time constant change, proposed regulator can't work efficiently [5]. Synthesis of ESCS, based on more accurate, nonlinear model of the machine, leads to increased complexity of both – the synthesis procedures and the obtained regulator equations.

So, there appears an actual task – to develop and research new control systems for DC motor electro-mechanical systems (EMS), which would, at the same time, provide nonlinear control and be easy and clear to set up.

## II. Energy-shaping control system with nonlinearity compensators

In order to improve regulation possibilities energy-based approaches can be combined with other different regulators. One of the main approaches to develop control system for nonlinear object is to include in control system nonlinear element, that will compensate nonlinearity of original object [6].

To have a certain flow in the machine, it is necessary to give it the corresponding current in the winding. On the basis of the magnetization characteristic  $F^*(i_{ex})$ , it is possible to construct an amper-bireh characteristic, which is inversed to magnetization, and corresponds to the value of the required excitation current  $i_{ex}$ , to achieve the desired flow [5]. It is proposed to correct control signal of linear regulator (1) with designed nonlinear compensator:

$$u'_{ex} = F^{*-1} \left( \frac{u_{ex}}{R_{ex}} \right) R_{ex}. \quad (2)$$

However, the proposed approach has a number of shortcomings, one of them alleviation of the natural properties of Hamiltonian systems, in particular asymptotic stability. Thus, it is proposed to take into account the nonlinearity of the system at the stage of forming the signal of  $i_{ex0}$ :

$$i'_{ex0} = F^{*-1} \left( \frac{w_n}{w_0} i_{exn} \right). \quad (3)$$

In this case the structure of ESCS (control system + controlled object) remains unchanged and corresponds to the desired PCHs.

In order to analyze in detail proposed nonlinear compensators for ESCSs, there have been conducted a set of comparative researches of ESCSs with different regulators (Fig.1). There have been researched the response of systems in cases of rapid task and load changes in nonlinear – second zone, as well as electrical energy consumption ( $E_{el}$  as integral sum of all electrical consumption) and energetic ECE ( $\eta$  as division of consumed and useful energies).

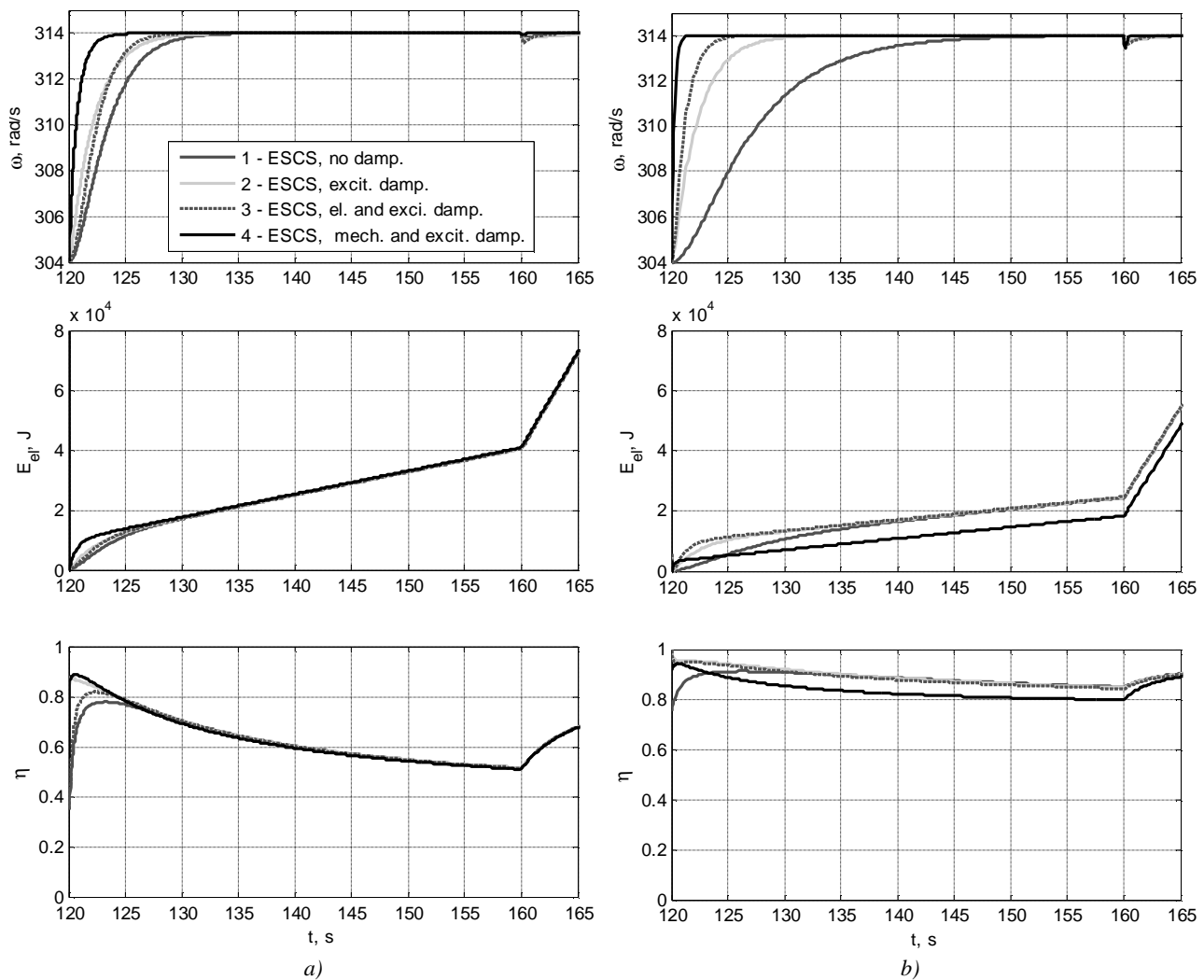


Fig.1. Comparative research of ESCSs with different settings in second zone:  
a) with control signal corrector (2); b) with reference signal corrector (3).

## Conclusion

It was proposed and researched two types of nonlinearity compensators, that allow to use simple linear ESCS regulators to work with nonlinear objects, on DC motor example. First type of compensation consists in correcting control signal of the ESCS  $u_{ex}$ , second – in correcting reference signal  $i_{ex0}$ .

Both types of achieved compensators support different ESCS structures. Reference signal corrector preserve desired PCHs structure of the system, provides better use of energy-shaping damping possibilities, also response and energetic characteristics of the whole system.

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