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Selection of control parameters in a control system with a DC electric series motor using evolutionary algorithm*

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Abstract: This paper presents a method of selection of regulator parameters in a control system using evolutionary algorithm. The control system has one PI controller and one hysteresis controller. The value of the proportional band and the value of the Integral time were defined by evolutionary algorithms. The object of control was a Brown Boveri GS10A motor. The task functions were the step change of rotational speed and step change of the motor's torque. The control system with the parameters selected by means of the evolutionary method was verified by using MATLAB/Simulink environment.

Key words: evolutionary algorithm, parametric optimization, DC electric series motor

1. Assumptions

DC Series motors, because of their properties, are often applied in devices requiring high rotation speed. Due to high starting torque, these motors are used in electric vehicles, cranes and fans. Additionally, DC Series motors can be powered from an AC source, which makes them universally applicable. An important issue is the choice of regulator parameters in control systems for such motors. Selection of regulator parameters in control systems was introduced in many articles [1-4, 6]. Currently, research is conducted into the application of artificial intelligence in parametric optimization. In this paper, the method of selection of regulator parameters in a control system by using evolutionary algorithm is presented.

2. The examined control system

Simplifications were applied as in [5, 7, 8]. With these assumptions, the DC electric series motor is described by the following formulae:

- Electrical equation:

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$$u_a = Ri + L\frac{di}{dt} + M_{st}\,\omega i. \tag{1}$$

- Mechanical equation:

$$J\frac{d\omega}{dt} = M_{st}i^2 + T_{obc}, \tag{2}$$

where: u_a – supply voltage, R – resistance (stator resistance and rotor resistance), L – inductance (stator inductance and rotor inductance), ω – motor's angular speed, J – moment of inertia, T_{obc} – torque.

Thus the rotational speed of the DC series motor is given by:

$$\omega = \frac{u_\alpha - Ri}{c\psi(i)}, \tag{3}$$

where: $\psi(i)$ – magnetic flux, M_{st}, c – parameters.

Parameters of the mathematical model of the inspected DC motor (Brown Boveri GS10A) are presented in Table 1.

Table 1. Parameters of the DC motor GS10A

Nominal data	
U_n	220-340 [V]
I_n	15-21 [A]
P_n	2.7-6.2 [kW]
n_n	1500-1900 rpm
Mathematical model parameters	
R (stator resistance and rotor resistance)	1.05 [Ω]
L (stator inductance and rotor inductance)	0.13 [H]
J	0.776 [kg/m^2]
M_{st}	0.09

The system control of the rotation speed of the DC motor GS10A with one PI controller and one hysteresis controller is shown in Fig. 1 and Fig. 3.

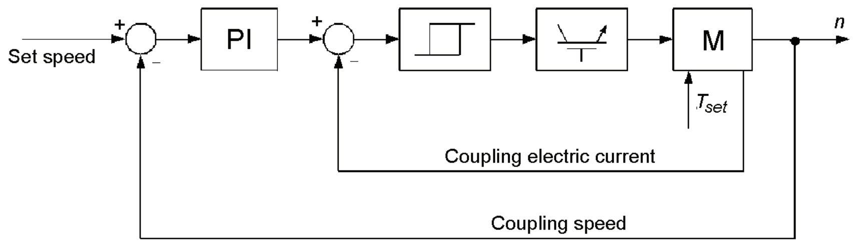

Fig. 1. Control system with a DC motor

The task functions were the step change of rotational speed and step change of the motor's torque (Fig. 2a, b).

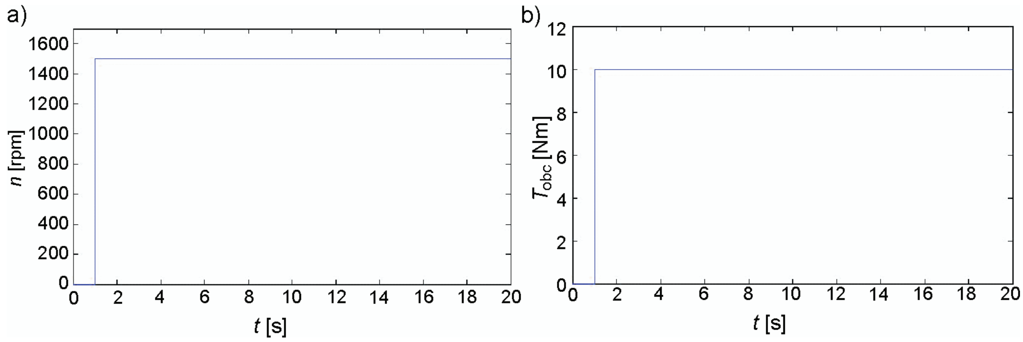

Fig. 2. a) Task characteristics of the rotational speed to be realized by the control system;
b) task characteristics of the torque of load to be realized by the control system

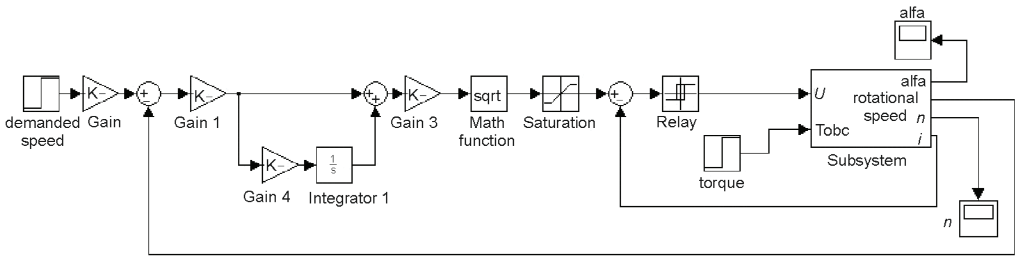

Fig. 3. Scheme of the examined control system in MATLAB/Simulink notation

3. Evolutionary algorithm and its parameters

The task of parameter optimization of the examined control system has many local extremes. It is related to the non-linear character of the control object and the applied constraints and simplifications. The evolutionary algorithm, unlike e.g. the greedy algorithm, simulated annealing or gradient methods, can "leave" local extremes on its own. At the same time, it operates on many possible solutions of the given problem (many individuals). Its operation time is divided into stages named generations. In one generation, new individuals (solutions of the given problem) are generated on the basis of the set of individuals (population) available at the given moment. New individuals are calculated by evolutionary operators such as: cross, mutation, and progressive mutation. New individuals are added to the population in the given generation, and together they form an increased population. By applying selection, individuals from the increased population are chosen to the new population. In the next generation the process is repeated. Depending on the evolutionary operators parameters, population largeness, the applied selection method, etc., the algorithm finds a local extreme with varied efficiency. There are numerous methods of selection: roulette-wheel method, tournament method, or deterministic method. Usually one method is used in the evolutionary process. As shown in [1, 2], application of two methods yields better results. Results of calculations performed with the use of evolutionary algorithms, due to the stochastic principle of their operation, are not optimal but suboptimal. If the accuracy is not satisfactory, the calculated results may be used as input for other optimization methods, e.g. those based on gradient methods. However, in many cases they are the only optimization method.

The following evolutionary operators were used on the generation of new individuals [1, 2]:

- Cross operator: it is a two-argument operator; from two parent-individuals we obtain one filial individual. This individual is found inside a limited rectangular area, and the parent-individuals are points on its diagonal.
- Mutation operator: it is a one-argument operator. From one parent-individual we obtain one filial individual. The filial individual is in a certain distance from the parent-individual. The distance depends on Gauss distribution. The calculated filial individual is more probable to be found in a small distance from the parent-individual than to be found in a greater distance.
- Progressive mutation operator: it is a one-argument operator, which modifies a given individual. The operator causes small positive changes in the given individual. If the calculated change of an individual's features causes a desirable change in the fitness function value, the mutation is accepted. If it doesn't, the individual is not modified.

The block diagram of the algorithm is shown in Fig. 4.

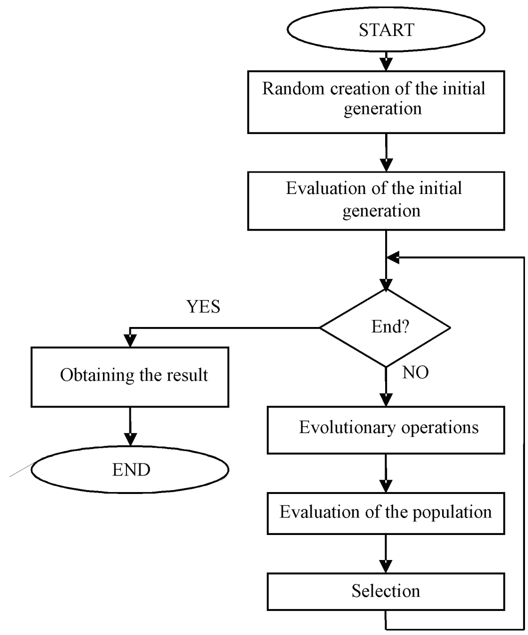

Fig. 4. Block diagram of the evolutionary algorithm

The evolutionary algorithm was used in the parametric optimization [1, 2, 8]. The following methods of selection were used: the tournament selection (70% of the population lifetime) and the deterministic method (30% of the population lifetime) [1, 2]. The individual is a two-element set of parameters of the PI controller: proportional gain k_p and Integral gain T_i. The output signal (speed n) for step change was on the base of the value of the individual (value k_p and T_i. The calculated characteristic was compared with the demanded characteristic. The sum of squares of errors in discrete moments of time between time characteristics (which were calculated on the base of the individual) is the value of fitness-function (value of the criterion of quality – F; Table 3).

Parameters of the evolutionary algorithm are shown in Table 2 [1].

Table 2. Parameters of the evolutionary algorithm

Generation amount	10000
Individual amount in population	200
Cross amount	80
Mutation amount	80
Progressive mutation amount	from 30 to 100. Every 100 generations the mutation amount was increased by 1 up to the limit of 100
The width of mutation range	$0.4 \times i$-th range
The width of progressive mutation range	$0.01 \times i$-th range

4. Parametric optimization of the control system

Parameters of the PI controller were calculated 20 times. The results of evolution are presented in Table 3.

The best individual was individual ‘6’ in Table 3. Fig. 5 shows the demanded rotational speed characteristic (Z) and the calculated rotational speed characteristic (O) based on regulator parameters k_p and T_i of the PI controller of the control system.

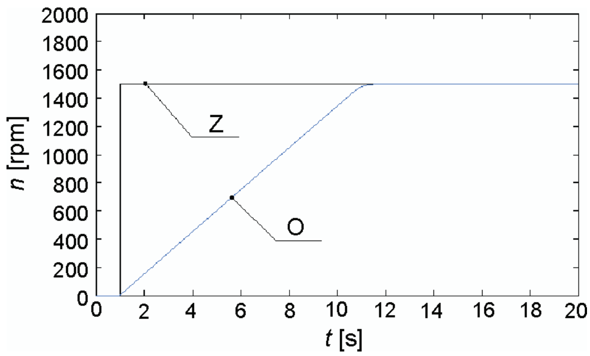

Fig. 5. Rotational speed characteristic: demanded (Z) and calculated (O)

Table 3. Results of parametric optimization of the control system

Ind.	k_p	T_i	F [rpm^2]
1	285.02	0.00511	7.541775*10^9
2	292.12	0.00498	7.541769*10^9
3	293.32	0.00419	7.541927*10^9
4	287.66	0.00521	7.541809*10^9
5	293.78	0.00492	7.541762*10^9
6	291.21	0.00489	7.541755*10^9
7	289.67	0.00501	7.541768*10^9
8	299.01	0.00517	7.541857*10^9
9	283.28	0.00492	7.541763*10^9
10	284.93	0.00497	7.541761*10^9
11	286.07	0.00501	7.541767*10^9
12	289.66	0.00498	7.541763*10^9
13	295.32	0.00510	7.541810*10^9
14	297.94	0.00507	7.541809*10^9
15	289.86	0.00520	7.541816*10^9
16	293.99	0.00502	7.541780*10^9
17	298.21	0.00497	7.541781*10^9
18	291.98	0.00505	7.541780*10^9
19	292.73	0.00508	7.541792*10^9
20	287.55	0.00501	7.541764*10^9

5. Conclusions

As follows from Table 3, the obtained results are recurring. The algorithm was convergent. The results are characterized by the assumed accuracy. The result in position '6' in Table 3 and Fig. 5 is the best one. Individual '6' has the smallest value. The demanded characteristic ('O', Fig. 5) has small overshooting. The evolutionary algorithm characterized by parameters presented in Table 2 is appropriate to parametric optimization of a control system with a DC series motor with one PI controller and one hysteresis controller. The obtained results are usable as input data to other optimization methods.

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