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Synthesis of a Control System Using the Genetic Algorithms

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Abstract: The approaches for the synthesis of an automatic control system using the genetic algorithms are suggested. The paper presents the results of system parameters optimization in the range of settings ruling out instable operation and self-oscillations; these results have been obtained in MATLAB. In addition, we solve the problem of multi-criteria optimization by constructing the set of Pareto-optimal solutions as a result of control system simulation and the use of genetic algorithm. Copyright © 2016 IFAC

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1. INTRODUCTION

Increasing requirements for the automatic control system (ACS) needs to improve methods for the automation and optimization of their design. This paper presents the results of automatic synthesis of an ACS realized on the basis of the digital local controllers VLR-2.1. The remote local controllers VLR-2.1 designed by Avtomatika-E (Omsk) are controllers intended for the objects of thermal and atomic power engineering. Nowadays, these objects undergo modernization in the field of automatic devices.

A testing rig with the mathematical modelling means of controlled industrial processes (IPs) for tuning and testing of the digital automatic controllers VLR-2.1 and for verification of their knoware and software has been created (Denisova, 2012, 2013, 2014; Denisova and Meshcheryakov, 2015). The rig includes the mathematical models of an ACS, designed using MATLAB tools (an environment for scientific and engineering computations). MATLAB / Simulink (Xue and Chen, 2013) and MATLAB Global Optimization Toolbox (Purohit et al., 2013) allow performing the simulation and optimization of an ACS.

2. PROBLEM DESCRIPTION AND METHODOLOGY

Due to the ASC models nonlinearity the tuning of controller parameters is a nontrivial problem. Bearing in mind the ACS efficiency criteria this problem could be solved by use of mono- and multi-objective optimization methods.

The parametric synthesis problem of an automatic control system lies in choosing the parameters guaranteeing an optimal system functioning in the sense of the selected performance criteria. The development of new information technologies, in particular, genetic algorithms (GAs), allows to make an efficient solution for the problems of automatic synthesis and tuning of ACSs. The mathematical apparatus of GAs (Holland, 1994) makes it possible to perform the optimization, if the performance criterion of ACS operation is a nonlinear nondifferentiable function having a local extrema. Representing the direct search algorithms, GAs do not require defining the gradient and high derivatives of a function, which is in a contrast to the classic optimization algorithms.

If the statement of the problem implies the existence of more than one criterion, it inevitably leads to the need for compromising solutions, since the improvement of system behavior by one criterion may be accompanied by worsening its behavior in terms of other criteria.

Among the most effective and well-known approaches for solving multi-criteria optimization is Pareto-optimization which provides the construction of the set of Pareto-optimal solutions, while not improving at all considered criteria (Podinovskiy and Noghin, 2007). To solve the problem of multi-criteria optimization the MATLAB based tools will construct Pareto set as a result of the simulation study of ACS and use of genetic algorithm.

The paper proposes a hybrid approach (synthesis of methods of Control Sciences and methods of Operational Research field), which allows to formalize the control system synthesis process and to ensure the effectiveness of control.

3. PARAMETRIC SYNTHESIS OF THE CONTROL SYSTEM

Automatic parametric synthesis has been realized for the pulse ACS of a typical automation object, i.e., pressure in the steam collector of a power-generating unit. Stabilization of the steam pressure and prevention of its large growth in dynamic operation are the conditions of the unit safety. For ACS analysis in MATLAB/Simulink, we have developed the mathematic model of the ACS (see Fig. 1), which includes the following models: the digital pulse controller, the actuat-

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ing mechanism (AM) with the regulating door (RD), and the control object. The controller's model consists of two bi-position relay sections with a common feedback loop in the form of a first-order inertial section. Zero-order hold serves for taking into account the time sampling of the controller's output signals; this device fixes the value of the input signal coming at the beginning of a quantization interval and maintains this value till the end of the quantization interval. The output sequence of pulses after sampling is supplied to the actuating mechanism of the regulating door.

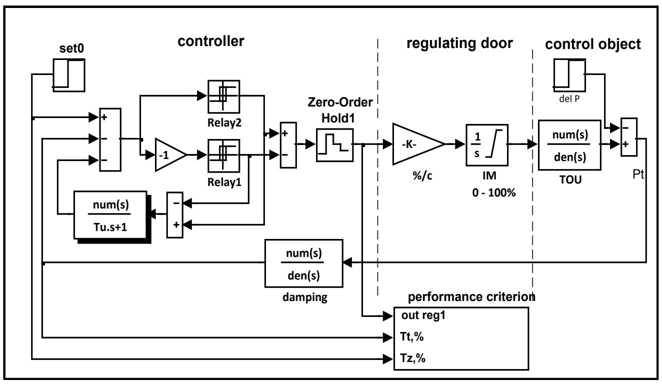

Fig. 1. The scheme of the mathematical model of the ACS in MATLAB/Simulink.

The regulating door equipped with the actuating mechanism is represented by (a) an amplifying section intended for realization of the gain taking into account the opening time T_{AM} and (b) an integration section with limitation of RD opening (0...100% AM position). The control object, i.e., the channel "AM position – pressure in the steam collector" is represented by a first-order inertial section. Note that, on the one hand, a large increase in pressure requires providing a rapid discharge of steam from the steam collector, on the other hand, rapid movement of RD may lead to an unacceptable decrease in pressure. Therefore, the model calculates the performance criterion allowing to take into account these factors

$$J = \int_0^T (\varepsilon^2 + (20u)^2)dt \,, \tag{1}$$

where ε indicates the deviation of the regulated parameter from a given value; u is the controller's output signal at the AM; t means current time; and finally, T specifies the upper limit of integration, which is not smaller than the response time. Minimization of the performance criterion J allows achieving fast response, avoiding overshoot and reducing the number of AM responses.

Considering in more details the model of the digital pulse pressure controller is to be optimized. This controller realizes a traditional control method used in the ACS with constant-speed actuating mechanisms. The base of the algorithm is a relay-pulse proportional plus derivative (PD) converter represented by two bi-position relay sections with the dead zone Δ_d and the hysteresis (the return zone Δ_r) with the common feedback loop in the form of a first-order inertial section. The inertial section in the feedback loop has the transfer function

$$W_{fb}(s) = \frac{1/k_r}{T_i s + 1} \,, \tag{2}$$

where k_r is the controller's gain; T_i stands for the integration time constant. The controller's input signal is the measured pressure signal, which is subsequently damped. The output signals are the pulses formed in the controller and supplied to the actuating mechanism for regulating door opening/closing. Moreover, the pulse ratio possesses the PD dependence on the variations of the deviation signal between the given and measured pressures.

The described relay-pulse controller together with the constant-speed AM approximately realizes a proportional-integral (PI) control law in the main (sliding) mode of ACS operation (Pupkov et al., 2004, Cava et al., 1984). In this mode, the AM gets actuated several times in a same direction, until the deviation goes down to the controller's dead zone.

The controller's tuning parameters are the gain k_r and the integration time constant T_i (the feedback section containing these parameters is shaded in Fig. 1). System stability has been analyzed to find the limits of the optimal solution search domain. The following considerations have been taken into account. In a sliding mode of its operation, the relay-pulse controller obeys a linear control law. Hence, the nonlinear algorithm of the PD converter with the AM representing an integrator is approximated by the linear PI law. For the linear approximating PI controller, the functional relationship between the controller's input signal and the regulating door position is described by the transfer function

$$W_r(s) = \frac{k_r T_i 100\%}{T_{AM}} \left(1 + \frac{1}{T_i s}\right). \tag{3}$$

Taking into consideration the digital controller sampling with the period t_0, the transfer function of zero-order hold is incorporated into the continuous model:

$$W_h(s) = (1 - e^{-st_0})/s \,. \tag{4}$$

The term e^{-st_0}, reflecting system delay and being representable by the Pade approximation formula (Dorf and Bishop, 2011) is reduced to a second-order fractional rational transfer function by *pade* function of MATLAB. The functional relationship between the AM position by the position indicator and the output pressure signal from the control object with damping is expressed by the transfer function

$$W_{co}(s) = \frac{k_{co}}{(T_{co}s + 1)(T_f s + 1)} \,, \tag{5}$$

where k_{co} indicates the control object's gain; T_{co} specifies the time constant of the control object, and T_f is the time constant of damping. The following values have been taken for calculations: k_{co} = 0.9%/% of the AM position indicator; T_{co} = 5 s; T_f = 3 s; T_{AM} = 25 s; t_0 = 0.2 s.

We have constructed the limits of the stability domain in the plane of the parameters T_i and k_r for the ACS with the linear