Identifying Ship Parameters with the Aid of Genetic Algorithm

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Abstract. The article discusses the problem of identifying dynamic parameters of the Bech-Wagner model in such a way that the output characteristics of the model are close to those of a model ship bearing the shipyard symbol B-481. The identification has been carried out in the off-line mode using a genetic algorithm. The included results of simulation calculations, done using Matlab/Simulink, testify to correct operation, in terms of accuracy and rate, of the genetic algorithm.

1 Introduction

Identifying parameters of a model ship is of particular importance when the control system is designed based on the mathematical model of the ship (for instance, using the backstepping method). Good knowledge of model parameters is necessary for those systems to work properly. In most cases the identification process consists in relevant selection of a set of model parameters, which is done is such a way that the selected static and dynamic characteristics of the activated model reflect as closely as possible the characteristics of the measured signals of the object. The model parameters obtained from the identification are then used for determining settings of the controllers that steer the real object. Applying relevant mathematical models in simulation tests reduces the risk of the appearance of divergences between preliminary results obtained from computer simulation and those recorded on the real object.

Numerous methods are used for identifying model parameters. They can be divided into parametric and non-parametric methods, or, with respect to the identified parameters, into static and dynamic methods. Another division makes distinction between classical methods (the smallest square method and its variants, the instrumental variable method, and others) and heuristic methods of solution space search. The latter include, for instance, genetic algorithms and neural networks. The present-day methods and problems of identification are discussed in detail in [8]

The article presents results of identification of dynamic parameters of the Bech model using a genetic algorithm. The identification procedure applied in the article is a typical optimisation analysis, in which one, a priori selected quality coefficient is minimised. In the task formulated in the above way various optimisation mechanisms can be used. Instead of the classical approach making use of the smallest square method, the instrumental variable method, etc., a genetic algorithm was used here for minimising the target function. Among other publications, genetic algorithms were used for solving ship identification problems in [2, 6, 7].

2 Mathematical model of the ship

The object selected for examination in the simulation tests was the model of a ship bearing the shipyard symbol B-481 [4]. However, this model is too complicated to make the basis for the synthesis of the control system. Usually, the synthesis of control systems is done using simplified models with parameters changing in time.

2.1 The identified object

The dynamics of the real ship B-481 was approximated using the simplified Bech-Wenger model given by the following equation [1, 4]:

$$\dddot{\psi}(t)+\left(\frac{1}{T_1}+\frac{1}{T_2}\right)\cdot\ddot{\psi}(t)+\frac{1}{T_1T_2}\cdot H\big(\dot{\psi}(t)\big)=\frac{K}{T_1T_2}\big(T_3\dot{\delta}(t)+\delta(t)\big), \tag{1}$$

where ψ is the ship course, $\dot{\psi}(t)$ is the angular velocity, $H(\dot{\psi})$ is the nonlinear function of the angular velocity. The function H defines the relation between rudder angle δ(t) and $\dot{\psi}(t)$ in steady-state conditions, when $\dddot{\psi}(t)=\ddot{\psi}(t)=\dot{\delta}(t)=0$. Parameters K, T_1, T_2, T_3 are defined as

$$K=K_0\left(\frac{u}{L}\right), \tag{2}$$

$$T_i=T_{i0}\left(\frac{L}{u}\right),\quad i=1,2,3. \tag{3}$$

where u is the longitudinal ship velocity, expressed in [m/s], and L is the ship length, expressed in [m].

The experiment oriented on determining the shape of the curve $H(\dot{\psi})$ bears the name of the "spiral test". For the here examined model it was approximated by the function :

$$H(\dot{\psi})=\alpha\dot{\psi}^3+\beta\dot{\psi} \tag{4}$$

in which α and β are constant real values. The Bech nonlinearity $\delta=H(\dot{\psi})$ was approximated by the third-order polynomial (4), the coefficients of which, α=47.25 and β=689.68, were determined using the linear regression method. The results of the approximation of the Bech nonlinearity by the polynomial (4) are shown in Fig. 1 for the ballasting state.

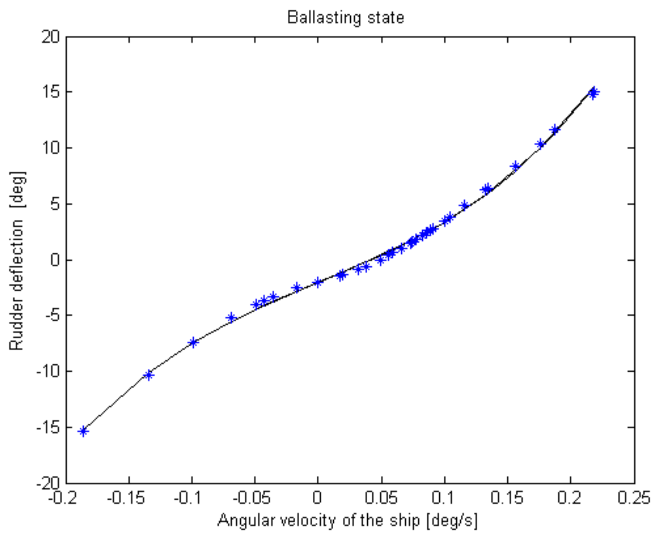


Fig. 1. The inverse spiral curve for the ballasting state ('*' measuring points)

2.2 Sample ship model

The sample ship model examined in the article is the mathematical model of the ship bearing the shipyard symbol B-481 [4]. Basic constructional parameters of the ship are given in Table 1. The examined model of the ship B-481 includes the dynamics of the hull, and that of the main propulsion system consisting of a single adjustable-pitch propeller, a blade rudder, and two lateral thrusters: at bow and at stern.

Table 1. Main parameters of the B-481 ship model

	Ballast	Units
Length overall	181	[m]
Breadth	28.2	[m]
Maximum displacement	16400	[m^3]
Maximum rudder angle	35	[deg]
Draught forward	5.55	[m]
Draught aft	6.7	[m]
Traveller speed	22,00	[knot]

2.3 Dynamics of the steering gear

An actuator on the ship is a hydraulic steering gear operating in the system of the nonlinear rudder deflection servomechanism with limited rudder deflection speed and maximum rudder deflection. The model of dynamic properties of the ship B-481 is complemented by the model of the steering gear, described in [1, 4] and schematically shown in Fig. 2.

Tests of rudder responses to step excitations have revealed the presence of the rudder speed limit approximately equal to $\dot{\delta}_{\max} = 2.5$ [deg/s]. At the same time, within the range $|\delta_z - \delta| \leq 3$ [deg] the rudder blade works in the linear part of the characteristics. The maximum rudder deflection equals $\delta_{\max} = 35$[deg].

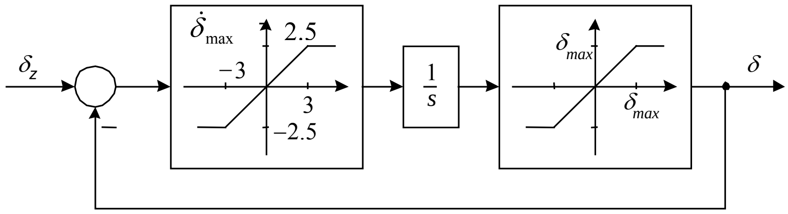


Fig. 2. Block diagram of the steering gear

The response of the ship steering gear is dominated by two nonlinearities: rudder angle and rudder speed. These nonlinearities can be simplified using a linear approximation. Conversion between the set limited value of the ruder angle $\delta_z(t)$ and its real value $\delta(t)$ can be approximated using relation [1]:

$$\dot{\delta}(t) = \frac{K_R}{T_R}\delta_z(t) - \frac{1}{T_R}\delta(t). \tag{5}$$

Time constants assumed in the investigations are K_R=96[deg], T_R= 156[s]. They were determined for constant ship speed u=5[m/s] and the set rudder angle δ_z=40[deg].

For the dynamics of the simplified Bech model to reflect the closest the behaviour of the real model, parametric identification of the simplified model is to be done, along with determining to which extent and with which accuracy the object is mapped by the Bech model. The objects of identification are four time-dependent parameters of the Bech model, which are three time constants T1, T2, T3 and the gain K.

3 The simulation model

Identification of the ship as a dynamic object was done based on the analysis of the angular velocity of the ship being the response to the set rudder deflection change. The identified time-dependent parameters of the Bech model include time constants T_1, T_2, T_3 and the gain K. The method of selecting Bech model parameters is illustrated in Fig. 3 [2]. The presented diagram of the system was constructed in the programme Matlab/Simulink. In the block “sample” the equations of dynamic characteristics of the B-481 ship were modelled with the parameters determined for the ballasting state, and with environmental disturbances being taken into account. In the block “model” the equations of dynamic characteristics of the Bech model, given by formulas (1), were modelled. Additionally, the both models were complemented by the dynamics of the steering gear.

The identification procedure consisted in setting, in a step manner, the input signal u(t) - the assumed rudder deflection, to the system shown in Fig. 3. The signal was transformed into relevant output signals of the sample and the model, which were then compared with each other. The distance between the characteristics is usually evaluated using the measures based on continuous or discrete measurements of the signal time-histories. In the reported investigations, the mean square measure was adopted, which is given by the relation:

$$J_C(T_1, T_2, T_3, K) = \frac{1}{N} \sum_{i=1}^{N} \left[(\dot{\psi}_{im} - \dot{\psi}_i)^2 + (\dot{\psi}_{im} - \dot{\psi}_i)^2 + (x_{im} - x_i)^2 + (y_{im} - y_i)^2 \right], \quad (6)$$

Here N is the total number of iterations in control system simulations, the difference $(\psi_i - \psi_{im})$, $(\dot{\psi}_i - \dot{\psi}_{im})$, $(x_{im} - x_i)$, $(y_{im} - y_i)$ is the i-th deflection respectively of the course, angular velocity, x-ship position, y-ship position characteristics produced by the system and the model for the given time instant. The calculated error provides opportunities for evaluating the accuracy of the identification.

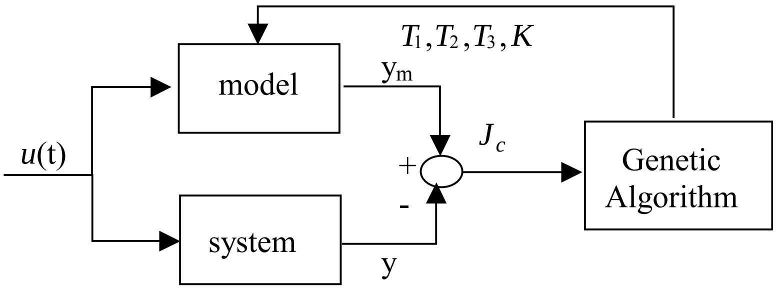


Fig. 3. Scheme of the genetic algorithm based identification system

Optimising the quality coefficient and selecting optimum values of the parameters T_1, T_2, T_3, K were done using genetic algorithms. A single chromosome contained identified parameters coded in a sequence of bits. The initial population was selected in a random way, using a bit-after-bit procedure. The chromosomes generated as a result of the action of the genetic operations of selection, crossing, and mutation composed a new population. The new-population chromosomes were evaluated in the same way as the initial population and the previously generated populations. First the chromosome was decoded to determine model parameters. Then the signals were simulated using the scheme shown in Fig. 3 for the decoded parameters. The output signals were evaluated using the quality criterion (6). Doing multiple simulations for all sets of parameters coded in the chromosomes, and evaluating particular simulations with the aid of the quality criterion, resulted in the creation of the ranking of parameters - chromosomes. Then the order of the chromosomes in the population was settled depending on the value of the fitness function – here, the control quality criterion. The created population was subjected to further action of the processes of selection, crossing and mutation. The above procedure was repeated many times and was limited by the maximum number of generations. Based on past experiments, the maximum number of generations was assumed as equal to 100, while the maximum number of populations was assumed as equal to 50. The final solution was the best solution found within the most recent population. The programme worked until the stopping conditions (exit from the main calculation loop) were fulfilled. Two conditions stopping the operation of the algorithm were possible. The first condition consisted in limiting the maximum number of generations in the parameter optimisation process, while in the second condition the algorithm checked whether the newly generated populations improved considerably the previous solutions. The calculations were also stopped when the change of the total identification error in 5 training cycles was smaller than the permissible level. When the current values were properly selected, these criteria made it possible to reduce the calculation times, at the same time keeping the accuracy at the same level.

4 Results of simulation tests

The simulation tests were performed using the scheme shown in Fig. 3. The input signal u for the system was the set rudder deflection angle, the value of which was step-changed by 5 [deg], within the range from 0 to 40 [deg]. The quality coefficient (6) was determined from the tests performed during the time equal to 1200 [s], with the sampling period equal to 0.01 [s]. The tests were performed for constant ship speed u=5[m/s]. The identification was done taking into account environmental disturbances, such as wind, waves, sea currents, at sea condition corresponding to $1[^0 B]$. The values of the Bech model parameters for which the smallest quality coefficient was obtained are collected in Table 2. The parameters were changed within the following ranges: $0<T_1<20$, $0<T_2<20$, $0<T_3<100$, $0<K<2$. The length of an individual chromosome was equal to 42 bits. Parameters T_1 and T_2, determined with the accuracy up to two digits after coma, were coded on 9 bits, while the parameter T_3, determined with the accuracy up to one digit after coma, was coded on 14 positions. The parameter K, determined with the accuracy up to four digits after coma, was coded on 10 bits. Figures 5-7 show sample results of simulation tests for selected data collected in Table 2 in test turning manoeuvre by δz=20 (deg). Figure 4 shows the variation of ship course and ship position. There is an excellent agreement between the sample values and the corresponding ones obtained by the simulation-optimisation process. Table 3 presents the values of cost indexes for the ship course, angular velocity and ship position calculated by (7).

$$e = \max\left|\frac{y_{im} - y_i}{y_i}\right| \cdot 100\% \,. \tag{5}$$

Table 2. Parameter values obtained with the aid of the genetic algorithm.
(N_max – maximum number of generations after which the algorithm was stopped)

N_max	δ_z [deg]	K [s^{-1}]	T_1 [s]	T_2 [s]	T_3 [s]	Jc
18	5	1.4016	7.67	4.02	79.5	2.3247
22	10	1.1969	4.54	17.58	64.5	2.3008
40	15	1.1969	19.72	10.93	14.9	2.3997
19	20	1.2598	19.96	1.22	3.9	2.6117
44	25	1.3071	19.84	1.78	91.3	16.20378
16	30	1.4331	8.81	7.46	35.4	21.2895
57	35	1.5433	19.37	15.60	20.4	11.0930
23	40	1.4961	3.49	15.82	74.8	16.7385

Table 3. Variable cost values [%]

δ_z [deg]	5	10	15	20	25	30	35	40
ψ	0.23	0.029	0.077	0.089	0.578	0.304	0.634	1.036
$\dot{\psi}$	1.22	1.753	1.584	1.335	9.688	8.590	7.774	7.782
x	2.16	4.132	2.029	0.681	2.46	1.103	1.966	3.832
y	0.96	0.527	0.760	1.495	3.94	4.158	6.198	7.024

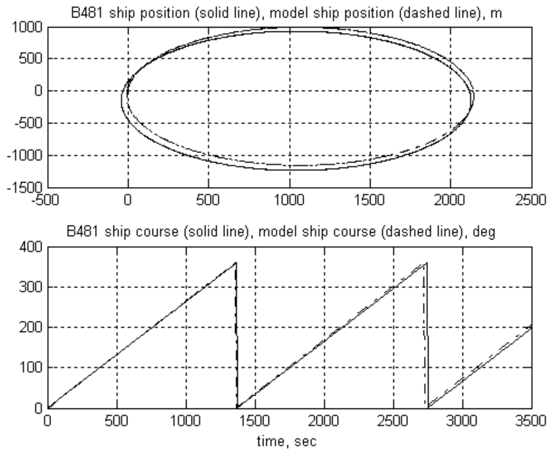


Fig. 4. Comparison of ship position and course characteristics in test turning manoeuvre by δz=20 (deg): solid line - B-481 ship model, dashed line - Bech-Wagner model.

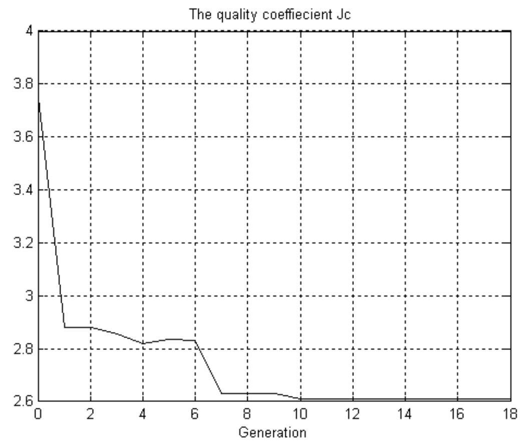
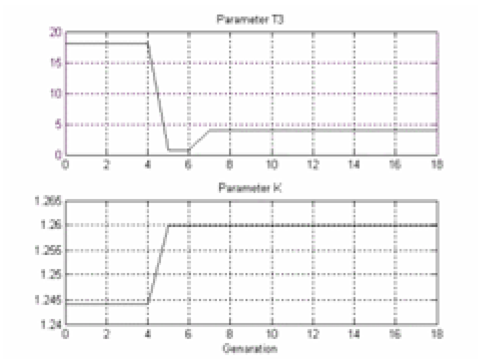


Fig. 5. Values of quality coefficient Jc in successive generations.



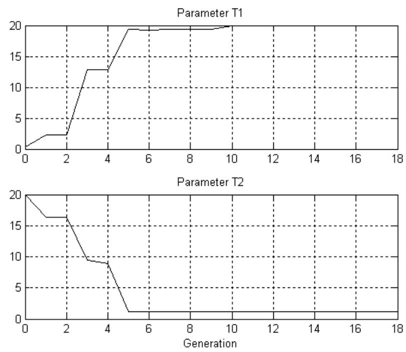


Fig. 6. Values of parameters T_1, T_2 in successive generations.

Fig. 7. Values of parameters K, T_3 in successive generations

5 Conclusions

In the article a procedure is proposed for an off-line identification of the dynamics of a nonlinear object using the genetic algorithm. The results obtained from the computer simulation confirmed the efficiency of the proposed method. The here identified object will be then used in the ship course control system designed using the backstepping method.

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