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Speed Control System for Marine Diesel Engine Using Genetic Algorithm

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Abstract : The conventional PID controller has been widely used in many industrial control systems although modern control theory has been remarkably developed recently. Because engineer can easily understand how to deal with the PID controller which consists of three parameters. This PID control method, however, has a tendency to depend on experience.

Genetic Algorithm can search the control parameters according to systematic procedure in a selected plant. In this paper the real coded genetic algorithm is used to search proper values of the PID controller parameters for marine diesel engine. Simulation results show the effectiveness of the proposed scheme.

Key words : PID control, Marine diesel engine, Real coded genetic algorithm, Time delay

1. Introduction

PID controller is widely used in industrial area due to its simple and practical usage. Especially the PID controller is often used for speed control of marine diesel engine. In PID control scheme the control parameters must be tuned properly to obtain good control performance according to the plant characteristics. For tuning the controller Ziegler-Nichols method, Cohen-Coon method, pole-placement and IMC etc are used[1]-[4]. Those tuning methods are in general based on intuition and experience of designer.

On the other hand the genetic algorithm(GA) could be used for this purpose due to its optimization characteristic. Unlike other searching mechanism based on gradient decent algorithm, the GA doesn't necessarily demand the information about continuity and differentiability of the search space. It can find convergency without those information easily. Because of this fact, GA can be utilized to system optimization problem, recognition problem, and control

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problem.

In this paper the real coded genetic algorithm(RCGA) is used to find suitable control parameters[5]. Firstly the control parameters are identified using the GA. Secondly this scheme is applied to the speed control of marine diesel engine. Simulation results are given to illustrate the usefulness of the proposed scheme.

2. Modeling of marine diesel engine

The speed control system comprises controller, governor and marine diesel engine which has fuel pump as shown in Fig. 1.

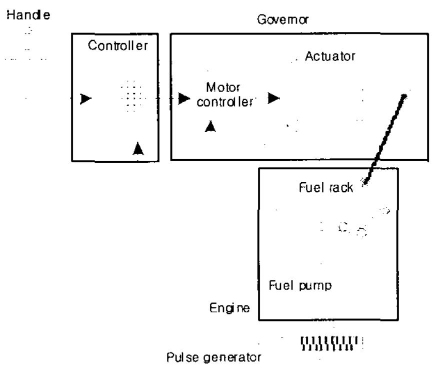

Fig. 1 Speed control system of marine diesel engine.

2.1 Modeling of engine

The marine diesel engine consists of combustion and revolution mechanisms. Assume the combustion mechanism being first order which has gain K_c, time delay T_c and the position of the rack $z(t)$, rotating torque $q_e(t)$, the transfer function becomes

$$T_c\dot{q}_e(t) + q_e(t) = K_c z(t-L)$$

$$\frac{Q_e(s)}{Z(s)} = \frac{K_c}{1+T_c s}e^{-Ls} \tag{1}$$

Where, L is time delay which includes injection delay and ignition delay.

The rotating torque q_e is expressed as follows

$$J_e\frac{d\omega_e(t)}{dt} = q_e(t) - q_l(t) - q_f(t) \tag{2}$$

Where, J_e denotes inertia moment, q_l denotes load torque. q_f denote friction torque which is proportional to engine revolution speed.

$$q_f = B_e\omega_e \tag{3}$$

Where, B_e is friction coefficient of shaft mechanism.

From Eq. (2) and (3) the following is obtained.

$$\Omega_e(s) = \frac{K_r}{1+T_r s}(Q_e(s) - Q_l(s)) \tag{4}$$

Where, $K_r = \frac{1}{B_e}$, $T_r = \frac{J_e}{B_e}$

Ignoring the load torque, the following is obtained from Eq. (1) and (4)

$$\frac{\Omega_e(s)}{Z(s)} = \frac{K_c K_r}{(1+T_c s)(1+T_r s)}e^{-Ls} \tag{5}$$

Put $K_E = K_c K_r$, $T_c T_r \approx 0$, $T_E = T_c + T_r$

Where, K_E and T_E denote total gain and total time constant of engine system respectively.

Therefore the model of the engine can be

$$\frac{\Omega_e(s)}{Z(s)} = \frac{K_E}{1+T_E s}e^{-Ls} \tag{6}$$

2.2 Modeling of actuator

Applying the Kirchihoff law to DC motor the following is obtained

$$L_a \frac{di_a(t)}{dt} = v(t) - R_a i_a(t) - K_b \omega_m(t) \tag{7}$$

Where, $i_a(t)$ and $v(t)$ are armature current and input voltage respectively, R_a and L_a are armature resistance and armature inductance. K_b is counter electromotive force coefficient, $\omega_m(t)$ is rotor angular velocity. Ignoring L_a, viscous friction and coulomb friction, the following is obtained.

$$J_m \frac{d\omega_m(t)}{dt} = K_t i_a(t) \tag{8}$$

Where, J_m is inertia moment, K_t is torque coefficient.
From Eq. (7) and (8) the following is obtained.

$$\frac{\Omega_m(s)}{V(s)} = \frac{\frac{1}{K_b}}{1 + \frac{J_m R_a}{K_t K_b} s} \tag{9}$$

The model of ball screw can be

$$\dot{z}(t) = K_V \ \omega_m(t) \tag{10}$$

$$Z(s) = \frac{K_V}{s} \Omega_m(s) \tag{11}$$

Where, K_V is motion converting coefficient.

2.3 Speed control system of marine diesel engine

The speed control system of Fig.1 can describe in detail as shown in Fig.2. N_r and N denote reference engine speed and real engine speed, z_r and z denote output signal of PID controller and real rack position, e and τ_d denote engine speed error and load change respectively.

In the control process z_r is compared with z, then this becomes reference angular velocity of the motor with multiplication of K_A. This reference signal is compared with the feedback signal of the DC motor angular velocity and the difference becomes input signal of the PI controller in voltage value. The voltage value is converted to current. The revolution motion with angular velocity ω_m is actuated by the current signal.

In Fig.2 K_A, K_N, T_N and K_{TG} are gain, proportional gain, integral time and feedback gain of tacho generator respectively. These parameters and their values[6] are shown in Table 1.

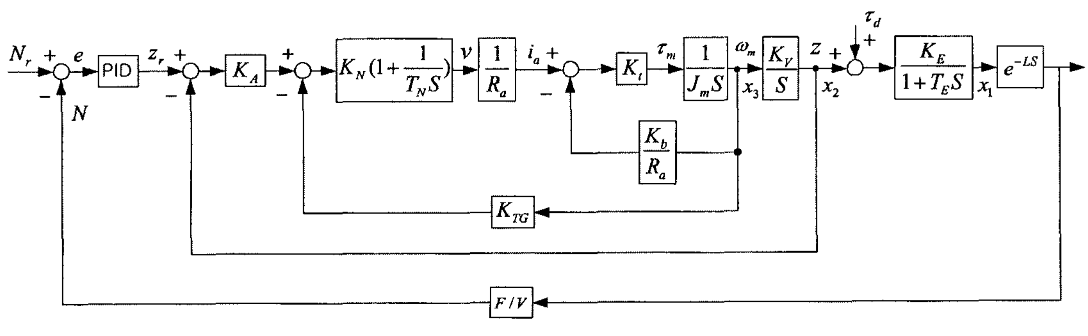

Fig. 2 Block diagram of marine main diesel engine speed control system.

Table 1 Parameter values of an actuator.

Parameters	Values	Unit
R_a	0.25	[V/A]
K_t	4.29	[kgf ·cm/A]
J_m	0.0226	[kgf ·cm·s^2]
K_{TG}	0.03184	[V·s/rad]
K_V	0.0796	[cm/rad]

From Fig. 2 the system can be expressed in state space format as follows [7].

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\\ \dot{x}_4\end{bmatrix} = \begin{bmatrix} -\frac{1}{T_E} & \frac{K_E}{T_E} & 0 & 0 \\ 0 & 0 & K_V & 0 \\ 0 & -\frac{K_tK_NK_A}{R_aJ_m} & -\frac{(K_tK_NK_{TG}+K_tK_b)}{R_aJ_m} & \frac{K_t}{R_aJ_m} \\ 0 & -\frac{K_NK_A}{T_N} & -\frac{K_NK_{TG}}{T_N} & 0 \end{bmatrix} \begin{bmatrix} x_1\\ x_2\\ x_3\\ x_4\end{bmatrix}$$

$$+\begin{bmatrix} 0\\ 0\\ \frac{K_tK_NK_A}{R_aJ_m}\\ \frac{K_NK_A}{T_N}\end{bmatrix} + \begin{bmatrix}\frac{K_E}{T_E}\\ 0\\ 0\\ 0\end{bmatrix}\tau_d \qquad (12)$$

Where, x_1 is engine speed without time delay, x_2 is rack position and x_3 is motor angular velocity.

3. PID controller based on RCGA

3.1 Real coded genetic algorithm

The RCGA compared with binary coded genetic algorithm is easy to program and to extend definition space of solution. It is also possible to omit encoding and decoding process. The RCGA also uses the elitist strategy[8].

3.2 PI controller for DC motor control unit

In order to obtain PI controller parameters of the actuator, step pattern z_r is provided. The most suitable K_A=10, K_N=4, T_N=0.5 are selected. Fig. 3 shows the simulation result with z_r=80.

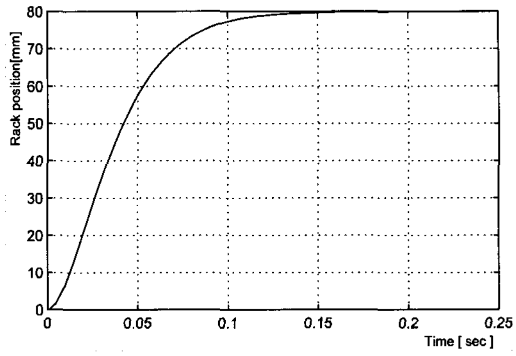

Fig. 3 Step response of an actuator.

3.3 PID controller

Fig. 4 shows the tuning of the PID controller using a RCGA. The cost function used is as follows Eq. (13).

$$J = \int_0^{t_f} |e(t)|\,dt \qquad (13)$$

Where, t_f is selected with reasonably large value.

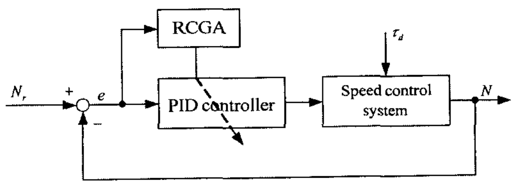

Fig. 4 The tuning of the PID controller using a RCGA.

4. Simulation

In order to carry out RCGA program

designer determines initial population and genetic operations. In this paper Population size is 40, reproduction coefficient is 1.7, crossover rate is 0.8, mutation rate is 0.1 are selected respectively. Table 2 shows the parameter values of the PID controller tuned by RCGA.

Table 2 Parameter values of PID controller.

Engine speed		25	35	45	55
PID Parameter	K_P	1.4016	1.7282	2.1856	2.8431
	K_I	0.4789	0.4805	0.5407	0.6392
	K_D	0.7103	0.6734	0.6632	0.6779

In the simulation the Characteristics of engine are used as shown in Table 3.

Table 3 Characteristics of marine diesel engine.

Parameters \ RPM	25	35	45	55
Time delay	1.08	0.77	0.68	0.49
Gain of diesel engine	1.03	1.04	0.98	0.89
Time constant	1.85	1.85	1.85	1.85

Fig. 5 shows the simulation result of the engine speed to reference speed and disturbances. In the case of reference speed a bit of overshoot and short rising time are observed. The loads equivalent to rack position ±5[mm] as disturbance are applied from 50 to 80[sec] and 130 to 160[sec]. In the case of disturbance the good control responses are also observed.

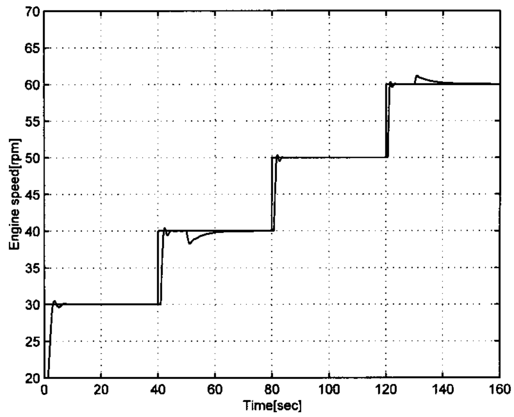

Fig. 5 Step response of PID controller using a RCGA.

5. Conclusion

A PID controller based on RCGA was proposed for speed control of marine diesel engine. The marine diesel engine was modeled with combustion and revolution mechanisms by assuming the combustion mechanism being first order. The reasonably suitable controller parameters were obtained through tuning process. The simulation results were given to verify the proposed control scheme.

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