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A New Control Method of Heart Pump Drive System Based on Neural Network Control

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Abstract—**In order to satisfy the special requirements of the artificial heart pump designed by brushless DC motor, this paper presented a pulsating control system which can mimic the rhythm beating of the natural heart. It was modeled and simulated by adapting an intelligent algorithm of neural network PID. The results proved that, neural network PID control could effectively solve the problem that the parameters of the traditional PID control were difficult to be determined and the uncertain problem of the environmental disturbance. Besides, it had very good dynamic and static properties.**

Keywords- artificial heart pump; brushless DC motor; neural network PID control; simulation

I. INTRODUCTION

With more and more applications and development of artificial heart pump, the portability of the device and the comfort of recipients had been paid more and more attention. This paper adapted a pulsating flow pump to simulate the rhythm beating of the natural heart, whose output can meet the physiological requirements of the pulsating blood flow and pressure. The output of the artificial heart pump flow and the output pressure varied with the change of the speed of the drive motor. As the drive system of artificial heart pump, when it met the requirement of durability, the control performance was particularly important. This paper compared the excellence of BP neural network PID control with traditional PID control strategy by modeling and simulation of the driving control system of heart pump..

II. ARTIFICIAL HEART PUMP

The artificial heart pump is a kind of medical device that can assists natural heart to pump blood. It is used for left ventricular assist circulation, and it is sutured in the position of the valve. Nowadays, the axial flow blood pump plays a dominant role in the field of artificial heart pump. Because of its small size, easy implant, and lower power consumption, the artificial heart pump has been paid more and more attention in the past several years.

For the pulse pump, the requirements of the drive system are as follows: (1) Reciprocating motion in a certain speed similar to the natural heart rate. (2) Appropriate outlet pressure to satisfy the physical conditions of perfusion pressure. (3) Proper reciprocating stroke order to meet the auxiliary demand of each pulse of blood flow. (4) Appropriate rotational speed to ensure that blood is not destroyed. The performance of the pump is required as follows: (1) Flow reaches to 4L/min. (2) Pressure achieves 40-80mm/Hg.The permanent-magnet motor is adopted in order to achieve high power density and high efficiency. Because the pump will be implanted into the natural heart, its size must be small. The outside diameter of the experimental blood pump is 34mm, the inside diameter of it is 15mm, and the length of it is 22mm. Fig.1 shows the picture of artificial heart pump in experiment.

Figure 1. Experimental artificial heart pump

III. THE MATHEMATICAL MODEL OF MOTOR

As we all know, an important part of the artificial heart pump is brushless DC motor. In order to model and simulate the whole control system of heart pump, we need to know the mathematical model of it at first.

The motor detects the position signal of the rotor poles by detecting the back electromotive force, and the controller logically processes the position signal of the rotor, then generates corresponding switching signals in a certain order to trigger the power switching devices of the inverter, next the controller allocates power to each phase winding of the motor stator in certain logical relationship, finally it makes the motor generate continuous torque to keep the motor running continuously.

With the purpose of modeling and simulating the control system, we should assume that the stator winding is three-phase symmetrical and Y shape connected; Permanent magnet flux density waveform is a square wave. Three-phase winding back-EMF is trapezoidal wave; Ignore the cogging and the influence of commutation symmetry and armature reaction;

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Armature windings in the stator surface are uniform and continuous distributed; The magnetic circuit is unsaturated, and the eddy current and hysteresis loss are not taken into account, a mathematical model may be established based on the characteristics of the brushless DC motor:

- Three-phase winding voltage balance equation can be expressed as:

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} P \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{1}$$

- Brushless DC motor electromagnetic torque equation can be expressed as:

$$T_e = \frac{e_a}{\omega} i_a + \frac{e_b}{\omega} i_b + \frac{e_c}{\omega} i_c \tag{2}$$

Where, T_e is electromagnetic torque; ω is rotation angular velocity of motor;

- The equation of motion of the brushless DC motor can be expressed as:

$$T_e - T_L - B\omega = J\frac{d\omega}{dt} \tag{3}$$

Where, *J* is the inertia moment of motor, *B i*s the damping coefficient.

However, as many assumptions stated above, the whole mathematical model can not reflect the facts exactly. We put forward the neural network PID control to meet their uncertainty and imprecision.

IV. TRADITIONAL PID CONTROL AND BP NEURAL NETWORK PID CONTROL

A. Traditional PID control

PID control is the abbreviation of proportional integral derivative control. It is widely adopted in many fields because of its simple structure and effective result.

Proportional regulation: Controller's outputs are proportional to the error signal of their inputs. Once the system has gone wrong, proportional adjustment immediately plays a regulatory role in reducing the error, proportional action can speed up the adjustment and reduce the error.

Integral regulatory role: The controller's outputs are direct proportion to the error signals of input. It will eliminate the steady state error continuously and improve accuracy until the integral control stop. When the error signal is not zero, the regulator output will continue to grow until it reaches the maximum threshold. The regulation of PID control is:

$$u(t) = K_P\left(e(t) + \frac{1}{T_1}\int_0^t e(t)\,dt + \frac{T_D}{dt}\,de(t)\right) \tag{4}$$

The traditional PID control used in classical control theory is mature and is a very effective engineering control method. For some clear structure, fixed parameter and time-invariant long systems, the regulation of PID control plays a perfect role. The traditional PID controller has the advantage of simple structure, good stability, high reliability, easy to engineering implementation and so on. But for some uncertainty in control, nonlinear, time-varying controlled object, because of the unclear mathematical model, the traditional PID regulator is often difficult to ensure the stability of the system.

B. Neural Network

Thanks to many advantages the neural network has, it has already become the tendency in the field of control. It has three layers generally: input layer, hidden layer and output layer. In this paper, the input is the reference speed of the DC motor, the output is signal to tune duty ratio in the PWM in order to control the motor to modulate the speed.

BP network is one of the artificial neural networks. It has the ability to approximate any nonlinear function. Its controller consists of two parts: a direct closed-loop control and Neural network ANN. According to the operation of the system state, it adjusts the PID controller parameters to achieve the desired optimization. It makes the output state in output layer neuron correspond to the PID controller of the three adjustable parameters Kp, Ki, Kd. Through neural network learning, and the adjustment of the weighting factor, it makes the steady state corresponds to a certain optimal control law under the PID controller parameters.

In the control system, BP neural network is widely used in the identification and control of the nonlinear system. BP neural network is formed by a number of simple nonlinear neurons which have advantages of complex non-linear processing power, simple structure and clear learning algorithm. The basic idea of neural network PID controller takes the output error e (n) = r (n)-y (n) as a learning signal, and BP neural network adjusts the PID parameters by the rulers, Where r (n) and y (n) are the reference values and the object output in the n time.

C. BP neural network PID control algorithm

The BP network controller structure is shown in figure 2.

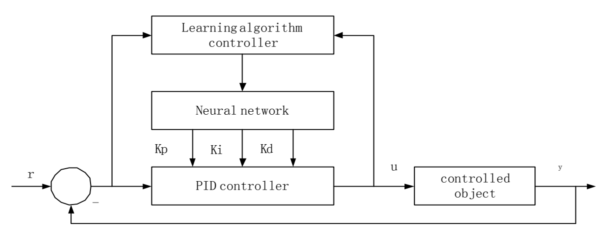

Figure 2. BP network controller structure

BP algorithm's learning process is composed of forward propagation and error back propagation process. When it is in forward propagation, input samples are introduced from input layer. After processed from hidden layer, it transmitted to the output layer. If the actual output does not match the expected output of the output layer, it will transfer to the error back-propagation stage. When it is in error back propagation, it will back propagate output errors in some form through the hidden layer to the input layer and distribute the errors to every unit. Then it can get the errors of every unit. And this error signal will be the foundation to correct the weights of each unit.

1) The PID control algorithm processes based on BP neural network are listed as below:

a) Pre-selected structure of BP neural network NN, selected input layer nodes M and the hidden layer points Q. Given the initial value of the number of layers of weighted, and Selected learning rate and inertia coefficient.

b) Sampling r (k) and y (k), computing e (k) = z (k) = r (k)-y (k).

c) R (i), y (i), u (i-1), i (i), (i = k, k-1, ... kp) were normalized as the NN input.

d) Calculated the input and output layers of the neural network ANN, the output of the NN output layer is three adjustable parameters of the kp (k), ki (k), kd (k).

e) Calculation of the output u(k) involved in the control and calculation.

f) Calculate the correction of the weighting coefficient of the output layer.

g) Calculate the correction of the weighting coefficient of the hidden layer.

h) Set k = k +1, return to b.

The combination of neural network PID controller is actually a class of intelligent PID controller. It can solve many complex, nonlinear, multivariate and faintness issues. For the uncertainty, nonlinear time-varying controlled object in the system, the BP neural network PID control is superior to traditional PID control.

V. MODELING AND SIMULATION

In order to analysis the whole system clearly, a simulation model for artificial heart pump drive has been established, as shown in figure3. In the process of simulation, there are 5 modules established in total: speed control module, speed control module, reference current module, current control module and the blushless DC motor module. Because the BP neural network algorithm is used to optimize the PID controller parameters, it is applied to the control object. The BP neural network structure is set in the speed control module.

We generally control rotate speed of the driving motor to adjust the output flow and the output pressure of the artificial heart. The input of model we give must be changed values, so that the blood pumped can meet the requirements of the pulsating blood flow and pressure, and the blood flow is closer to the physiological heart.

To the pump used for experiments, the learning rate is chosen as 0.24, and inertial coefficient is selected as 0.03.Rated speed n = 8000r/min. Stator winding resistance r = 0.6Ω. Stator winding inductance L= 0.02H. Torque TL= 5.5N.m. DC power supply U = 24V. The moment of inertia J = 0.005kg.m2. The number of pole pairs P = 2.

We give the constant speed pulsating speed as the inputs, and compare the waveform in different control method.

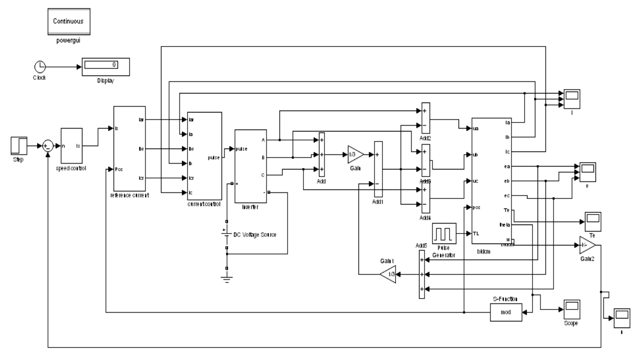

Figure 3. Simulition model based on BP neural network

The input we give is a throb waveform, so that we can simulate the whole system of throb flow valve pump drives.

VI. ANALYSIS

Computer simulation is employed to verify the theoretical analysis. In order to illustrate the control system suitable for throb flow pump, we give some different rotate speeds as the input speeds. We simulate the whole system in different speeds and in different times.

The simulation of rotational speed in the running state is shown in fig4.

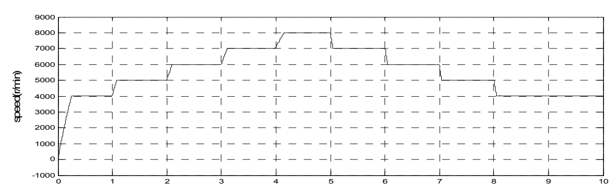

Figure 4. Simulation waveforms in different speeds

We can get 3information from the picture: 1.The speed of response is fast; 2.The range of speed regulation is wide; 3.The speed of every stage to reach stable is fast. They are ready for simulation of throb flow. Good dynamic performance is gained.

The waveforms of rotational speed in reciprocating running state are shown in fig5.

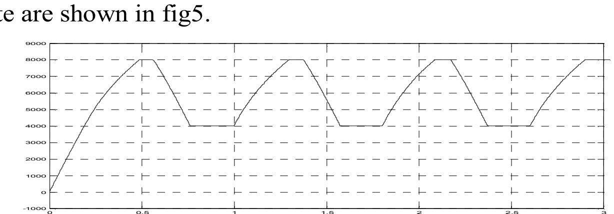

Figure 5. Simulation waveforms in pulsating speed

Fig5 shows the wave simulated from throb flow rotate speed. The input is a pulsating and reciprocating speed. From the wave, the adjustment time is short, the overshoot is small, and the tracking performance is good by using BP network PID control. Besides it improves the anti-jamming capability and inhibits the instability of the system. It proves that the BP network control strategy is suitable for artificial heart pump.

Fig6 and Fig7 show the Simulation waveforms of current running in the speed of 8000 r/min based on the BP network PID control and the traditional PID control.

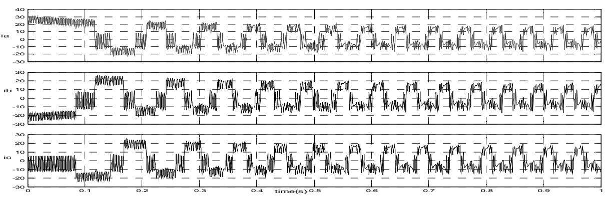

Figure 6. Current waveforms of BP network PID control

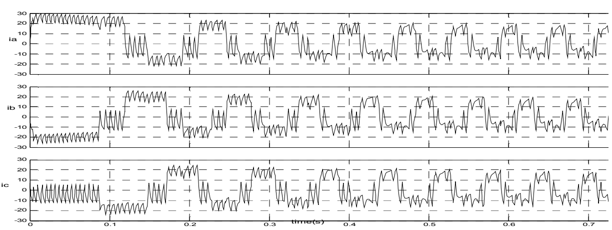

Figure 7. Current waveforms of traditional PID control

Compared with the two figures above, the waveforms based on BP network PID control is better than that based on traditional PID control. It has shorter rise time, more robust and more adaptive capacity.

The simulation of Back EMF based on two control strategies above is shown in fig8 and fig9.

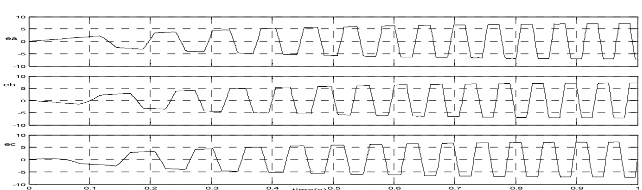

Figure 8. Back EMF waveform of BP network PID control

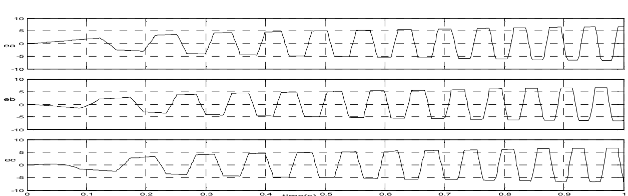

Figure 9. Back EMF waveform of traditional PID control

From the two Back EMF waveforms based on different control strategies, the response time based on BP network PID is shorter than that based on traditional PID. The stability is also better than that based on traditional PID.

VII. CONCLUSION

Using BP neural network to implement online self- turning of PID control parameters for brushless DC motor control system is an effective way to realize the nonlinear control for complex motor. It can overcome the limitation of parameter adjusting and poor performance when the plant has nonlinearity, time-varying uncertainty in the model. Adapting to the model and environments, it can achieve real-time self-tuning adaptive PID control by adjusting the weights of the neural network, and has many advantages as follows: short-time adjustment, small overshoot and strong robustness, good tracking performance. Better control results above can prove the feasibility of neural network PID control.

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