Realization of Automatic Measurement and Bionic Control of Rotary Heart Pumps

K.X. Qian, T. Jing, L. Li

Abstract- The comfortability of the receiptor with a left ventricular assist pump becomes more and more important along with the daily prolonged survival. Thereby it is necessary to achieve automatic measurement and bionic control for heart pump. The key-point is to improve the sensitivity of flow rate change after the pressure head variation in the pump, so as to maintain the flow rate balance between the left ventricular assist pump and the natural right ventricle. This paper presents the measurement of the pump flow and head by computation from motor driving parameters, and the control of the pump imitating the natural ventricle, much more sensitive than available constant voltage and constant RPM control.

Key words- automatic measurement ;bionic control ;neural network

I. INTRODUCTION

The comfortability of the receiptor with a heart pump becomes more and more important in the future. It is necessary to achieve automatic measurement and bionic control for heart pump. The key-point is to improve the sensitivity of flow rate change after the head variation in the pump, so as to maintain the flow rate balance between the left ventricular assist pump and natural right ventricle. Measurement of pump flow rate and pressure head by ventricular assist is important but difficult. On the one hand, the pump flow and pressure are indicators of pump performance and the physiology of the receptor (experimental animals or patients), meanwhile providing a basis for controlling the pump itself. On the other hand , the direct measurement of pump flow and pressure forces the receptor to connect with a flow meter and manometer, as well as resulting in hematological problems and increasing the danger of infection. Therefore, many investigators have intended to measure the pump flow and head by computation of the driving parameters [1.2].

For the displacement pump , in which the blood is delivered by air displacement , the authors had developed a method with acceptable accuracy for measuring the pump flow by computing the driving parameters[3]. For both rotary centrifugal and axial pumps, it is more difficult to compute the pump flow from driving parameters, because the blood is delivered by rotating impeller and there is no driving parameter corresponding directly to the pump flow.

Recently, the authors have developed a novel method for measuring rotary pump flow rate and pressure head by computing the driving motor power and rotating speed. The first results obtained by applying this method to the authors' impeller pump demonstrated that this new approach has a better accuracy than that of most available noninvasive measuring methods, and on this basis a bionic control for heart pump was developed, its sensitivity of pump flow change after the pump head variation had largely improved.

II. AUTOMATIC MEASUREMENT OF HEART PUMP

A. Exemplary experiments

The impeller pump [4] was used first in example experiments (Figure 1).The pump performed at five different rotating speeds from 3000 to 4000 rpm. At each speed n, the motor power P, pump flow Q and pump head

H were measured. The motor power was determined by the product of voltage and current, measured with a locally made direct current supply, which displays the voltage and the current digitally. The pump flow rate was measured by a locally made flow meter , its accuracy reaches 98%in the range of 1-10 L/min. The pump head was determined by the pressure difference between the outlet and inlet measured by Hewlett-Packard M1205A monitor. All the data are shown in Figs. 2 and 3.

Figure1. The left ventricular assist device with impeller pump (left), direct current supply (middle) and controller (right).

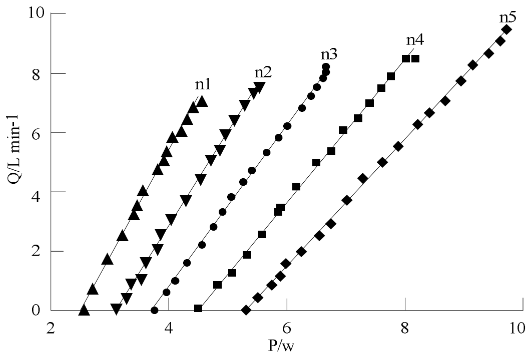

Figure 2. Several Q-P curves measured directly in example experiments.

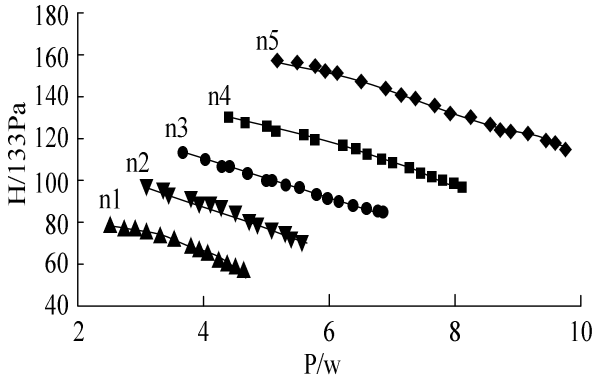

Figure 3. Several H-P curves measured directly in example experiments.

B. Training of BP neutral network

The curves shown in figures 2 and 3 demonstrate the relations between Q and P as well as H and P at some separate rotating speeds. In order to obtain these relations at other arbitrary rotating speeds, the neutral network was used. In figure 4 there is a 3-layer BP (back propagation) neural network.

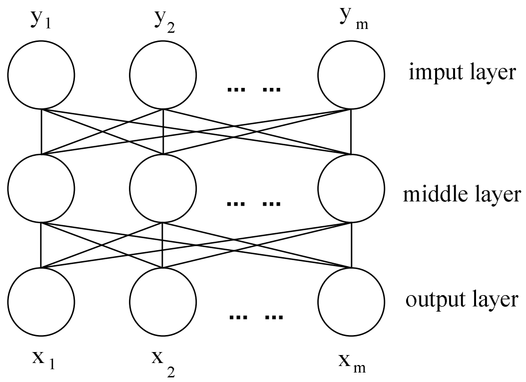

Figure 4. The 3-layer Back Propagation (BP) neural network can convert the Q-P and H-P relations into Q=f(P,n) and H=g(P,n) functions.

The P and n values from exemplary experiments were loaded into the input layer and the Q and H values into the output layer, after training of this BP network, the Q-P and H-P relations can be transformed into Q=f(P,n) and H=g(P,n) functions. That means, for every arbitrary P and n values, once they are loaded into the input layer of above mentioned BP network shown in figure 4 , the corresponding Q and H values can be obtained from output layer of this BP network.

C. Establishment of database

The functions of Q=f(P,n) and H=g(P,n) were stored by computer to establish a database as an archive of the pump used in example experiments.

D. Verifying tests

In animal experiments or clinical trials , the pump performance speed and motor power were automatically recorded and loaded into the neural network . And the pump flow rate and pressure head were digitally displaced . At the beginning , some verifying tests were made in the laboratory in order to demonstrate feasibility. The authors' impeller pump used in exemplary experiments was performed at two rotating speeds different from those in exemplary experiments. The P, Q and H values were measured using the same method as in exemplary experiments. The measured Q and H values were compared with the computed values from this new method.

E. Results

Figures 5 and 6 show the results of the verifying tests and the results computed according to this method. Compared with the direct measuring method, this computing method has an error for pump head less than 2%, and that for pump flow under 5%, So the accuracy is better than that of most non-invasive measurements.

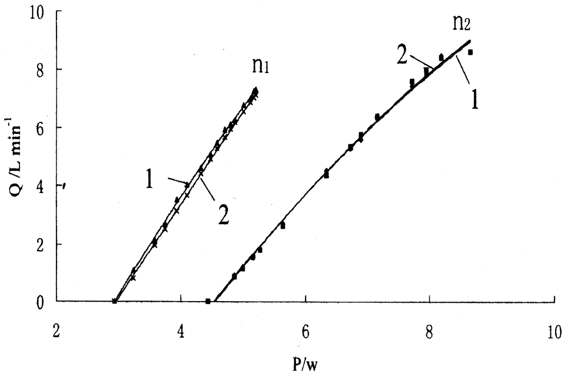

Figure 5. Compared with the Q-P curves measured directly in verifying tests, the results computed according to this method have an error under 5 %.

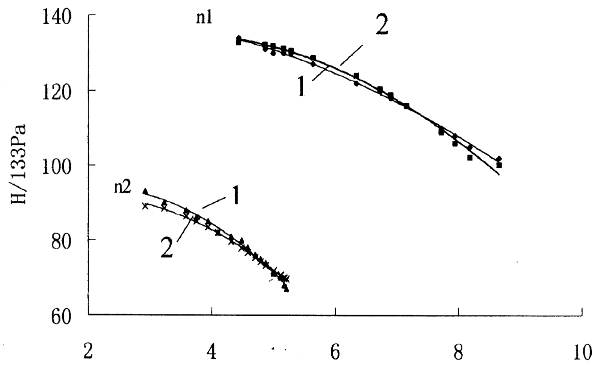

Figure 6. Compared with the H-P curves measured directly in verifying tests, the results computed according to this method have an error within 2 %.

III. BIONIC CONTROL OF HEART PUMP

A. Relationship between flow rate and pressure head under constant RPM and constant voltage control

The pump performed at three different rotating speeds from 3000 to 4000 rpm and three different voltage from 12~24V in exemplary experiments. The pump flow and head were directly measured with a flow-meter and a manometer. All the data measured are shown in Figs. 7and 8.

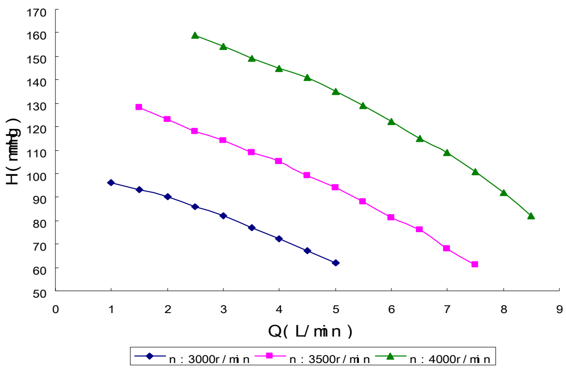

Figure 7. Several H-Q curves measured directly at some separate rotating speeds in exemplary experiments under constant RPM control.

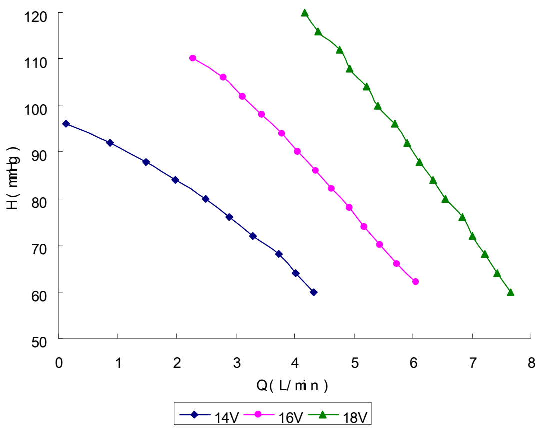

Figure 8. Several H-Q curves measured directly at some separate voltages in exemplary experiments under constant voltage control.

The curves shown in Figures 7 and 8 demonstrate the relationship between H and Q at some separate rotating speeds and voltages under commonly used constant RPM and constant voltage control respectively. It can be seen that under the available control with constant voltage or constant rotating speed, the heart pump head decreases (or increases) about every 7-17mmHg while the flow rate increases(or decreases) 1L/min. The flow of cardiac output changes 1L/min when the left atrium average pressure changes about 1mmHg [5]. To achieve bionic control, it is necessary to improve the sensitivity of flow rate change after the head variation.

B. Control strategy analysis

The relation between voltage and flow rate by constant head was recorded. The pump performed at three different heads from 60 to 120mmHg. At each head, the voltage and pump flow rate were measured. The data are shown in Figure 9.

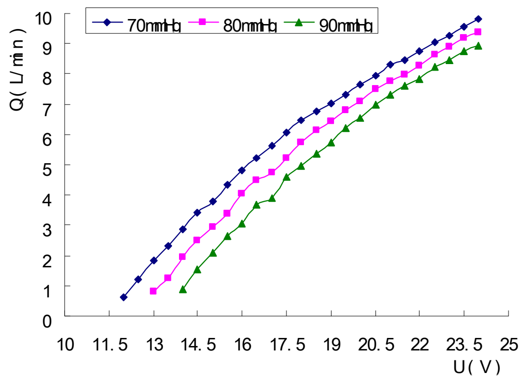

Figure 9. Several Q-V curves measured directly at some separate heads in exemplary experiments.

From the above curves it can be seen that voltage increases about 1.2~1.3V when the flow rate increases 1L/min.

Based on comprehensive analysis of Figure 8 and Figure 9, a control strategy of the control system was determined and shown in Figure 10. When the pressure head of heart pump decreases, the flow rate increases, then increase the input voltage, so that the flow rate of heart pump will further increase; when the blood pump’s head increases, its flow rate decreases, then reduce the blood pump's input voltage, so that the blood pump’s flow rate further decreases, to improve the sensitivity of heart pump flow rate after the head.

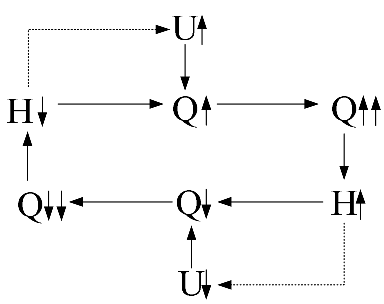

Figure 10. The strategy chart of bionic control system.

Then the authors made following exemplary experiments to measure the voltage values manually along with the head variation (2mmHg, 3mmHg, 4mmHg, 5mmHg), meanwhile maintained the change of the flow rate (1L/min) (Figure 11).

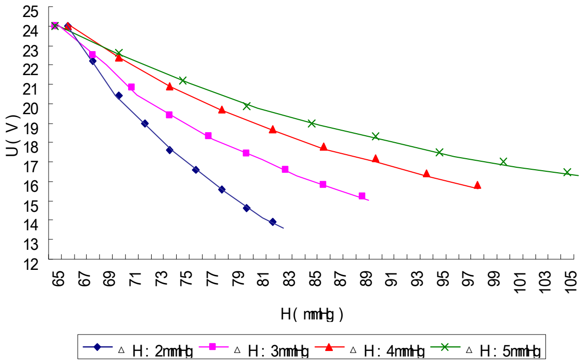

Figure 11. The voltage changes under constant head change 2,3,4 and 5mmHg,the flow change keeps 1L/min.

As the curvature of U-H relation in Fig. 11 is not remarkable, a linear formula (1) was taken to replace the relation of U-H in Fig.11, in order to simplify this method:

$$U= -kH + a \qquad (1)$$

Where, U: motor input voltage; H: pump head; k and a: constants.

Substituted the appropriate data from Fig.11 into equation (1), it follows:

$$\triangle H=2mmHg: U_1= -0.6H_1+62 \qquad (2)$$

$$\triangle H=3mmHg: U_2= -0.4H_2+50 \qquad (3)$$

$$\triangle H=4mmHg: U_3= -0.26H_3+40 \qquad (4)$$

$$\triangle H=5mmHg: U_4= -0.2H_4+36 \qquad (5)$$

The data were selected to enable these 4 lines to approach the 4 curves in Fig.11 as closely as possible.

Based on the above relationship of input voltage and the pump head, a heart pump control system was designed, then the heart pump head was computed by neutral network and was sent to MCU to control the blood pump input voltage. Thus the sensitivity of flow rate change with pressure head variation was increased.

C. Results

This control system is divided into four modes: 2mmHg, 3mmHg, 4mmHg and 5mmHg mode. The 2mmHg mode refers to the blood pump head changing about 2mmHg when the flow rate changes 1L/min, and so on.

The improved control system was used in exemplary experiments to measure the relationship between heart pump head and flow rate in each mode respectively. Then it was compared with the curve measured under 16V constant voltage and 3500r/min constant rotating speed (Figure 12 , 13 , 14 ,15).

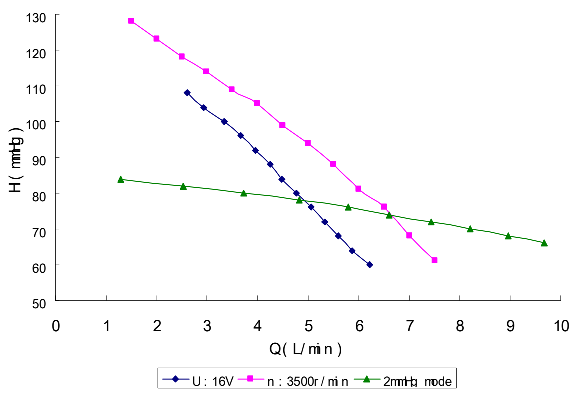

Figure12. The curve of 2mmHg mode compared with constant voltage and constant rotating speed.

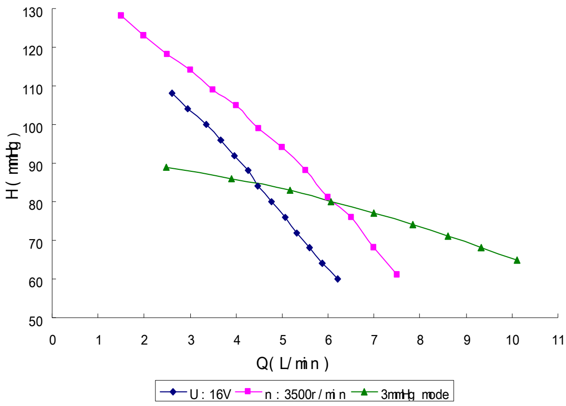

Figure13. The curve of 3mmHg mode compared with constant voltage and constant rotating speed.

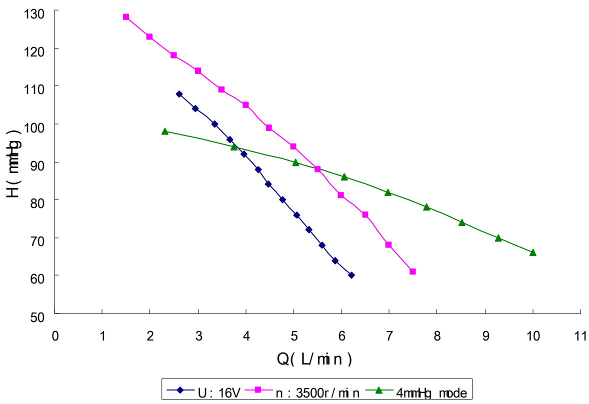

Figure14. The curve of 4mmHg mode compared with constant voltage and constant rotating speed.

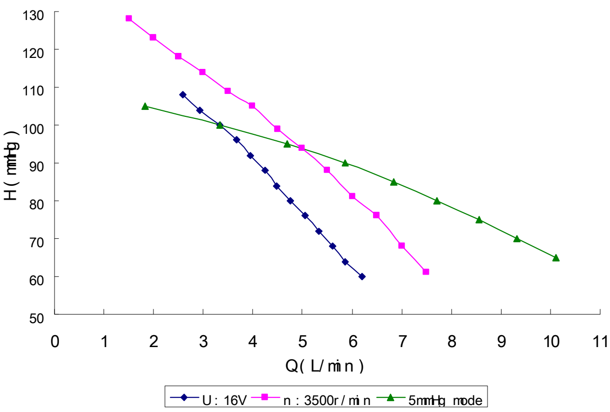

Figure15. The curve of 5mmHg mode compared with constant voltage and constant rotating speed.

IV. CONCLUSION

The method presented in this paper is quite simple but has high accuracy for measuring the pump flow rate and pressure head, and it has been used further to achieve bionic control of the artificial heart, improving the comfortability of the receiptor. The neural network is used to transform some separate data directly measured to continuous function, with which it is possible to obtain the required date by computation in every performance point. Therefore, a simple computation solved a difficult measurement problem, achieved automatic measurement and bionic control of heart pump , represented a significant advance in clinical application research of the heart pumps.

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