World Scientific Research Journal (WSRJ) ISSN: 2472-3703
www.wsr-j.org

Study on Control Algorithms of Nanometer Photocatalytic Banknote Disinfection System

Chuansheng Wu, Yang Xi

University of Science and Technology Liaoning, China.

Abstract: According to the characteristics of wind field control system such as delay and uncertainty, hydrodynamics theory and modern control theory are used to design and achieve a practical wind field control system. Firstly, the mathematical model of the wind speed distribution of the system is analyzed from the angle of hydrodynamics. Then the Galerkin method is used to turn it into state space expression in lumped parameter form. Finally, through the estimation of the system state and optimal control, the wind field uniformity control is implemented. The simulation results show that this algorithm has good robustness and anti- interference ability.
Keywords: wind field control; hydrodynamics; Galerkin method; optimal control.

---

1. INTRODUCTION

In modern society, friendly living environment and fresh paper money are being pursed more and more urgently. Therefore, the development and application of paper money Sterilizing disinfection system is being concerned, its market demand continues to improve. In such system, the control of its internal paper money flow is directly related to the effect of paper money Sterilizing. Previous studies mainly focus on the control of the average wind speed. Where Li Yin made a more systematic summary of the traditional PID algorithm-based fan control [1] , Li Ke, who design an expert - fuzzy PID control system, he introduced the intelligent control and made some innovations [2] , B R Sorensen, who gives full consideration to low-carbon, environmental and other factors, designs a more energy-efficient fan control strategy, and makes the fan more energy efficient through the control [3].
However, due to the wind speed in space is not evenly distributed; the results obtained by the average wind speed is in fact valid only for some local area of the system, when Considering the overall system performance, control of gas flow of surface uniformity is very important, which is rarely seen in previous research. In the field of industrial control, wind power, aerospace, the uneven distribution of wind speed will have a big impact on the scientific research and product performance. Thus, the wind even control problems must be taken seriously.

Considering the above factors, this paper presents a control algorithm based on the hydrodynamic theory and optimal control methods, analysis of the performance of the algorithm, in order to get the satisfactory performance of the control system.

2. SYSTEM ARCHITECTUREDESIGN AND MATHEMATICAL MODELING

A. System Architecture Design and Analysis

Design the system architecture model, according to the flow field in photo catalytic paper money Sterilizing disinfection system, which is shown as

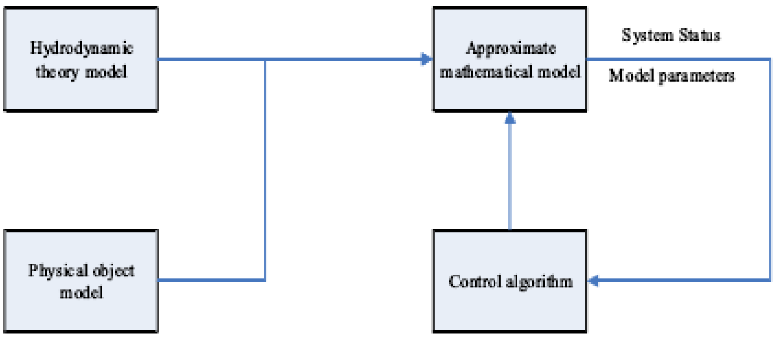

Figure 1. Systems architecture design diagram

After getting theoretical model, it should be fixed to the real system model by adjusting some parameters. Introduced the model initial conditions and boundary conditions, constitute the boundary conditions of the problem. By the theoretical properties of these constraints and system itself, it can guarantee the closed nature of the system model equations [4]. Finally, design a suitable control algorithms based on the system mode for the real-time and closed-loop control of the system. In order to get a more uniform distribution of flow field, to improve the overall system disinfection performance.

Through experimental determination, the effect of the photo catalytic Sterilizing achieve the best when wind speed around 0.8m/s, as is Shown in Figure 2. Therefore, wind speed should be controlled close to the optimal wind speed, which could improve the disinfection efficiency. The control algorithm is what these paper tries to figure out.

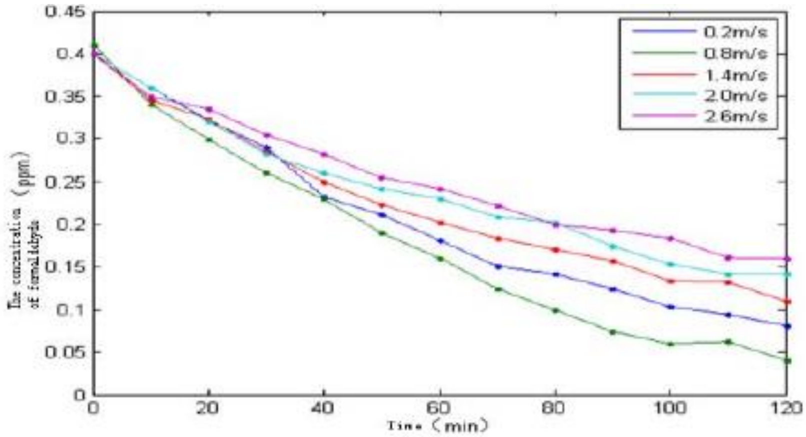

Figure 2. relationship diagram between Photo catalytic effect and wind speed (25 ° C)

B. The mathematical model based on the N-S equations

As the object fluid flow is low, assume that the fluid object incompressible viscous fluid. Wind speed in the chamber fits the parabolic distribution. Then take the inertial frame of reference for the study, describe the object fluid in Euler mode. Paper money gravity is so tiny that could be ignored.

Take the fan force as the major force, and the fluid system is laminar flow model. According to the basic fluid mechanics equations andcommon model, take the viscous incompressible closedequations of fluid as the model of the system. Simplifiedform of formula is shown in (1).

$$\frac{D\vec{V}}{Dt} = \frac{1}{\rho}\nabla\vec{p} + \frac{\mu}{\rho}\nabla^2\vec{V} \tag{1}$$

Where,' is the Hamiltonian operator, ois velocity vector, andoo , '˜ ww ois material derivative, ois surface force, here mainly refers to the upward traction on the fluid from fans, density U constant, viscosity P constant. This is the N-S equation for the paper money flow in this paper. Expand material derivative and Hamiltonian operator, and then get the partial derivative of time and the velocity vector on the three-dimensional coordinates. As the fluid inthis paper is the Z-axis of laminar flow, the velocity vector in both directions in the x, y component is zero. Simplified
form of formula is shown in (2)

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial z} = \frac{1}{\rho}\left(\frac{\partial p}{\partial x} + \frac{\partial p}{\partial y} + \frac{\partial p}{\partial z}\right) + \frac{\mu}{\rho}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) \tag{2}$$

According to the law of conservation of mass, fluid continuity equation could be in this form: ˜'o[4].Meanwhile the component of the velocity vector in the direction of x, y is zero, then ww. In addition, under the assumption that in this system, forces from the fan on the fluid surface only have an effect in the z direction. Mathematic expression could be made further simplified. Use ideal wind speed distribution to estimate the surface force, then it could take the surface forces for the parabolic equation [4]. Beginning with the one-dimensional wind speed distribution, take wwU, andUP . Then the N-S equation of the system can be expressed as 3

$$\frac{\partial u}{\partial t} = a^2\frac{\partial^2 u}{\partial x^2} + p(x,t) \tag{3}$$

C. The application of the Galerkin method

Solving the system theoretical model using methods of mathematical physics, transform the system model into a form of that control theory can be used to solve. Giving the boundary conditions that component of the gas flow rate on the chassis wall must be zero, and the problem can be described as 4

$$\begin{cases} u_t - a^2 u_{xx} = p(x,t) \\ u\big|_{x=0} = 0, u\big|_{x=l} = 0 \end{cases} \tag{4}$$

This is actually the typical finite pole of heat conduction problem in mathematical physics method. In this system, refers to the max length in x axis, which measures . Take , and . Where and can be figured out through the system fitting method. Then Consider the Galerkin method to solve the Boundary Value Problems 1) Select a relatively complete set of functions, like{ , ,⋯, ,⋯}.2) Take a linear combination as the approximate solution of the equation. can be expressed as this (5)

$$u_k(x,t)=\sum_{i=1}^{k}\lambda_i(t)\cdot v_i(x)=\sum_{i=1}^{k}\lambda_i(t)\cdot x^i(l-x) \tag{5}$$

Where O to be determined, substitute into (4), and then get (6)

$$\sum_{i=1}^{k}\frac{d(\lambda_i(t))}{dt}v_i(x)=a^2\sum_{i=1}^{k}\lambda_i(t)\frac{d^2(v_i(x))}{dx^2}+q(x)f(t) \tag{6}$$

3) Use the components of to multiply the above equation on both sides. Doing the integral in the region, get (7)

$$\begin{aligned}&\int_D\begin{pmatrix}v_1(x) & v_2(x) & \dots & v_k(x)\end{pmatrix}\cdot v_i(x)dx\begin{pmatrix}\dot{\lambda}_1(t)\\ \dot{\lambda}_2(t)\\ \dots\\ \dot{\lambda}_k(t)\end{pmatrix}\\ &=a^2\int_D\begin{pmatrix}\frac{d^2(v_1(x))}{dx^2} & \frac{d^2(v_2(x))}{dx^2} & \dots & \frac{d^2(v_k(x))}{dx^2}\end{pmatrix}\cdot v_i(x)dx\begin{pmatrix}\lambda_1(t)\\ \lambda_2(t)\\ \dots\\ \lambda_k(t)\end{pmatrix}\\ &+\int_D q(x)v_i(x)dx\cdot f(t)\end{aligned} \tag{7}$$

with each element of the u dimensional coefficient matrix, and then the partial differential equations can be turned into ordinary differential equations. Choose ,and Substitute it into the expression of and ,gets:

$$\begin{aligned}&\int_0^l\begin{pmatrix}x^2(l-x)^2 & x^3(l-x)^2 & x^4(l-x)^2\\ x^3(l-x)^2 & x^4(l-x)^2 & x^5(l-x)^2\\ x^4(l-x)^2 & x^5(l-x)^2 & x^6(l-x)^2\end{pmatrix}dx\begin{pmatrix}\dot{\lambda}_1(t)\\ \dot{\lambda}_2(t)\\ \dot{\lambda}_3(t)\end{pmatrix}\\ &=a^2\int_0^l\begin{pmatrix}-2x(l-x) & 2x(l-3x)(l-x) & 6x^2(l-2x)(l-x)\\ -2x^2(l-x) & 2x^2(l-3x)(l-x) & 6x^3(l-2x)(l-x)\\ -2x^3(l-x) & 2x^3(l-3x)(l-x) & 6x^4(l-2x)(l-x)\end{pmatrix}dx\begin{pmatrix}\lambda_1(t)\\ \lambda_2(t)\\ \lambda_3(t)\end{pmatrix}\\ &+\int_0^l\begin{pmatrix}x(l-x)(b(x-l/2)^2+c)\\ x^2(l-x)(b(x-l/2)^2+c)\\ x^3(l-x)(b(x-l/2)^2+c)\end{pmatrix}dx\cdot f(t)\end{aligned} \tag{8}$$

Take, and In Fluid Mechanics, when the temperature is 300K, the paper money dynamic viscosity is Pu, density is U, and then u . Take the inverse of the derivative coefficient matrix of O, and multiply on both sides of the equation (8). By doing all these, system model can be expressed in the flowing form 9

$$\dot{\lambda}=A\lambda+Bf \tag{9}$$

Where,

$$A = \begin{pmatrix} -1.7808 \times 10^{-3} & 2.2260 \times 10^{-4} & -1.4310 \times 10^{-4} \\ 1.0685 \times 10^{-2} & 0 & 2.6712 \times 10^{-3} \\ -2.1370 \times 10^{-2} & -5.3424 \times 10^{-3} & -8.0136 \times 10^{-3} \end{pmatrix} \tag{10}$$

$$B = \begin{pmatrix} 24.8072 & -208.3836 & 416.7672 \end{pmatrix}^T$$

It is obvious that by using Galerkin method to simplify the system theory model, state space equation of modern control theory is easy to get.

3. DESIGN OF CONTROL ALGORITHM

A. Methods of modern control theory based on state feedback

State feedback can provide richer state information and more available Degrees of freedom, which make the system achieve better performance in control, so use the state feedback for closed-loop control. However, the system state variables often cannot directly detect, which requires some means of estimating. Here expands the wind speed distribution in the spatial domain, and mesh the solution region Use of the finite element method. Take the four regions which are meshed by three measurement points and border demarcation as the grid, denoted as .

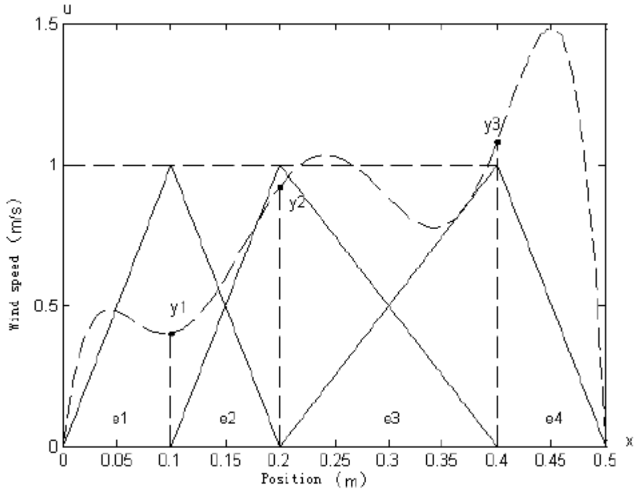

Figure 3. Schematic diagram of the wind speed distribution Basis function sin spatial domain base

Where, is the data from three measurement points, two segments at the measurement point is a set of basis functions, denoted as . The wind speed distribution in the spatial domain can be expanded as shown in the form of (11):

$$u(x,t) = \sum_{i=1}^{3} X_i(x) y_i(t) \tag{11}$$

Construct wind speed interpolation function on each interval, using linear interpolation, gets:

$$\begin{cases} u_j = a_1 + a_2 x_j \\ u_m = a_1 + a_2 x_m \end{cases} \tag{12}$$

Where, j and m are Interval endpoints. Calculate and from Figure 3. Get wind speed interpolation function oneach region as follows:

$$\begin{cases} u_1 = 10y_1 \cdot x \\ u_2 = (2y_1 - y_2) + (-10y_1 + 10y_2)x \\ u_3 = (2y_2 - y_3) + (-5y_2 + 5y_3)x \\ u_4 = 5y_3 - 10y_3 \cdot x \end{cases} \tag{13}$$

Organize (13). Get the expression of as shown in (14):

$$\begin{cases} X_1(x) = \begin{cases} 10x & 0 \le x < 0.1 \\ 2 - 10x & 0.1 \le x < 0.2 \end{cases} \\ X_2(x) = \begin{cases} 10x - 1 & 0.1 \le x < 0.2 \\ -5x + 2 & 0.2 \le x < 0.4 \end{cases} \\ X_3(x) = \begin{cases} -1 + 5x & 0.2 \le x < 0.4 \\ 5 - 10x & 0.4 \le x \le 0.5 \end{cases} \end{cases} \tag{14}$$

Define the indicator function:

$$J_e = \int_D (\sum_{j=1}^{3} X_j(x) y_j(t) - \sum_{k=1}^{3} x^k (l - x) \lambda_k(t)) X_i(x) dx = 0 \tag{15}$$

Get a set of relationship between measuring the output and estimated state.as shown:

$$\begin{cases} \int_0^{0.5} X_1(x) \sum_{j=1}^{3} X_j(x) y_j(t) dx = \int_0^{0.5} X_1(x) \sum_{k=1}^{3} x^k (0.5 - x) \lambda_k(t) dx \\ \int_0^{0.5} X_2(x) \sum_{j=1}^{3} X_j(x) y_j(t) dx = \int_0^{0.5} X_2(x) \sum_{k=1}^{3} x^k (0.5 - x) \lambda_k(t) dx \\ \int_0^{0.5} X_3(x) \sum_{j=1}^{3} X_j(x) y_j(t) dx = \int_0^{0.5} X_3(x) \sum_{k=1}^{3} x^k (0.5 - x) \lambda_k(t) dx \end{cases} \tag{16}$$

Substituting (14) into (16), get the following relations:

$$\begin{pmatrix} y_1 \\ y_2 \\ y_3 \end{pmatrix} = \begin{pmatrix} 0.04114 & 0.00308 & 0.00017 \\ 0.06541 & 0.01367 & 0.00257 \\ 0.04570 & 0.01894 & 0.00756 \end{pmatrix} \begin{pmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \end{pmatrix} \tag{17}$$

(17) Gives the relationship matrix of the system output and system state. This relationship is based on (15), the purpose is to estimate the system state according to the output of the three measurement point. The interpolation function maintain continuous, that is, satisfy the compatibility conditions, for using a linear interpolation. Therefore, the calculation of the expansion of different forms can get the estimate of system state, which solves the problem of undetectable system's state that is used as feedback.In normal circumstances, state feedback matrix can be figured out, using the state estimates. But the control objective, in this system is the uniformity of the wind surface.It is unable to determine the Pole assignment expectations of the matrix . Optimal control theories should be introduced into the problem.

B. Optimal control algorithm

Use the energy and the error of the system to construct the linear quadratic, and design an infinite time state regulator to control the system. According to the estimation of system state space expression, take the performance functional as follows:

$$J = \frac{1}{2}\int_0^{\infty}(x^T Q_1 x + u^T Q_2 u)dt \tag{18}$$

In the functional of performance, error vector is equivalent to the system state vector O and estimates O., which denotes the control constraints in the dynamic control process, is equivalent to the control volume fin the actual system. and represent the intensity of the controller. , , [1] • ¨ ¨ © § , =1, then:

$$J = \frac{1}{2}\int_0^{\infty}(3\lambda_1^2 + 4\lambda_2^2 + f^2)dt \tag{19}$$

Infinite time state regulator requires that the system can completely control, so the controllability of the system need to be verified. The rank of controllability matrix is , so this system is not completely controllable. The necessary and sufficient condition forlinear time-invariant system which can be stabilization when it is used state feedback for controlling is that the uncontrollable subsystem is asymptotically stable [8]. Therefore, decompose the system in accordance with the controllability. The result shows in (20). The relationship between the output of the system and the system state shows in (21).For the feature of one-dimensional control subsystem is negative, this system is stabilization.

$$\dot{\hat{\lambda}} = \begin{pmatrix} 0 & 3.4615\times10^{-4} & 0 \\ 1 & 0.0564 & 0.0115 \\ -5.4629 & -0.3258 & -0.0661 \end{pmatrix}\hat{\lambda} + \begin{pmatrix} 0 \\ 1 \\ 85.2 \end{pmatrix} f \tag{20}$$

$$\begin{pmatrix} y_1 \\ y_2 \\ y_3 \end{pmatrix} = \begin{pmatrix} 0.45081 & -0.00241 & 0.00017 \\ -0.15689 & 0.00195 & 0.00257 \\ 0.33687 & -0.00159 & 0.00756 \end{pmatrix}\begin{pmatrix} \hat{\lambda}_1 \\ \hat{\lambda}_2 \\ \hat{\lambda}_3 \end{pmatrix} \tag{21}$$

Consider the question of the applicability of the optimal control method. The control exerted within a limited time is able to make the controllable components back to the zero state from the non-zero status, when it comes to the controllable subsystem. And the uncontrollable subsystem is asymptotically stable. So it is feasible to exert the state feedback control on the system. Set the system matrix and control matrix, respectively c and c , and the controllable subsystem expression as follows:

$$\dot{\hat{\lambda}}' = \begin{pmatrix} 0 & 3.4615\times10^{-4} \\ 1 & 0.0564 \end{pmatrix}\hat{\lambda}' + \begin{pmatrix} 0 \\ 1 \end{pmatrix} f \tag{22}$$

and are both positive definite, so the optimal control could be:

$$u^*(t) = -Q_2^{-1}B'^T P\hat{\lambda}'(t) = -1\begin{pmatrix}0 & 1\end{pmatrix}\begin{pmatrix}p_{11} & p_{12}\\ p_{12} & p_{22}\end{pmatrix}\begin{pmatrix}\hat{\lambda}_1(t)\\ \hat{\lambda}_2(t)\end{pmatrix} \quad (23)$$

$$= -p_{12}\hat{\lambda}_1(t) - p_{22}\hat{\lambda}_2(t)$$

Here the matrix P is the positive definite solution of the
Riccati algebraic equation c c cc
Under the condition that P is ensured to be positive definite, the solution is, , ¹ • ¨ ¨ © § u. Hence 734the optimal control is OO ,and the optimal feedback gain matrix K is c . According to the optimal control theory and previous discussion, it is known that this closed-loop system is stable. The structure of the completed closed-loop system is shown in figure 4, with the closed-loop system state equation as OO c, , ¹ • ¨ ¨ © § uc ˜.

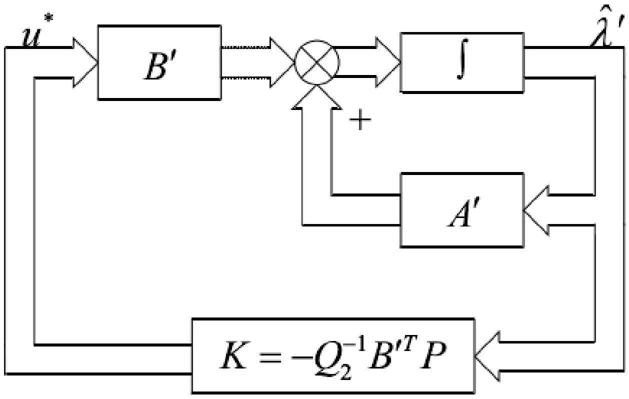

Figure 4. Structure of closed-loop system of wind surface control algorithm basing on the model

4. SYSTEM SIMULATION AND PERFORMANCE ANALYSIS

In order to verify the control performance of the designed algorithm, the system is simulated with Simulink in Matlab 2007b, and a system output curve is drawn. Figure 5 compares the control performance of the new algorithm and the traditional PID algorithm.

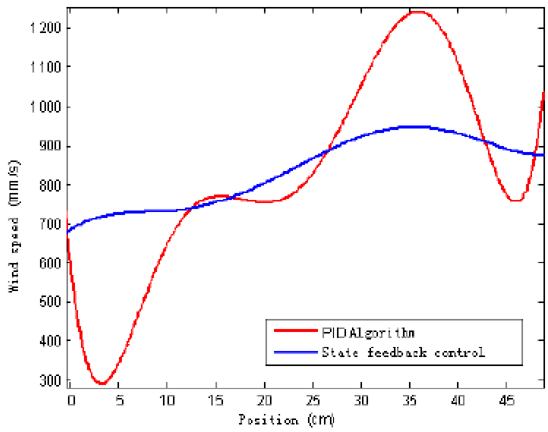

Figure 5. The comparison chart of wind surface uniformity from different algorithm

It can be seen that the uniformity of the wind field distribution has been further improved compared with the original condition. The application of new designed algorithm to photo catalytic paper money Sterilizing and disinfection system will increase its overall performance. In this case, the selection of wind speed value in three measurement points for control, respectively , and ,has its reasons. As is shown in the red curve of figure 5, these three points respectively represent the low, gentle and high points of the curve, which possess the most representative features. Therefore, in order to avoid the system calculating a large dimension, choosing these three points to control is most representative, which gets a better performance. We have tried to change the different parameter, and the control effect has proved this idea.

5. CONCLUSION

This research is based on the Nano Photo Catalytic Paper money Sterilizing and Disinfection System In practical applications. This paper proposes the wind surface control problem aiming at the project needs, and makes certain exploration on the control algorithm and finally gives certain solution, which is rare in the previous existing researches. On the basis of the N-S equation, this paper makes the best of the Galerkin method idea to simplify the complex system models. Through the comparison of wind speed distribution in the time domain and space domain, this paper solves the system state estimation problem and realized the optimal control through state feedback. The result of the system simulation shows that the designed control algorithm could meliorate the wind speed distribution in wind farm to some extend and increase the overall performance of the system on site.

From another perspective, the proposed wind farm control algorithm is still available for further improvement. For example, the control of the wind farm can be further extended to higher dimensional space; the viscous fluid laminar flow model can be established into higher mode curve; the estimation method of control system state can be further improved, etc. In addition, if the designed algorithm is applied to the system on site and achieves good effect, great progresses will be made in the theoretical research and engineering application of fluid motion control area.

REFERENCES

[1] Li Yin, PID control algorithm and its application in wind speed control Huazhong University of Science and Technology, 2007. (in Chinese).

[2] Li Ke, Liu Wangkai, Wang Jun, Experts - Fuzzy PID in the low-speed wind tunnel speed control system (in Chinese).

[3] Sorensen B R. An energy efficient control strategy for fan static pressure difference[C]. International Conference on Consumer Electronics, Communications and Networks, 2011: 4736-4739.

[4] Lin Jianzhong, Ruan Xiaodong, Chen Bangguo, Fluid Mechanics,Tsinghua University

Press, 2005, 9. (in Chinese) .

[5] Zhao Linning, Huang Xiang, Di Yuhui, ACF material with nanometer Ti O2 paper money Sterilizing performance, Xi'an Engineering Institute of Technology Journal, 2006(4): 437−439.

[6] Yan Guifeng, Methods of Mathematical Physics, Beijing Institute of Technology Press, 2009.6. in Chinese).

[7] Cha Zhongwei, Partial differential equations of mathematical physics, Southwest Jiaotong University Press, 2006.7. in Chinese).

[8] Liu Bao, Tang Wangsheng, Modern control theory, Mechanical Industry Press, 2006.6. in Chinese) 735.