MODELING AND SIMULATION FOR A VARIABLE SPRAYER RATE SYSTEM

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Abstract: Variable spraying technology is an important content and developing direction in current plant protection machinery, which can effectively save pesticide and lighten burden of ecological environment in agriculture according to characteristic of spraying targets and speed of aircraft crew. Paper established mathematic model and delivery function of variable spraying system based on designed hardware of variable spraying machine, making use of PID controlling algorithm to simulate in matlab. Simulating result explained that the model can conveniently control gushing amounts and can arrive at satisfied controlling.

Keywords: spraying system; variable spraying; matlab simulation

1. INTRODUCTION

So far, although biological measures for crop protection has attracted more attentions, chemistry prevention is still the fastest and most economical cure measure for disease and weeds. Using routine spraying machine to spray pesticide is the most common spraying technology, but the entire field has been continued splashing in the process of spraying which has not only brought about pesticide waste, but also brought about environmental pollution.

Lots of scholars have carried out a large quantity of study to reduce pesticide deposition outside targets and improve utilization rates of spraying medicine both at home and abroad. D.K. Giles et al.(1997) have developed a kind of machine system that can spray for targets in line. The optic guiding device of the system controls sprayer to locate above the crop, and the mechanical member which controlled by electric power has made the sector sprayer go round central shaft rotate in order to change deflection angle for sprayer. These measures ensured that the fog droplet distribution width could consistent with crop width to cover with the crop commendably, and decrease pesticide waste and environmental pollution. Sadjadi et al. (1997) have invented a kind of real time identification machine about weed, which can spray targets by actuating mechanism; Doruchowski et al. (1998) has developed a kind of spraying machine system which can selectively spray crop in orchard and field; Slaughter D.C. et al. (1999) have developed a kind of machine system for target which can spray pesticide for trees on roadway, and the system is composed of a machine optic system which has a rapid response. The sprayer can selectively spray according to the allocation. Rongben Wang et al. (2001) have designed a kind of intelligent machine system about fertilizing maize based on computer vision. The system can make science decision for spraying dosages of pesticide by building state image database in the process of corn growth and corn growth process image information which has been collected real time and using the computer expert decision-making system, so that it can complete spraying assignment by automation navigation of tractor and of auto control discharging machinery. Maocheng Zhao et al. (2003) have designed the variable spraying control system based on characteristic image which can precisely spray medicine for targets of tree. According to the growth characteristic of different kinds of tree, planting density and the handling resultes of the crown images of a tree, the computer controls sprayer to carry out spraying on targets accurately. Xiongqui He et al. (2003) have designed a kind of automatic electricity spraying machine of orchard which adopted infrared sensing technology to probe targets. In this system, continuous traditional spraying was changed to the automatic toward-target spraying.

Being compared with and routine large area spraying machine, automatic spraying methods to targets can effectually decrease dosages of pesticide and increase rates of droplet deposition about targets crop. Because the flow rate about spraying system is constant, it can gain comparatively good prevention and cure effect under less condition of change of spraying target characteristic and the aircraft crew speed. But it is difficult to guarantee spraying result under more condition of change of spraying target characteristic and the aircraft crew speed.

The author designed a variable spraying system in order that we can independently adjust spraying dosages according to characteristic change of spraying objects and change of aircraft crew speed. At the same time, the fog droplet dimension and spraying distribution mass do not change. The system consists of machine optesthesia system and variable spraying system. The paper established mathematic model of variable spraying system based on designed variable spraying system, adopted PID control algolithm to simulate for the model by matlab and got more satisfied controlling result.

2. OPERATING PRINCIPLE OF VARIABLE SPRAYING SYSTEM

CCD telecamera was been assembled in front of spraying machine in order to get image information of spraying targets. We adopted radar sensor to measure speed signal of an aircraft crew. Implantation computer handled picture signal gained and speed signal in real time, and the handled result is gaven to the controller which controlles entering liquid switch action of every shower unit about spraying system respectively so that it can realize independent variable spraying of every spraying element.

Every spraying element is composed of 3 electromagnetic valve and 3 standard sprayer which have different spraying amounts. These sprayers are assembled on spraying poles of spraying machine. The 3 electromagnetic valve control every sprayer respectively and the stress of sprayers is determined by electro-hydro proportion relief valve. According to handled result, the computer sends out “on” and “off” signal for every electromagnetic valve by I/O module. Different combination of 3 electromagnetic valves can realize 8 combination of working state. So we can realize 7 spraying amounts.

3. MATHEMATIC MODEL OF THE VARIABLE SPRAYING SYSTE

3.1 Establish mathematic model of electromagnetic valve

The following elements are neglected in establishing model: loop resistance coefficient; loop magnetic leakage; changes about medium magnetic induction; effects of the system resistivity and effects of magnetic inductivity on temperature.

The equilibrium equation:

$$m\ddot{x}_v + c\dot{x}_v = K_F i^2 - k(x_v + x_0) \tag{1}$$

In the equation： $K_F = \dfrac{N^2 \mu \times 10^7}{8\pi[l_H + 2\mu(x_{v\max} - x_v)/\mu_0]}$

Magnetic loop equation: $iN = Hl_H + H_0\delta = Hl_H + H_0(x_{v\max} - x_v)$ (2)

$$H\mu = H_0\mu_0$$

Electric current equation:

$$\begin{cases} u_c = R_L i + \varepsilon_L & 0 \le t \le t_p \\ (R_L + R + R_D)i + \varepsilon_L = 0 & t_p \le t \le T \end{cases} \tag{3}$$

Magnetism equation: $\phi = s_0\mu_0 H_0 = s_0 \mu H$ (4)

Induced E. M. F equation EMF: $\varepsilon_L = N\dfrac{d\phi}{dt}$ (5)

(2), (4)and(5) has been finished and linearized ,the result is as follows:

$$\varepsilon_L = K_i \frac{di}{dt} + K_x \frac{dx_v}{dt} \tag{6}$$

In the equation: $K_i = \dfrac{N\phi}{i} = L;$

$$K_x = \frac{H_0^2 s_0 \mu_0}{i}$$

The result is the following equation:

$$\begin{cases} m\ddot{x}_v + c\dot{x}_v = K_F i^2 - k(x_v + x_0) \\ u_c = R_L i + K_i \dfrac{di}{dt} + K_x \dfrac{dx_v}{dt} & 0 \le t \le t_p \\ x_v(0) = 0 \quad ; \quad i(0) = 0 \\ \dot{x}_v(0) = 0 \quad ; \quad \ddot{x}_v(0) = 0 \quad ; \quad \dot{i}(0) = 0 \end{cases} \tag{7}$$

$$\begin{cases} m\ddot{x}_v + c\dot{x}_v = K_F i^2 - k(x_v + x_0) \\ (R_L + R + R_D)i + K_i \dfrac{di}{dt} + K_x \dfrac{dx_v}{dt} = 0 \qquad\qquad t_p \le t \le T \\ x_v(0) = x_{v\max} \quad ; \qquad i(0) = \dfrac{u_c}{R_L} \\ \dot{x}_v(0) = 0 \quad ; \qquad \ddot{x}_v(0) = 0 \quad ; \qquad \dot{i}(0) = 0 \end{cases} \tag{8}$$

(7) and (8) has been transformed by Rumsfeld and gained following results：

$$\begin{cases} (ms^2 + cs + k)X_v = K_F i^2 - kX_0 \\ U_c = (R_L + K_i s)I + K_x s X_v \qquad\qquad 0 \le t \le t_p \\ x_v(0) = 0 \quad ; \qquad i(0) = 0 \\ \dot{x}_v(0) = 0 \quad ; \qquad \ddot{x}_v(0) = 0 \quad ; \qquad \dot{i}(0) = 0 \end{cases}$$

$$\begin{cases} (ms^2 + cs + k)X_v = K_F i^2 - kx_0 \\ (R_L + R + R_D)i + K_i \dfrac{di}{dt} + K_x \dfrac{dx_v}{dt} = 0 \qquad\qquad t_p \le t \le T \\ x_v(0) = x_{v\max} \quad ; \qquad i(0) = \dfrac{u_c}{R_L} \\ \dot{x}_v(0) = 0 \quad ; \qquad \ddot{x}_v(0) = 0 \quad ; \qquad \dot{i}(0) = 0 \end{cases}$$

Parameter meanings in equation:
m: slide valve mass; c: equivalent damp;
k: spring stiffness;
x_v: slide valve displacement;
x_0: spring compressing amounts in advance;
R_L: coil electric resistance;
R_D: diode electric resistance;
l_H: magnetic materials closed circuit length；
σ: air gap；
s_0: intercepts area of gap air；
μ: induced modulus of magnetic materials；
μ_0: air magnetic induction modulus；
Φ: circuit magnetism；
ε_L: Induced E. M. F

i: the current in the coil;
N: Coil turns;
H: magnetic field strength;
H_0: air magnetic field intensity;
k_F: Current-force conversion factor
The electromagnetic valve system consists of two non-linear links:
(1) Square links;
(2) Saturated and close links of Spool displacement, $0 \le x_v \le x_{v\max}$;

The transfer function block diagram were gained when the electromagnetic valve opened and closed by equation (7)and (8), figure 1 and figure 2 are as follows:

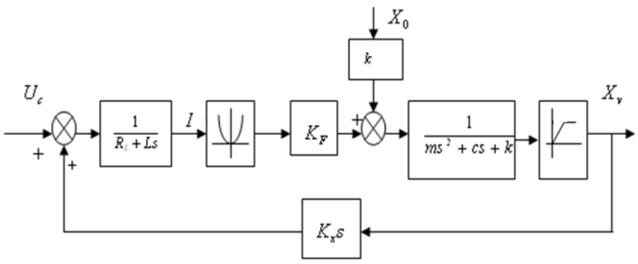

Fig.1: The transfer function block diagram when the electromagnetic valve is closed

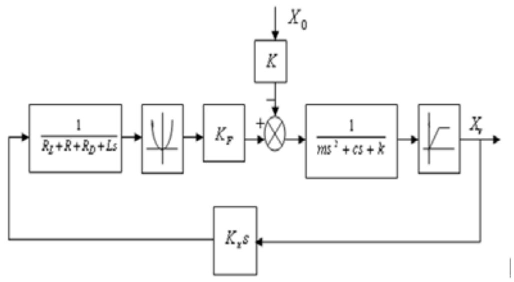

Fig.2 The transfer function block diagram when the electromagnetic valve is opened

Opened process of electromagnetic valve has been simulated by making use of MATLAB software, figure 3 was the simulation results. Transition process response time of opened process about electromagnetic valve was about 0.11s and equivalent to 9HZ, which can meet the system requirements of object. The two nonlinear part of electromagnetic valve system were almost no impact to response from simulation result. In fact, electromagnetic valve can avoid nonlinear effect if electromagnetic valve is took appropriate control. It will not have aborting and saturation phenomenon if we control spool within the scope of work. Nonlinearity of square category can be overcome by adopting small range linearization or method of inserting value.

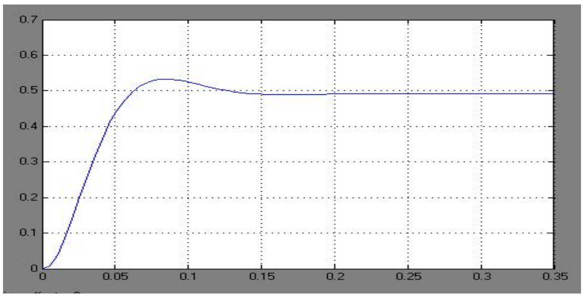

Fig.3 Response curve electromagnetic valve is opened

3.2 Establish mathematic model of variable spraying system about level

Dynamic response frequency of proportional valve pilot stage is very high, proportioning valve for response frequency under 10Hz can be regard as a proportional component (Yongxiang Lu, 1987). Delivery function block diagram of electro-hydro proportion relief valve is figure 4.

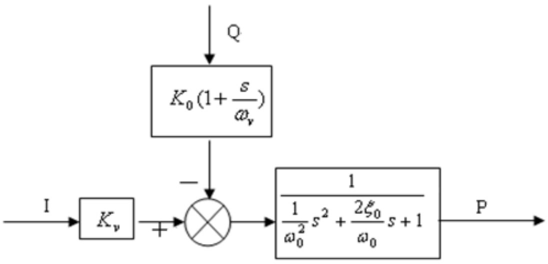

Fig.4 Delivery function block of electro-hydro proportion relief valve

According to operating principle of automatic level variable spraying system, the shower nozzle consists of three closure devices of different fixed damming mouth, taking *Kq*=0 and regarding other parameters as modulus of equivalent mass, equivalent damp, equivalent spring stiffness, equivalent effective area, and equivalent pressure rate of flow after different shower nozzle combination. Equivalent block diagram of delivery function about shower nozzle is figure 5.

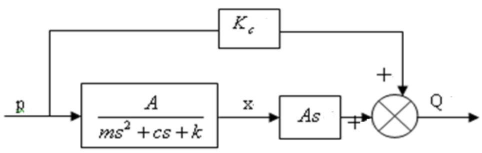

Fig.5 Equivalent block diagram

According to operating principle of level automatic variable spraying system, results are as follows:

(1)Actuating pressure of shower nozzles is decided by electricity liquid proportion valve, therefore, entrance pressure change of shower nozzle (outlet pressure is 0) is same to output pressure of electricity liquid proportion valve.

(2)It gives medicine pump to a part of export the rate of flow, and another part floods by electricity liquid proportion valve. Flow rate of shower nozzle will increase if outputting flow rate of medicine pump is invariable, which means flow rate of that electricity liquid proportion valve floods will decrease. In a word, change amounts (increasing amounts and decreasing amounts) are equal.

According to above analysis, lock diagram of entire system was gained by linking with figure 4 and figure 5, block diagram of entire system is figure 6.

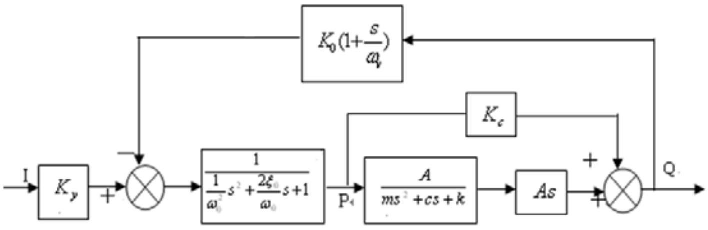

Fig.6 Block diagram of level variable spraying system

4. SIMULATION RESULTS AND ANALYZING OF SYSTEM

Simulating model is figure 7 when a spraying shower nozzle works.

Step response result is figure 8 by matlab simulating. When the steady state accuracy of system is 2%, response time of transition process is 0.208s, surpassing amount of system is 10%. Analyzing result of system frequency is figure 9.The system is stable, and bandwidth is 44.5rad/sec, about 7Hz, which is consistent with frequency of proportion flooding valve. It explained that characteristic of proportion flooding valve decides entire systematic characteristic and system is able to satisfy actual request.

Front passage of delivery function from P to Q about delivery function changed when 2 and 3 shower nozzles worked. In a word, delivery function of 2 or 3 shower nozzles were overlayed. Denominator of the delivery function after overlying does not change but molecule changes. The systematic characteristic equation does not change for output of systematic general rate flow, the systematic stability, time respond and frequency respond do not change. The flow rate of output is also different for every shower nozzle because opening aperture amounts are different.

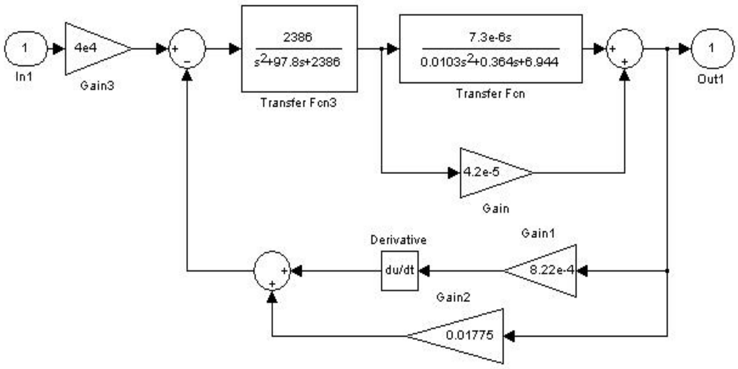

Fig.7 Simulation model of system

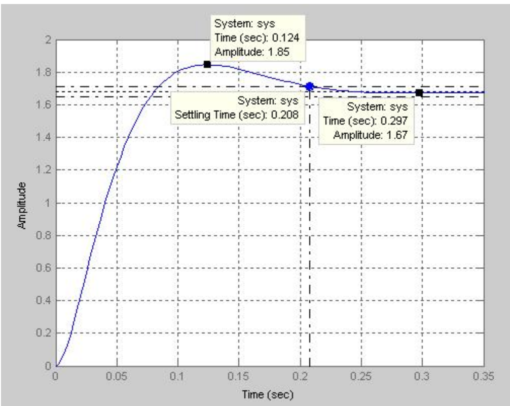

Fig.8 Result of step response

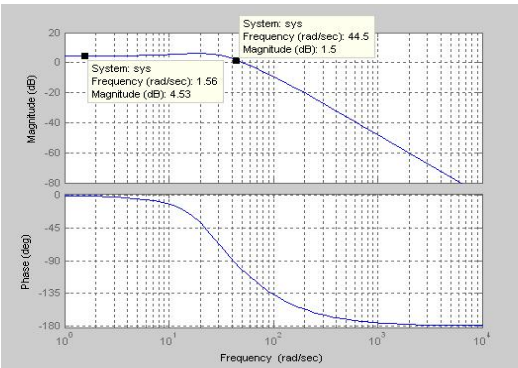

Fig. 9 Analyzing result of frequency

Change mathematic model into state space equation:

$$\dot{X} = AX + BU$$
$$Y = CX + DU$$

In the equation:

$$A = 10^3 \begin{bmatrix} -0.0353 & -0.6742 & 0 & 2.3860 \\ 0.0010 & 0 & 0 & 0 \\ 0 & 0 & -0.1278 & -2.3860 \\ 0 & 0 & 0.0010 & 0 \end{bmatrix} \qquad B = 10^4 \begin{bmatrix} 0 \\ 0 \\ 4 \\ 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 0.0007 & 0 & 0 & 0.1002 \end{bmatrix} \qquad D = [0]$$

Controllable matrix is:

$$P = [B \quad AB \quad A^2B \quad A^3B]$$
$$= 10^{10} \begin{bmatrix} 0 & 0 & 0.0095 & -1.5570 \\ 0 & 0 & 0 & 0.0095 \\ 4 & -0.0005 & 0.0558 & -5.9099 \\ 0 & 0 & -0.0005 & 0.0558 \end{bmatrix}$$

$$rank(P) = 4 = n$$

It can be seen that system is controllable. Standard form of controllable matrix is:

$$A_c = 10^6 \begin{bmatrix} 0 & 0 & 0 & -1.6086 \\ 0 & 0 & 0 & -0.1705 \\ 0 & 0 & 0 & -0.0076 \\ 0 & 0 & 0 & -0.0002 \end{bmatrix} \qquad B_c = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$C_c = 10^7 \begin{bmatrix} 0 & 0.0004 & -0.0445 & 4.4871 \end{bmatrix} \quad D_c = [0]$$

Original systematic zeros are -28.83 and -23.38, poles are -17.67+ 19.02i, -17.67-19.02i,-105 and 227, and open loop gain is 4008.Because system is controllable, we can deploy a pole so that systematic function reach expected function. If systematic poles are supposed -5+20i, -5-20i, -25 and -40, feedback matrix will be K=[0.0001 0.0045 -0.0022 -0.0597]. The step response is figure 10 after systematic poles are deployed again. Comparing with Figure 8 and figure 10, we can know that response time will decrease after deploying poles again, but oscillating function is bad. If we hope that oscillating function is better as well, we can deploy poles again and analyze. Finally, we can gain satisfied results.

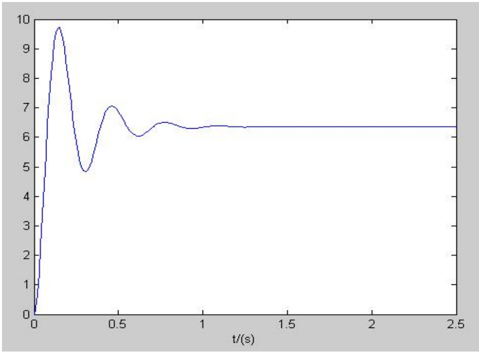

Fig.10 Step response after deploying poles

Observed matrix is :

$$Q = \begin{bmatrix} C \\ CA \\ C^2A \\ C^3A \end{bmatrix} = 10^4 \begin{bmatrix} 0.0001 & 0 & 0 & 0.0001 \\ 0 & 0.0001 & 0 & 0.0002 \\ 0 & 0.0017 & -0.0011 & -0.0299 \\ 0.0002 & -0.0275 & 0.1122 & 2.7495 \end{bmatrix}$$

$$rank(Q) = 4 = n$$

It can be seen that system is observed. Standard form of observed matrix is:

$$A_o = 10^6 \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ -1.6086 & -0.1705 & -0.0076 & -0.0002 \end{bmatrix} \qquad B_o = \begin{bmatrix} 0 \\ 0.0004 \\ -0.0445 \\ 4.4871 \end{bmatrix}$$

$$C_o = [1 \ \ 0 \ \ 0 \ \ 0] \qquad D_o = [0]$$

5. CONCLUSIONS

Paper established mathematic model and delivery function of variable spraying system based on designed hardware of variable spraying machine. We used PID controlling algorithm to simulate with matlab. Simulating results explained that level variable spraying system is stable, and when the steady state accuracy of system is 2%, the response time of transition process is 0.208s, surpassing amount of system is 10%, bandwidth is 44.5rad/sec, about 7Hz, which is consistent with frequency of proportion flooding valve. The system is able to satisfy actual request as well. Controllable nature and observed nature were analyzed for variable spraying system. As a result, system is controllable and observed. We can deploy poles in order to make systematic function reach the best capability according to requirements. Designed system is reasonable, able to satisfy usage request and easy to control.

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