2011 Fourth International Conference on Intelligent Computation Technology and Automation

The Permanent Magnet Linear Synchronous Motor Distribution System Based on Fuzzy PID Control

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Abstract*—Considering the disadvantages of the distribution system, which is made of the rotating machine and the mechanical transmission device, such as low positioning accuracy, vulnerable to load influence, this paper puts forward a new kind of distribution system consists of the permanent magnet linear synchronous motor (PMLSM), which is based on the fuzzy Proportional-Integral-Differential (PID) control. Having researched the equation of the permanent magnet linear synchronous motor on the direct-quadrture (d-q) axis, the paper not only gives the mathematical model of the vector control system, but designs the fuzzy Proportional-Integral-Differential velocity controller. Through the on-line adjustment of the parameters of fuzzy rules, the controlled objects can not only get wide speed range and high repeat positioning accuracy, but also keep the robustness of the outputs in special field conditions. Simulation results show that the control method has a strong perturbation resistance and stability, and the algorithm is also simple.

Keywords-PMLSM; fuzzy PID controller; fuzzy ruler

I. INTRODUCTION

The distribution system in the industrial production is usually a linear motion system, which consists of the rotating machine and the mechanical transmission device, the simplified diagram is as shown as fig.1.it is mainly made of two conveyor belts, distribution bucket and annular chute. The distribution bucket could movement in the chute under the action of the rotating motor car and the mechanical transmission device, sending the materials to the stove through the feed opening. The currently widely used system in the industry is not only difficult to control, but also it has the following defaults: low efficiency, limited load ability, complex structure, and installation and maintenance difficulties. Compared with the above situation, the driving system made of PMLSM can produce large electromagnetic thrust, and its operation is smooth. At the same time, the PMLSM system has the following advantages compared with the linear motion system, which is made of the traditional rotating electrical machine and transmission chain: be convenient to control, nice robustness, simple structure, high efficiency and low noise etc. As a result, the PMLSM system has already be widely used in the industrial production.

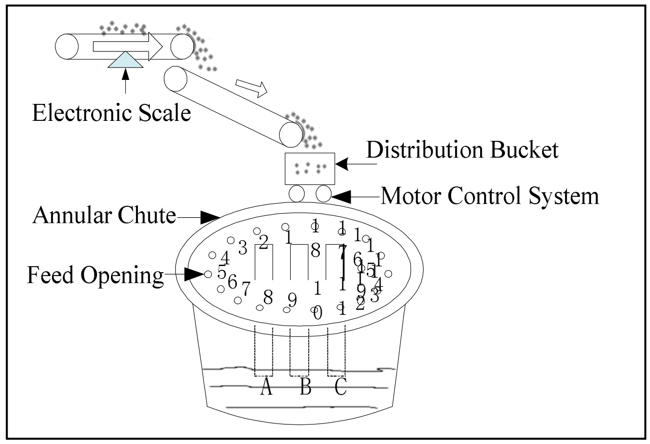

Figure 1. Distribution system

The PID control algorithm is used in great quantities in the Industrial process, but it has a strong dependence on the model of the controlled objects, and the anti-jamming ability is poor. The traits of the distribution system, such as the relatively bigger control overshoot and the long regulating time, makes it not suitable for the need of real-time speed regulation. However, the fuzzy control is not dependent on the mathematical model of the controlled objects, it also has a strong robustness. Furthermore, it has the inhibition on the change of model parameters and the nonlinear disturbances. The proposed fuzzy PID control algorithm in this paper take the input variables, the output error and the variations of the error as the overall input and uses the fuzzy control rules in the online-setting of the parameters. And as a result, the fuzzy PID control algorithm has both extensive applicability and high control accuracy, which is from the traditional control, and the evident adaptable characteristics, which is from the fuzzy control. Simulation results of the fuzzy PID controller show its good performance in terms of the ability of control.

II. CONTROL SYSTEM AND MATHEMATICAL MODEL

The d-q shaft model can be used on the following assumptions: only the first content of the primary magnetic motive force (MMF) is considered, ignoring the magnetic saturation, the stator potential is changed by sinusoidal regular. As the MMF of the permanent magnet is a constant value, and the linear motor sub-prime is without damping

978-0-7695-4353-6/11 $26.00 © 2011 IEEE
DOI 10.1109/ICICTA.2011.592

windings, then the d-q shaft voltage balance equation of the linear motor can be described as

$$U_d = R_s i_d + L_d \frac{di_d}{dt} - \frac{\pi}{\tau} v L_q i_q \tag{1}$$

$$U_q = R_s i_q + L_d \frac{di_d}{dt} - \frac{\pi}{\tau} v (L_d i_d + \psi_{PM}) \tag{2}$$

Where U_d and U_q represents the direct-axis voltage and the quadrature-axis voltage respectively, i_d and i_q represents direct-axis current and quadrature-axis current separately, R_s is the resistance of the armature winding, L_d , L_q denotes the direct-axis and the quadrature-axis synchronous inductance respectively. ψ_{PM} represents the MMF of the permanent magnet, v is the linear velocity of the linear motor, τ is the polar distances.

The expression of the electromagnetic thrust of the PMLSM can be described as

$$F_e = \frac{3\pi}{2\tau} \left[\psi_{PM} + \left(L_d - L_q \right) i_d \right] i_q \tag{3}$$

In the actual system, the mechanical motion equation of the PMLSM is

$$F_e = F_L + B_m v + M_m \frac{dv}{dt} \tag{4}$$

Where F_L is the load resistance, M_m is the total weight of the loads, B_m is the sticky friction coefficient.

In the PMLSM system, through the adoption of the field-oriented vector control and the $i_d = 0$ strategies, the d、q shaft become decoupling, and then the thrust is proportional to the quadrature-axis current i_q . The control diagram of PMLSM is as shown as fig.2, and its dynamic mathematical model is as follows

$$\frac{dv}{dt} = -\frac{B_m}{M_m} v + \frac{3\pi}{2\tau M_m} \psi_{PM} i_q - \frac{F_L}{M_m} \tag{5}$$

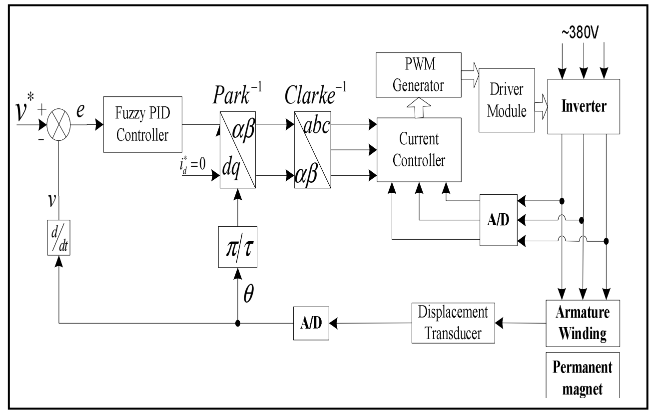

Figure 2. Configration of the PMLSM system

III. THE DESIGNATION OF THE FUZZY CONTROLLER

In the classical control theory, the PID control contains the proportion link, the integrator link and the differential link. And the discrete PID control algorithm can be described as follows:

$$U(n) = K_p e(n) + K_i \sum_{i=1}^{n} e(i) + K_d e_c(n) \tag{6}$$

$$K_i = K_p \frac{T}{T_i} \tag{7}$$

$$K_d = K_p \frac{T_d}{T} \tag{8}$$

Where K_p is the scale coefficient, K_i is the integral coefficient, and K_d is the differential coefficient, T_i denotes the integral time, T_d represents the differential time, and $e_c(n) = e(n) - e(n-1)$ is called the error variation.

The fuzzy control is designed on the basis of factual experience, it does not need the internal structure of the controlled object or its mathematical model, but it can provide strong robustness and tracking abilities in the nonlinear and time-varying systems. In this paper, the new control strategy, which is the combination of the fuzzy control and the PID control, is adopted in the speed loop of the PMLSM system. The online parameters can be adjusted to meet the requirements of the controlled objects through fuzzy reasoning. The relative structure diagram is as shown in fig. 3.

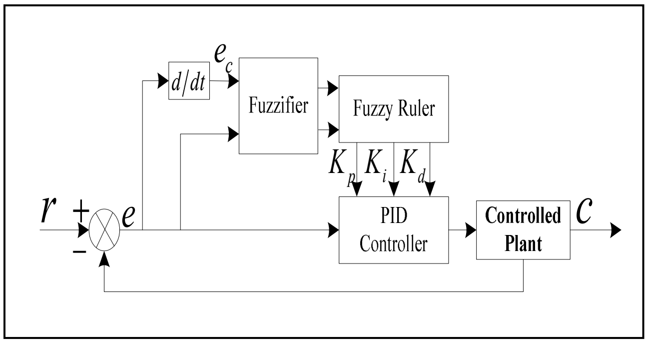

Figure 3. Configration of the fuzzy PID control

In the PID controller, the three parameters K_p, K_i and K_d have different effect on the response speed, the stability and the overshoots of the system. K_p is to speed up the response speed of system, and improve the system of regulating accuracy; K_i is to eliminate the steady-state error of the system; K_d is used for improving the dynamic behavior of the system. In order to make the fuzzy controller achieve the optimal control, the following principles of adjustment parameters should be accorded to: when the deviation e is larger, K_p should take bigger, and K_d smaller, and when $e * e_c$ is less than zero, we should let $K_i = 0$, otherwise take the bigger. When the deviation is medium, we should take the smaller K_p, K_i, and the proper K_d to make sure the quicker response speed. And when the deviation is lesser, K_d should be appropriately selected in order to avoid the oscillation around the setting values and enhance anti-jamming of the system.

In the PMLSM system, which is based on the PID control system, the microprocessor can obtain deviation between the actual pace and the given speed e and also the deviation variation e_c on the basis of the reference input and the output feedback signals. Take the above two variables as the input language variables of the fuzzy controller, and every language variable take seven linguistic value, respectively NB, NM, NS, ZO, PS, PM, PB; then the three output variables K_p, K_i and K_d will be obtained through fuzzy reasoning, and every variable take three linguistic values respectively S, M, B; at last we should focus on the reasoning and reconciliation of fuzzy in the method of Min-Max according to the summary expert practical experience, by which the fuzzy control rule is formulated as shown in table 1.

TABLE I. PMLSM FUZZY REASONING RULE

Kp,Ki,Kd		E						
		PB	***PM***	***PS***	***ZO***	***NS***	***NM***	***NB***
EC	***PB***	B,B,S	M,S,M	S,M,S	M,B,S	S,M,S	M,S,M	B,S,S
	PM	B,B,S	M,S,M	S,M,M	M,B,S	S,M,M	M,S,M	B,S,S
	PS	B,B,S	M,S,M	S,M,M	M,B,M	S,M,M	M,S,M	B,S,S
	ZO	B,S,S	M,S,M	S,M,B	M,B,B	S,M,B	M,S,M	B,B,S
	NS	B,S,S	M,S,M	S,M,M	M,B,M	S,M,M	M,S,M	B,B,S
	NM	B,S,S	M,S,M	S,M,M	M,B,S	S,M,M	M,S,M	B,B,S
	NB	B,S,S	M,S,M	S,M,S	M,B,S	S,M,S	M,S,M	B,B,S

IV. SYSTEM SIMULATION AND THE RESULTS

According to the load model, we establish a complete simulation system model by simulation and carrying on the performance testing and the contrast between the fuzzy PID controller and PID controller. In this simulation model we use a step function as the stochastic load, and a pulse function as external disturbance, which occurs in 1.25 s point. Fig. 4 is for a specific simulation model, and fig. 5 is for the simulation results.

From the simulation results we can see that the velocity response adjusting time is respectively 0.6 s and 0.25 s in the traditional PID control and the fuzzy PID control system. At the same time, the fuzzy PID control has the bigger overshoot, and the better adjusting and tracing ability under the external disturbances. Therefore, compared with the traditional PID controller, the fuzzy PID controller not only has a strong dynamic tracking performance, it also has the high anti-interference capability.

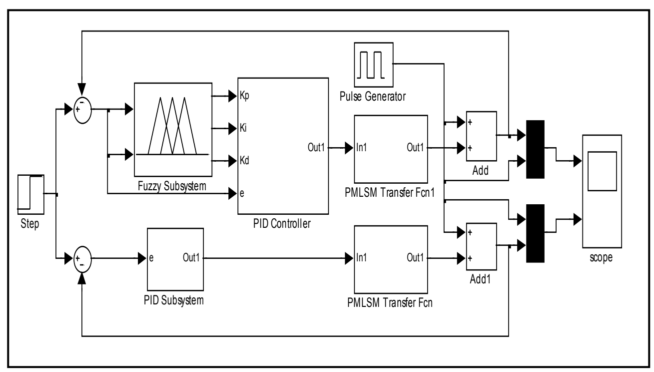

Figure 4. The simulation model of fuzzy PID controller

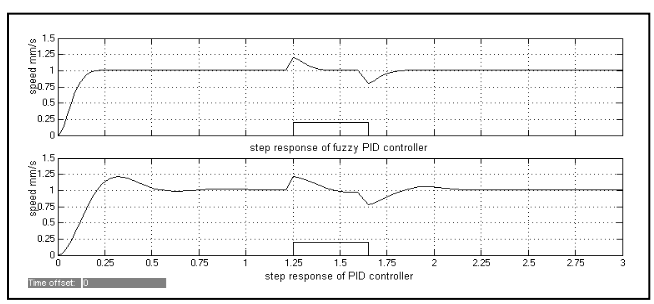

Figure 5. Simulation results

V. Conclusions

Owing to the complexity and uncertainty of the working conditions in the distribution system, in is hard to get good control performance in the system made of the rotating motor and the transmission. Considering the characteristics of PMLSM, this paper not only puts forward the new idea of replacing the traditional rotating motor with PMLSM, it also designs the fuzzy PID controller, which comes from the combination of advantages of the traditional PID control and the fuzzy control. The simulation results show that the fuzzy PID control strategy has some advantages, for example, the strong robustness, the good tracking performance, the small ripple and the stable operation, compared with the traditional PID controller, which makes the PMLSM-based distribution system has the wide speed range, high positioning accuracy and strong capability of restraining the change of load. Therefore, the PMSLM distribution system, which is based on the fuzzy PID control, is applicable to the industrial field such as the load is variable and the requirement for the positioning accuracy is high.

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