Level control system of connecting rod ultrasonic cleaning based on fuzzy algorithm

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Abstract: During the ultrasonic cleaning of the connecting rod, the liquid level should be constantly changed to minimize the impact of the cleaning blind area. Dealing with the level requirement of connecting rod ultrasonic cleaning, this paper uses the controller based on fuzzy algorithm to control the level. The design of control system including Analysis of liquid level system, fuzzy variables, the controlling rule and control polling list. The controller outputs the actual variable and then operates the solenoid valve to change the liquid level. The response curve of level control system in ultrasonic cleaning is obtained through simulation. The test result of Matlab simulation indicate how fast the system is on responding, and the design meets the requirements.

1 The introduction

The connecting rod of automobile engine usually needs to go through many processing steps in the production process, among which the cleaning process is very important but easy to be ignored. In fact, unqualified cleaning is easy to cause rust, machining error, short service life and other problems. Because of the rapid progress of scientific processing means today, the clean way of products also appear new breakthroughs. The new cleaning method of ultrasonic cleaning is among the more prominent, the basis of its effects is formed by the high frequency resonance signal which made of driving power supply, spreads to the liquid through transducer. There are many 50-500 m diameter of small bubbles forming in the liquid, vibration to rupture, the process will produce huge pressure, can make the dirt broken, to achieve a good cleaning effect. The connecting rod has screw holes and other difficult cleaning positions, the shape is complex and difficult to clean, cleanliness requirements are high, the test proves that the function of cleaning connecting rod by ultrasonic is very obvious, clean degree can meet the industrial needs. But during the cleaning operation, the ultrasonic wave travels through the detergent in the tank, when it reaches the liquid level of the detergent, a reflection occurs, which causes a standing wave sound field to be generated along the detergent's upward direction. This situation results in the parts near the wave node can not be effectively cleaned, videlicet there is a cleaning blind area [1]. According to the changing amount of detergent at different times during the cleaning process, the liquid level also changes, thus reducing parts that cannot be cleaned effectively, to minimize the impact of the cleaning blind area, each part of the parts can be thoroughly cleaned [2]. The control system based on

fuzzy algorithm is designed to change the liquid level of detergent in ultrasonic cleaning of connecting rod in real time.

2 Analysis and control scheme of liquid level system

This level control system about ultrasonic cleaning controls the level height of the reservoir to keep the level near the set value with an error of no more than 10 mm. Under the control of the set system, when the cleaning process is affected and the liquid level changes, the liquid level can quickly return to the set value within a short period of time [3]. And the control model is simplified according to the specific device. The structure diagram is shown in Figure 1 below. The control structure consists of liquid level sensor, controller, liquid storage pool, electromagnetic regulating valve and related electrical components. The function of the level sensor is to detect the level height of the liquid storage pool in real time. The function of the Electromagnetic regulating valve is to change the amount of water entering the liquid storage pool. The controller is designed with an output variable, which means to change the action of the control valve.

3 Design of liquid level fuzzy controller

3.1 Blur the input and output

The trapezoidal tank is used as the liquid storage pool. The error of the liquid level inside the tank is set as E , and the range is $[-e, e]$. In addition, set the variation of

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error as EC, and its range is $[-EC, EC]$. Variation E and EC are indispensable access values for the controller of

1.Upper tank 2.Electromagnetic regulating valve 3.Lower tank 4.Liquid level sensor 5.Fuzzy controller 6.Electromagnetic regulating valve 7.Liquid storage pool 8.water pump

Fig. 1. Structure diagram of liquid level control model

trapezoidal tank. The controller's output value of voltage is U , which is used to operate the action of the regulator. The operating range of the regulator, that is, the voltage range, is set from minus U plus U .

According to the above, the designed controller defines the error as E . In the ideal setting, E has a certain limit, and its value is determined. Let $E = \{-n, (-n+1), \dots, 0, \dots, (n-1), n\}$ as the boundary of fuzzy subset of value E . Assuming $K_e = n/E$, K_e is determined as a quantitative factor. Affected by different numerical values of quantitative factors, the variation of variable range $[-e, E]$ is also different, and the change of variable range will reduce the agility of error. Based on the above, k was selected as the quantitative factor of the error change rate of EC, and $K_{ec} = n/EC$ was defined, thus $K_u = U/n$ was obtained as the quantitative factor of the control quantity [4].

Because the product of K_u times n is the real control quantity, the n appearing in the above equation represents a classification of the voltage range $[-U, U]$ of the solenoid valve. If K_u exceeds a certain value, the damping of the controlled process will be suppressed. On the contrary, too small a value of K_u causes delays in the reflection properties of the control system. For this particular case, choose $n=6$. The goal of the initial design is a two-dimensional controller, that is, only two elements are effective. The domain of the three variables E , EC and U set through fuzzy processing can be defined as follows. The language variation is used to describe the deviation $T(E) = \{\text{negative large, negative medium, negative small, zero, positive small, positive medium, positive large}\}$, the corresponding abbreviation of language variation is $\{NB, NM, NS, ZO, PS, PM, PL\}$, and the set of variables E , EC , and U is $\{NL, NM, NS, ZO, PS, PM, PL\}$, the change region of E , EC and U is $\{-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6\}$. The corresponding function selects the membership style of the triangle, and after processing, the specific graph is shown in Figure 2.

Fig. 2. Membership function diagram of error E, change of error EC and voltage U

3.2 Establish control standards

The fuzzy control standard is the principle followed by the controller when the liquid level changes as the cleaning process progresses. The determination of control standards is based on numerous relevant experts' extensive professional theoretical research and the experience of predecessors' long time of front-line work. The control criterion is a literal representation of logic whose principles follow a theoretical derivation in the context of one's intuition. Write with logical words like "if", "then", "else", "or", etc. The established control standard is the main representation method of fuzzy control at present. It has the advantages of simple language structure, easy to write and quick to grasp. In the corresponding control criteria, "if" is the condition of the operation variable, and "then" is the corresponding implementation variable of the operation. Control standard implementation commands follow the law: in the case of large error, the purpose of selecting the control quantity should be to minimize the error in the shortest time [5]. Relatively speaking, when the error is relatively small, the control quantity should be selected to prevent the phenomenon of overshooting, reduce the impact, and put the stable system in the first place. The controller designed in this paper has two input variable and one output variable. Relevant text regulations can be summarized through practical experience, which can be expressed in the following form:

if $E = PL$ and $EC = NL$ or NS or ZO

then $U = NL$ (1)

According to these language regulations, the following relationships can be summarized as follow:

$$R = \bigcup_{i=1}^{19} (R_{A_i} \cap R_{B_i}) = ((\bigcup_{i=1}^{19} R_{A_i}) \cap (\bigcup_{i=1}^{19} R_{B_i})) = R_A \cap R_B \quad (2)$$

The general standard control table is shown in Table 1 below.

3.3 Queried table corresponding to fuzzy control

The queried table of control system shows the functional relationship between each control rule and the corresponding input and output. Once the specific input is determined, the system is optimized by querying the table and deriving the rules and reasoning process used.

Table 1. Standard of Fuzzy control

U \ E \ EC	PL	PM	PS	ZO	NS	NM	NL
PL	NM	NS	ZO	PS	PM	PL	PL
PS	NM	NM	ZO	PS	PS	PL	PL
ZO	NL	NM	NS	ZO	PS	PM	PL
NS	NL	NL	NS	NS	ZO	PM	PM
NL	NL	NL	NM	NS	ZO	PS	PM

In order to determine the queried table, three membership functions related to error E, error change quantity EC and voltage U should be taken into account. By using the method of triangular fuzzy theory [6], the assignment table can be calculated after quantizing the function, and the resulting assignment table can be used for relational calculation, so as to determine the query table. The design of the queried table follows the principle: when the error is "negative large" and the change in the error is negative, then the change in the error tends to increase. In order to ensure the stability of the system, eliminate the tendency of error increase and reduce the influence of error, the setting of control quantity is positioned as "negative large". Similarly, in the case where the error is "negative" and the change in the error is positive, the fuzzy system now has a tendency to avoid the error, in order to reduce the error in a short time and avoid overshoot, the control quantity should be positioned at a relatively small value. In other cases, there is a different level of error, but the control process are basically the same [7]. For an example: If the error E is "negative medium"(NM), that is the water level in the trapezoidal tank is at a high level. In this case, if the EC is "positive small"(PS), the water level in the water tank has a rising trend at this time. The method with the maximum membership degree is used for calculation, and the output voltage is calculated.

$$u = \frac{(-2 - 1 + 0 + 2 + 3)}{5} = 0.4 \quad (3)$$

After summarizing the above principles and multi-step calculation, the corresponding control queried table can be deduced. The specific control queried table is shown in Table 2 below.

Table 2. Queried table of fuzzy control

u		e						
		PL	PM	PS	ZO	NS	NM	NL
ec	PL	-2	-1.5	-1	0	1	2	2.5
	PS	-2	-2	-1	0.5	0.5	2	3
	ZO	-2.5	-2.5	-1	0	1	2	2.5
	NS	-3	-2	-0.5	-0.5	1	2	2
	NL	-2.5	-2	-1	0	1	2	2.5

4 Realization of control system

The control system is designed with Mitsubishi FX2N series PLC to control the liquid level in the trapezoidal water tank. PLC uses the electromagnetic regulating valve to debug the amount of water entering the trapezoidal water tank, so as to achieve the goal of changing the liquid level. The system is mainly composed of four components, which are specifically solenoid valve, PLC controller, input components, output components. In addition, input sensors are selected in the control system and placed in the liquid inside the trapezoidal tank, inducing liquid level height change, using input component to obtain the value of the liquid level, input to the PLC for processing, compared with the existing value in the controller, according to the principle of fuzzy operation solenoid valve to change the height of the liquid level [8]. After the control calculation, the controller will output the current using the output components. The liquid level control structure of the controller is shown in Figure 3 below.

Fig. 3. Liquid level control structure of controller

Based on the fuzzy control of PLC, the control principle is to save the quantized factors in the relay, and then process the collected signals, corresponding to the principle of control queried table, calculate the output variate, the controller output the variate, and then operate the solenoid valve to change the height of the liquid level inside the trapezoidal water tank.

According to the fuzzy algorithm, its control flow chart is drawn as shown in Figure 4 below.

Fig. 4. Flow chart of fuzzy control algorithm

5 Simulation and Analysis

This paper design the ultrasonic cleaning liquid level control system of connecting rod. The MATLAB modeling visualization module SIMULINK is used to simulate the system. The output system reflection curve is shown in Figure 5 below.

Above can be seen from the response curve, the simulation results show that the fuzzy controller quickly reaching liquid level height which originally set by in less than 10 seconds. This proves that the response time of the controller is short and the control is accurate, it can meet the requirements of the water level operation of the liquid storage tank in this subject. Therefore, the

Fig. 5. Response curve of Level control system in ultrasonic cleaning

controller based on fuzzy algorithm, with correct principle and reasonable design, can be applied in practice.

6 Conclusion

The control system often has time delay when the liquid level as object, but ultrasonic cleaning has special requirements on the liquid level because of its special cleaning principle. Fuzzy control solves the requirement of real-time automatic change of liquid level in ultrasonic cleaning by formulating appropriate control rules, reducing regulation time and reducing overshoot. The experimental results show that the performance of the system is effectively improved by adjusting the liquid level.

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