Liquid Level Control System for Degassing Chamber of Vacuum Oil Filter Based on Fuzzy PID

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Abstract. This paper proposed a fuzzy PID control method to address the complexities associated with the inertia and nonlinear variations in liquid level control within the degassing chamber of vacuum oil filter. Tailored to meet practical control demands, a fuzzy control rule table was devised. This solution was simulated and applied in MATLAB/Simulink. The results indicated that, in comparison to classic PID, fuzzy PID exhibited faster adjustment speed and reduced overshoot, making it a more suitable option for vacuum oil filter applications.

Keywords: vacuum oil filter; degassing chamber; fuzzy PID; liquid level control.

1. Introduction

The insulating oil within electrical equipment performs crucial functions of cooling and insulation. Nevertheless, with prolonged operation, the insulating oil gradually ages, resulting in a decrease in its insulating properties and cooling efficiency [1]. To restore the physicochemical properties of the oil, vacuum oil filters are employed, utilizing vacuuming, heating, and filtering techniques [2].

Once the insulating oil enters the vacuum oil filter, it undergoes degassing and dehydration within the degassing chamber [3]. However, various factors such as the oil's viscosity and the pressure differential at the inlet and outlet can lead to fluctuations in the liquid level within the chamber. An excessively high liquid level can compromise the efficiency of the dehydration and degassing processes [4]. Therefore, it is necessary to analyze and control the liquid level within the degassing chamber.

Given the inertia and nonlinearity associated with the liquid level fluctuations in the degassing chamber [5], the application of fuzzy PID control is explored in this paper. The simulation results indicated that, fuzzy PID control exhibits improved adjustment speed, minimized overshoot, and overall better control performance compared to classic PID control.

2. Degassing Chamber of Vacuum Oil Filter

2.1 Working Process

The vacuum oil filter employs a multi-stage process to purify the insulating oil. The oil first passes through pre-filtration, followed by heating, vacuum treatment, condensation, and post-filtration [6-7]. This sequential treatment removes dissolved gases, moisture, and sedimentary impurities, effectively restoring the oil's physicochemical properties, as shown in Fig. 1.

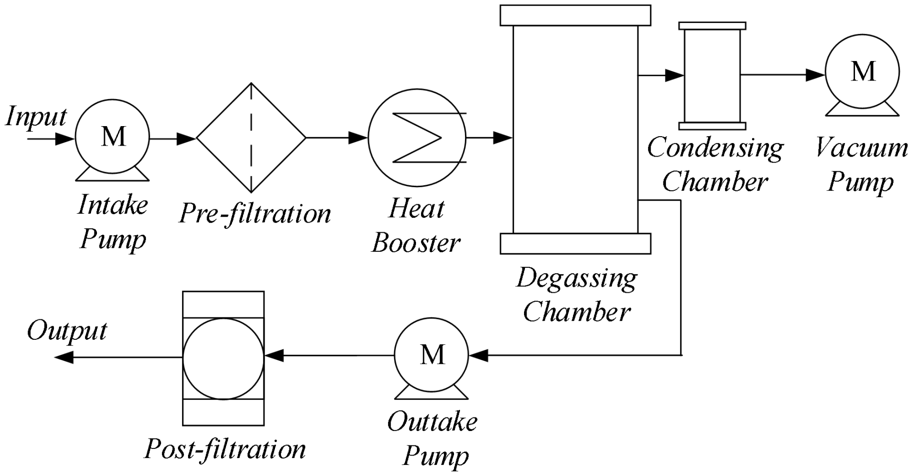

Figure 1. Working process of Vacuum Oil Filter.

Inside the degassing chamber, a rotating device atomizes the heated oil into a semi-mist state [8]. In the high vacuum environment, the moisture in the oil rapidly evaporates into water vapor, and gases dissolved in the oil also escape from the oil [9]. The vacuum pump draws the separated moisture and gases into the condenser. Simultaneously, the insulated oil passes through a fine filter tank to remove particulate impurities, thus completing the entire filtration process. Fig 2 shows the structure of degassing chamber.

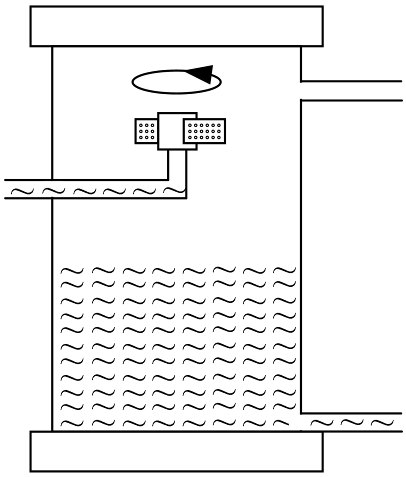

Figure 2. Structure of degassing chamber.

2.2 Liquid Level Control

The liquid level inside the degassing chamber has a direct impact on the efficiency of degassing and the overall safety and stability of the vacuum oil filter [10]. Adequate space within the chamber is essential for the insulated oil to undergo thorough evaporation and separation. High liquid levels can impede the effective discharge of steam, affecting the dehydration and degassing efficiency [11-12].

Maintaining an appropriate liquid level prevents the vacuum pump from operating with suction or overload, safeguarding critical components from damage. Precise automatic control of the oil level within the degassing chamber maintains a continuous and stable filtration process, enhancing the efficiency and reliability of the equipment.

3. Fuzzy PID control

3.1 Process of Fuzzy PID Control

PID control adjusts the output of the controlled object through three correction links: proportion, integration, and differentiation [13]. Its advantages lie in its simple algorithm and ease of implementation, making it effective for controlling linear time-invariant systems. However, its limitations are also evident, mainly manifesting in insufficient adaptability to complex nonlinear systems, the complexity of parameter tuning, and sensitivity to disturbances [14-15]. Fig. 3 shows the process of PID control.

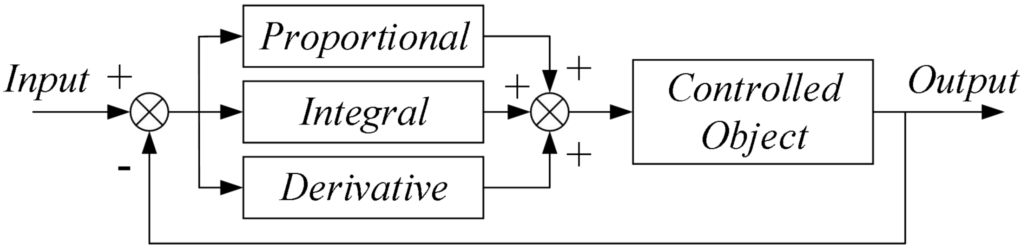

Figure 3. Process of PID control.

Fuzzy PID control represents an advanced control strategy that seamlessly integrates fuzzy logic with PID control. It utilizes a fuzzy controller to perform online self-tuning of PID parameters, effectively addressing system uncertainties and nonlinearities [16]. By combining fuzzy logic's ability to handle uncertainties with the stability offered by PID control, this method enhances the system's robustness and adaptability [17]. Its primary advantage lies in its ability to adaptively manage complex dynamic behaviors. Fig. 4 shows the process of fuzzy PID control.

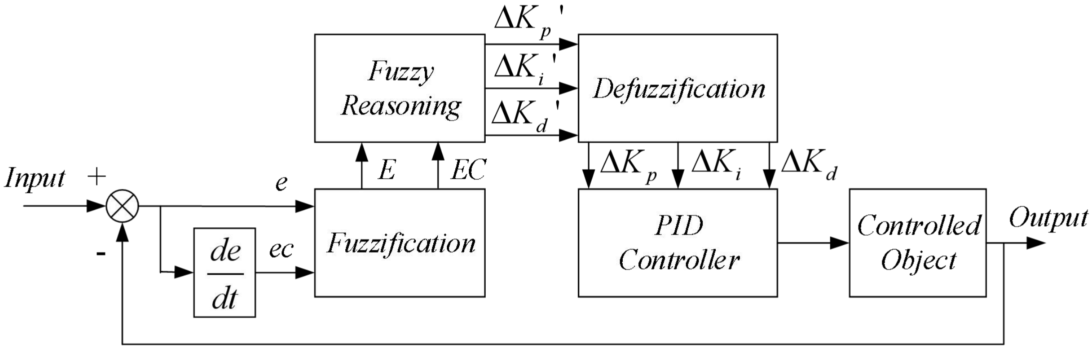

Figure 4. Process of fuzzy PID control.

3.2 Design of Fuzzy PID Control

3.2.1 Fuzzification

The deviation of liquid level and its rate of change in the degassing chamber are taken as input variables e and ec, with a triangular membership function selected. The fuzzy subset is set with seven elements: NB (negative big), NM (negative middle), NS (negative small), ZE (zero), PS (positive small), PM (positive middle), and PB (positive big), as shown in Tab. 1.

Table 1. Parameters setting of Fuzzy control

	Input		Output		
	e	***ec***	$\triangle K_p$	$\triangle K_i$	$\triangle K_d$
Basic Domain	[-5, 5]	[-5, 5]	[-3,3]	[-2,2]	[-1,1]
Fuzzy Subset	{NB, NM, NS, ZE, PS, PM, PB}				
Fuzzy Domain	[-6, 6]				

3.2.2 Fuzzy Control Rule

The direction of adjustment for Kp, Ki and Kd varies based on the liquid level deviation e and its rate of change ec. Based on specific control needs, a fuzzy control rule table is formed, as shown in Tab. 2.

Table 2. Fuzzy control rule

△K_p/ △K_i/ △K_d		**EC**						
		NB	*NM*	*NS*	*ZE*	*PS*	*PM*	*PB*
E	*NB*	*PB/ NB/ PS*	*PB/ NB/ PS*	*PB/ NB/ ZE*	*PM/ NM/ ZE*	*PS/ NM/ ZE*	*PS/ ZE/ PM*	*ZE/ ZE/ PS*
	NM	*PB/ NM/ PS*	*PB/ NM/ NM*	*PB/ NM/ NS*	*PM/ NM/ NS*	*PS/ NS/ ZE*	*ZE/ ZE/ PM*	*ZE/ ZE/ PS*
	NS	*PM/ NM/ NB*	*PB/ NM/ NM*	*PM/ NM/ NM*	*ZE/ ZE/ NS*	*NS/ ZE/ NM*	*NM/ ZE/ NM*	*NM/ ZE/ PM*
	ZE	*PM/ NS/ NM*	*PS/ NS/ NS*	*PS/ NS/ NS*	*NM/ ZE/ ZE*	*NB/ PS/ NS*	*NB/ PS/ PS*	*NB/ ZE/ PM*
	PS	*PS/ NS/ NB*	*PS/ ZE/ NS*	*ZE/ ZE/ NS*	*NS/ ZE/ NS*	*NM/ PS/ PS*	*NM/ PM/ PM*	*NM/ PM/ PS*
	PM	*ZE/ ZE/ NM*	*ZE/ ZE/ NS*	*NS/ PS/ PS*	*NM/ PM/ PS*	*NM/ PM/ PS*	*NB/ PM/ PM*	*NB/ PM/ PS*
	PB	*ZE/ ZE/ PS*	*NS/ ZE/ ZE*	*NS/ PS/ ZE*	*NM/ PM/ ZE*	*NB/ PB/ ZE*	*NB/ PB/ PB*	*NB/ PB/ PB*

By integrating fuzzy PID control with PLC, the system control speed is enhanced as the control parameters are automatically adjusted through referencing the fuzzy control rule table.

4. Simulation and analysis

In the liquid level control system of degassing chamber, the change in liquid level primarily depends on the difference between the incoming and outgoing oil flow rates. By comparing the deviation between the liquid level input and the setpoint, the control system adjusts the speed of the intake oil pump, thereby regulating the oil intake rate of the vacuum oil filter to achieve the desired liquid level control [18]. The transfer function is as follows:

$$G(s)=\frac{0.08}{s+0.02} \tag{1}$$

A simulation model for liquid level control of degassing chamber is established in Simulink. The PID parameters selected are Kp=2.0, Ki=0.12, and Kd=0.02, as shown in Fig. 5.

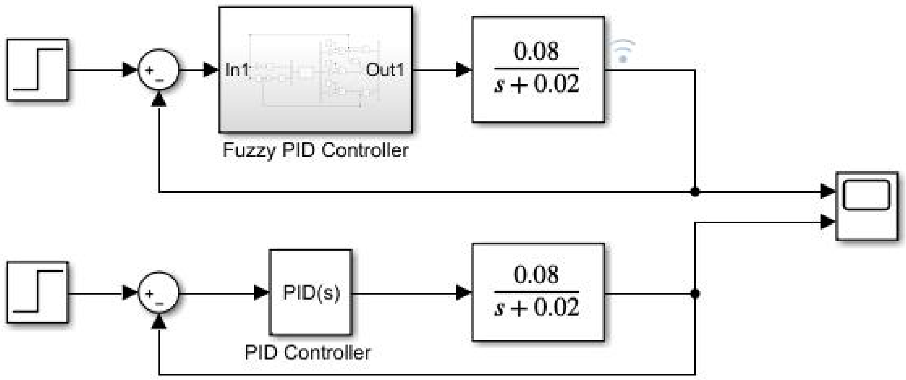

Figure 5. Liquid level control system of degassing chamber.

With an initial liquid level of 50, a comparison is undertaken to determine the regulatory performance of two control methods. Fig.6 shows the respective liquid level simulation curves. Tab. 3 shows the performance metrics.

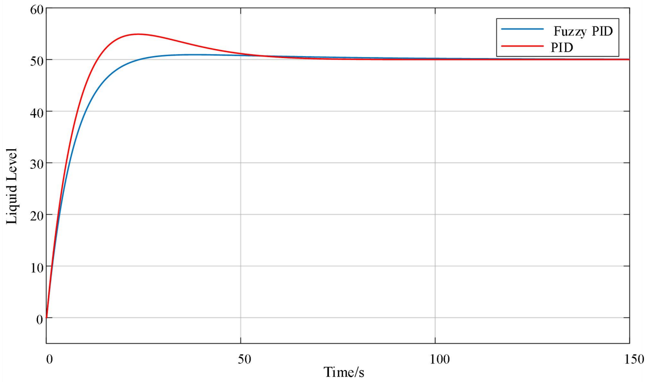

Figure 6. Liquid level simulation curves.

Table 3. Performance Metrics

Type	Steady-state Time	Steady-state Value	Overshoot
PID	68.20s	50.05	9.81%
Fuzzy PID	59.10s	49.99	1.99%

Based on the simulation curves presented in Fig. 5 and the data summarized in Tab. 2, it is evident that the fuzzy PID control outperforms the classic PID control. Specifically, the steady-state time is shortened by 9.1 seconds, and the overshoot is reduced by 7.82% with the fuzzy PID control.

In the actual operation of a vacuum oil filter, the liquid level changes are not ideal and are subject to various disturbances such as temperature, foam, oil viscosity, inlet and outlet pressures of the equipment, and more. To validate the differences in stability between the two control systems, a white noise disturbance signal with amplitude of 1 was added to the simulation model. Fig. 7 shows the simulation results.

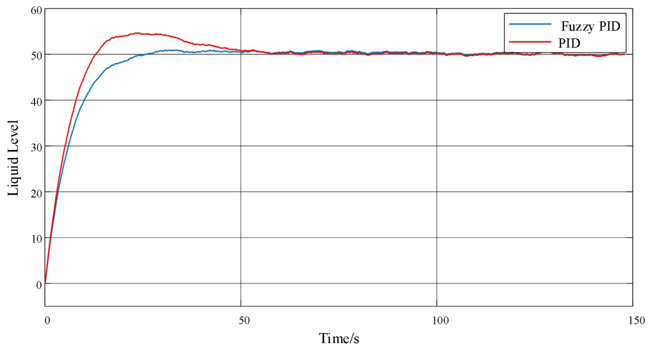

Figure 7. Liquid level simulation curves with white noise disturbance signal.

The results depicted in Fig. 7 indicate that, when white noise disturbance is introduced, both classical PID control and fuzzy PID control exhibit acceptable levels of error during the regulation process. However, the latter demonstrates a faster adjustment speed and superior control of overshoot.

These results reveal that fuzzy PID exhibits superior control performance in regulating the liquid level of the degassing chamber.

Conclusion

This paper presents a fuzzy PID control strategy for the liquid level of degassing chamber in the vacuum oil filter. Through a comparison of simulation results, it is found that the fuzzy PID control outperforms the classic PID control in terms of adjustment speed, overshoot, and stability. This study provides insights for practical industrial process control and offers implications for improving control effectiveness.

Liquid level control of the degassing chamber is an integral part of the automated control of the vacuum oil filter. However, there are some limitations in the simulation study presented in this paper. In practical applications, the fuzzy control rules need to be adjusted and optimized based on the influence of various factors to ensure a more stable control effect. Only through continuous improvement and refinement can the controller be applied to actual industrial control processes.

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