Design of Fuzzy Variable Frequency Control System for Local Ventilator

Tianyi Jia, Lijun Xu, Zhifeng Chen, Luxiang Mi, Xin Su, and Di Zhu

Abstract Local ventilator frequency conversion control has a certain lag. Because of the failure to control the abrupt gas emission in time, it will lead to the problem of gas exceeding the limit. If the ventilator continues to operate at full frequency, it will be in an under load state during the process of tunneling in coal mines, leading to waste of electrical energy. In response to the above issues, the principle of variable frequency energy-saving control for local ventilator is analyzed based on their ventilation characteristics. A fuzzy variable frequency control system for local ventilator is designed based on fuzzy control theory. A testing platform combining local ventilation devices and signal acquisition devices was established, and frequency conversion testing tests were conducted on the system. The experimental results show that the fuzzy variable frequency control system has certain practicality, which can timely control the real-time emission of gas, control the gas concentration within a safe range, and effectively overcome the hysteresis of ventilation system control.

Keywords Mine ventilation system · Local ventilator · Fuzzy control

1 Introduction

Energy is the foundation and driving force for a country's modernization development. Rich coal, poor oil, and limited gas are the basic national conditions of China. With the application of comprehensive mechanization and automation equipment in coal mining, the production efficiency and safety of coal mining have been continuously improved [1]. However, there are still some safety problems such as gas accumulation in the process of coal mining, which is closely related to the ventilation system of coal mining. In the process of coal mining, coal mining heading face is the coal mine safety accidents, such as gas explosion, coal dust explosion, and so on [2]. About 80% of gas explosion accidents are related to the imperfect

T. Jia · L. Xu (✉) · Z. Chen · L. Mi · X. Su · D. Zhu
Xinjiang Coal Mine Electromechanical Engineering Technology Research Center, Xinjiang Institute of Engineering, Urumqi 830023, China
e-mail: xulijun612@163.com

S. Yadav et al. (eds.), *Energy Power and Automation Engineering*, Lecture Notes in Electrical Engineering 1118, https://doi.org/10.1007/978-981-99-8878-5_39

mine ventilation system. As an important device of mine ventilation, the flexibility and efficiency of mine local ventilator will directly affect the coal mine gas emission [3]. When selecting the local ventilator, the ventilator power is usually selected according to the principle that the maximum driving distance must ensure the normal breathing of underground workers, and the gas concentration does not exceed the limit. In the initial stage of coal mining, if the local ventilator operates at a constant frequency of 50 Hz, it will lead to the waste of air volume and the loss of electric energy when it is running under load [4]. Local ventilator is mainly used for air exchange inside and outside the mine roadway and to reduce the gas concentration in the coal heading face [5], the power consumption accounts for a large proportion of the total power consumption. Therefore, it is necessary to properly adjust the output power of the local ventilator to ensure the efficiency of the ventilator and precisely control the speed of the local ventilator. The application of frequency conversion technology can change the running frequency of the ventilator through the signal size given by the sensor in the heading face to further control the air volume [6]. In the recent years, a lot of improvements and application researches have been made on the variable frequency control system of local ventilator. Zhang [1] reformed the variable frequency speed regulating system of local ventilator based on PLC, which can realize the adjustment of ventilator speed and the control of air volume, so as to achieve the intelligent and automatic delivery of air volume by the ventilator. Du [7] used a particle swarm optimization PID control algorithm to control the speed of local ventilator and improve its output performance.

In this paper, based on fuzzy control theory, a multi-variable coupling nonlinear model of local ventilator speed, gas concentration, air volume, and other factors are established to optimize the mine ventilation network. The system determines the main control mode by logical judgment and adjusts the air volume of local ventilator in time. It can not only effectively control the gas emission in real time, but also maintain the relative balance between air volume and gas concentration, so as to realize on-demand ventilation, energy saving, and consumption reduction, so as to ensure the safety, energy saving, and high efficiency of coal mining.

2 Local Ventilation Arrangement

In the excavation roadway ventilation system, the layout of local ventilator and sensors is illustrated in Fig. 1.

According to the relevant provisions of “Coal Safety Regulations”, the gas sensor T_1 is arranged at the coal mine heading face. In case of $T_1 \geq 1.0\%$, work must be stopped, personnel should be evacuated, and corresponding measures should be taken to deal with it. In case of $T_1 \geq 1.5\%$, gas-electric locking is required. Meanwhile, the “Coal Safety Regulations” stipulate that the wind speed in the coal mine roadway must be maintained at 0.25–4 m/s, and the underground air supply standard is 4 m^3/min.

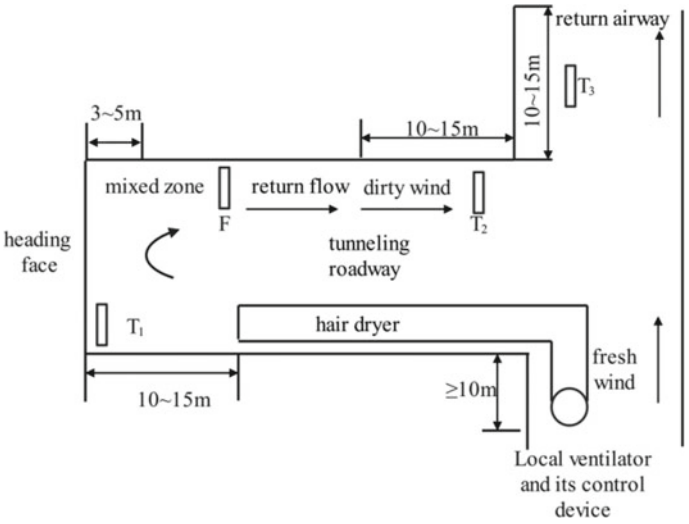


Fig. 1 Layout of local ventilator and sensors

3 Local Ventilator Ventilation Characteristics

In the actual working process, the relationship between air volume Q, air pressure H, ventilator power P, and speed n is as follows: air volume $Q \propto n$, air pressure $H \propto n^2$, and ventilator power $P \propto n^3$. The air volume Q is proportional to the frequency f: $Q \propto f$. When frequency conversion is adopted for local ventilators, the baffle plate is fully open and the ventilation resistance of ventilation pipes basically remains unchanged. H–Q characteristic curve of ventilator is illustrated in Fig. 2. By reducing the frequency of the local ventilator, the air volume of the local ventilator can be reduced, and then the output power can be reduced to achieve frequency conversion energy saving.

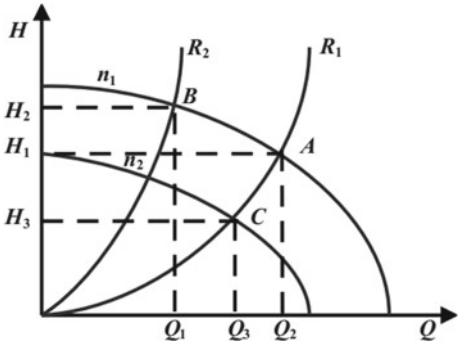


Fig. 2 H–Q characteristic curve of ventilator

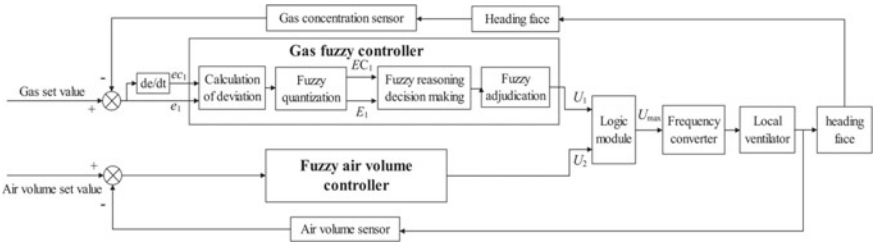


Fig. 3 Principle of control system

4 Design of Control System

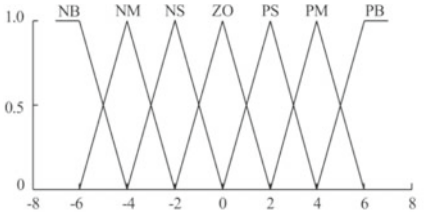
4.1 Principle of System Control

The principle of fuzzy variable frequency control system of local ventilator is illustrated in Fig. 3. The control system consists of a gas fuzzy control loop and an air volume fuzzy control loop. In the closed loop of gas fuzzy control, the gas concentration deviation e_1 and deviation change rate ec_1 in the heading face serve as the input of the fuzzy controller, and the output is the signal U_1 that controls the output of the converter, and the air volume is automatically controlled by changing the speed of the ventilator. In the closed loop of air volume fuzzy control, it takes the standard underground air demand per capita of 4 m^3/min as the expected value, collects the air volume signal through the air volume sensor, takes the deviation and deviation change rate of air volume as the controller input, and outputs the signal to control the inverter. Comparing with the traditional control mode, the output of the fuzzy controller is no longer the signal that directly controls the output of the converter, but a control quantity U. Compare the output control quantity U of the gas fuzzy control and the air volume fuzzy control, take the larger value of the two, add a judgment process for the larger control quantity U, take the maximum value of the two, and send it to the voltage input terminal of the mine frequency converter to realize the adjustment of local ventilator speed. When the output control quantity is the same, the gas fuzzy control is the main control.

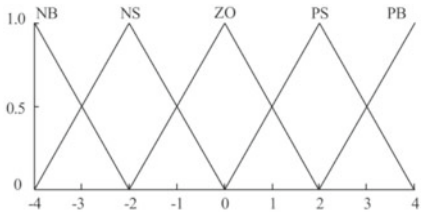
4.2 Fuzzy Control Approach

Fuzzy Quantization Processing

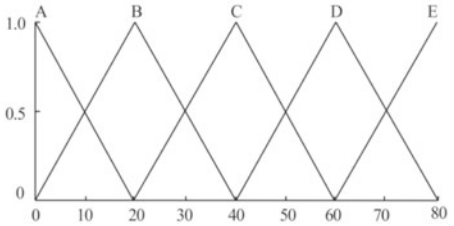
The expected value of the gas concentration input of the fuzzy controller was set as 0.8%, and the gas concentration range was 0–1.5% according to the ventilation requirements of the heading face. The membership function of gas fuzzy control is illustrated in Fig. 4.



(a) Membership function of deviation E_1



(b) Membership function of deviation rate of change EC_1



(c) Membership function of the output U_1

Fig. 4 Membership function of gas fuzzy control

The basic theory domain of the gas concentration deviation e_1 was set as [− 0.7, 0.7], and the language variable E_1[− 7, 7] was obtained by scaling the basic theory domain of e_1. The domain of E_1 is divided into seven grades, the fuzzy language set is {NB, NM, NS, ZO, PS, PM, PB}, and the language variable is described as {negative big, negative medium, negative small, zero, positive small, positive median, positive big}. The basic theory domain of the deviation rate ec_1 is set as [− 0.4, 0.4], and the language variable EC_1 [− 4, 4] is obtained by scaling. The theory domain of EC_1 is divided into five grades, the fuzzy language set is {NB, NS, ZO, PS, PB}, and the language variable is described as {negative large, negative small, zero, positive small, positive large}. The basic theory domain of the output quantity U_2 is set as [0, 80], the theory domain of U_2 is divided into five grades, the fuzzy language set is {A, B, C, D, E}, and the language variable is described as {small, smaller, medium, large, and maximum}.

In the fuzzy control of air volume, the expected air supply of the local ventilator is set as the minimum air supply required by the space with the farthest driving distance when the roadway is being driven. The basic theoretical domain of the deviation E_2 between the actual value and the expected air output of the local ventilator is [− 4, 4], the fuzzy language set is {NB, NS, ZO, PS, PB}, and the language variable is described as {negative large, negative small, zero, positive small, positive large}. The basic theoretical domain of deviation change rate EC_2 is [− 2, 2], the fuzzy language set is {NB, NS, ZO, PS, PB}, and the language variables are described as {negative large, negative small, zero, positive small, large}. The basic domain of output U_2

is [0, 80], the fuzzy language set is {A, B, C, D, E}, and the language variable is described as {small, smaller, medium, large, maximum}.

Fuzzy Inference Decision

According to the influence of frequency conversion conditions, gas concentration deviation E_1 and deviation change rate EC_1 on output characteristics combined with the technical knowledge of field technicians and field operation experience, and the gas fuzzy control rule is as follows: the higher the gas concentration, the higher the deviation change rate, the larger the output value; moderate gas concentration, moderate deviation rate, moderate output value; the smaller the gas concentration, the smaller the deviation change rate, and the smaller the output value. Table 1 gives the fuzzy control rules for gas concentration is illustrated in Table 1.

The fuzzy control rule of the air volume is as follows: if the air volume of the local ventilator is less than the minimum air supply volume required by the space at the farthest driving distance of the driving roadway, the smaller the air volume, the smaller the deviation change rate, the smaller the output value, and the air volume of the local ventilator needs to be increased. If the air volume of the local ventilator is equal to the minimum air supply volume required at the farthest driving distance of the roadway, the air volume of the local ventilator can be kept unchanged and the change of gas concentration in the roadway can be monitored continuously. If the air volume of the local ventilator is greater than the minimum air supply volume required for the location at the farthest driving distance of the driving roadway, the greater the air volume, the greater the deviation change rate and the greater the output value, the lower the air volume of the local ventilator.

Fuzzy Adjudication

Fuzzy control rules of MATLAB fuzzy toolbox are applied to clarify the output fuzzy quantity U_1 and U_2, respectively. The output variable surfaces of gas fuzzy control and air volume fuzzy control are shown in Fig. 5.

Table 1 Fuzzy control rules for gas concentration

E_1	EC_1				
	NB	NS	ZO	PS	PB
NB	A	A	B	B	C
NM	B	B	B	C	C
NS	B	C	C	C	D
ZO	C	C	D	D	D
PS	C	D	D	D	E
PM	D	D	E	E	E
PB	D	E	E	E	E

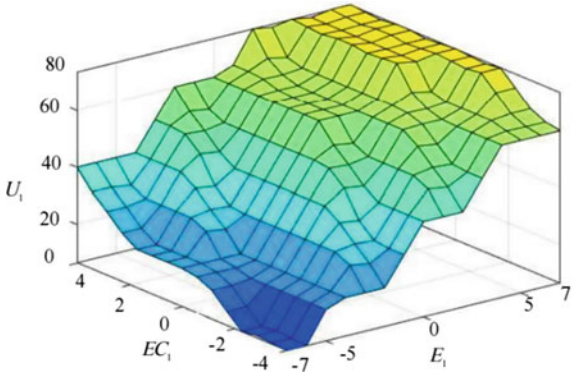


Fig. 5 Gas fuzzy control output variable surface

Hardware Principle

The gas concentration sensor, air volume sensor, and other information acquisition devices are arranged in the coal mine roadway for signal acquisition. The gas concentration of coal mine heading face is taken as the main controlled quantity. The output signal of sensors is used as the input value of fuzzy controllers after f/v conversion, and the information is processed by the fuzzy control algorithm. After converted by D/A and V/I, the output digital signal then drives the frequency converter to adjust the ventilator air volume.

The long-distance transmission of communication information is realized through the drive of amplifier MCP2551, the output of CAN module, and the host computer. The LCD touch screen can locally display the changes of gas concentration and air volume at various positions in the driving roadway, and the paperless recorder can record these data changes. The hardware structure of the system is shown in Fig. 6.

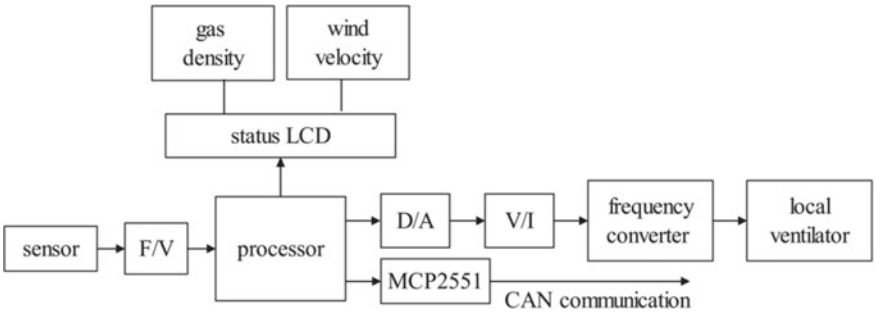


Fig. 6 Hardware structure of the system

Table 2 Main equipment and instruments used in the experiment

Equipment	Specifications and models
Counterrotating axial flow local ventilator	FBDNo_5.0/2 × 7.5
Frequency conversion governor	BPJ-75/690SF
Gas concentration sensor	GJC4
Mine air volume sensor	KGF2
Paperless recorder	MIK-R5000C

5 Test Results and Analysis

5.1 Experiment Platform

The test was carried out by Xinjiang Coal Mine Electromechanical Engineering Technology Research Center. Taking a fully mechanized mining face of coal mine of Xinjiang Coking Coal Group as the research object, combined with the general situation of coal mine roadway and the layout of ventilation devices in coal mine roadway, the relevant provisions of gas concentration, wind speed and air volume of coal mine roadway were tested according to "Coal mine Safety Regulations". In this experiment, the mine flameproof type compressed-in counterrotating axial flow local ventilator FBDNo_5.0/2 × 7.5, BIJ mine frequency conversion governor and signal acquisition devices, and other instruments were used to build a test platform. The main equipment and instruments used in the experiment are given in Table 2.

5.2 Experimenting Result

Experimenting result is given in Table 3. As can be seen from the table, with counter-rotating axial flow local ventilator FBDNo_5.0/2 × 7.5, the input gas concentration is 0.1%–1.0%. Under the local ventilator frequency conversion control system, with the increase of gas concentration, the output active power of the asynchronous motor of the local ventilator will also increase gradually. When the gas concentration is 0.1%, the output power of the frequency converter is 13.15 Hz, and the output power of the local ventilator is 2.15 kW. The frequency conversion control system controls the wind speed as the minimum wind speed 0.25 m/s as required by the "Coal Mine Safety Regulations". As the gas concentration detected by the local ventilation system gradually increases, the output power of the motor of the local ventilator keeps increasing. When the gas concentration reaches 1.0%, the output frequency of the frequency converter reaches 49.5 Hz and the output power of the motor reaches 11.37 kW. The speed of local ventilator will increase with the increase of gas concentration, realizing the automatic regulation of gas concentration by air volume of local ventilator, achieving the purpose of frequency conversion and energy saving.

Table 3 Experimenting result

Serial number	Frequency (Hz)	Active power (kW)	Gas density (%)
1	49.5	11.37	1.0
2	45.9	9.85	0.9
3	41.3	9.25	0.8
4	36.5	7.94	0.7
5	31.5	7.18	0.6
6	27.2	6.15	0.5
7	22.7	5.21	0.4
8	19.65	4.73	0.3
9	13.57	3.23	0.2
10	13.15	2.15	0.1

6 Conclusion

Based on the operation characteristics of local ventilator, the fuzzy variable frequency control system for local ventilator is designed, and it can improve the ventilation capacity of coal mine roadway. When the gas concentration exceeds the limit, the output volume of the ventilator will be automatically increased, which can control the gas concentration within the safe range more quickly, effectively improve the working environment of the coal mine, and greatly improve the safety of coal mine production. According to the gas concentration, the output air volume of the local ventilator can be automatically adjusted to avoid the ventilator from working at full frequency all the time.

Acknowledgements The project is supported by Foundation project: National Natural Science Foundation of China (Grant No. 51967020); Key R&D projects of Xinjiang Uygur Autonomous Region (China): (Grant No. 2022B01003-1). Xinjiang Uygur Autonomous Region Youth Science and Technology Top Talent Project: (Grant No. 2022TSYCCX0053).

References

1. Zhang S, Tang J, Wang M (2022) The challenges and opportunities faced by China's coal industry development under the background of "dual carbon". China Coal 05:1–5
2. Hao H (2018) Analysis of mine gas control and research on outburst prevention measures. Sci Technol Wind 28:120
3. Jing G, Liu M (2022) Statistics and regularity analysis of coal mine gas accidents in China from 2015 to 2019. J Saf Environ 03:1680–1686
4. Bi QP, Li YC, Shen C (2021) Screening of evaluation index and construction of evaluation index system for mine ventilation system. Sustainability 13:11810

5. Yin Z (2019) Stability analysis of coal mine ventilation system. Chin Petrol Chem Stand Qual 02:163–164
6. Yin Y, Yin L (2007) Application of frequency conversion technology and fuzzy control in local ventilation fans in mines. Coal Min Mach 01:139–141
7. Du G, Ma X, Zhang P (2020) Research on speed control algorithm for local ventilation fans in coal mines. Ind Min Automat 09:69–73 + 87