Monitoring the composition of the air environment in livestock buildings using a programmable logic controller

Alexander Kondratyev1*, and Aleksei Evdokimov1

1Volgograd State Agrarian University, 26, Universitetskii Ave., Volgograd, 400002, Russian Federation

Abstract. A system for monitoring the composition of the air environment in livestock buildings has been developed. The system consists of a programmable logic controller, frequency converter, operator panel and gas sensors. A control program in LD language was developed for multi-stage control of the fan motor speed. The linear nature of the relationship between the fan speed and the air flow it creates has been experimentally confirmed.

1 Introduction

One of the important indicators for the proper development and vital activity of animals in the premises of the agro-industrial complex is the standardized content of harmful gases (ammonia, hydrogen sulfide, carbon dioxide, etc.) in the indoor air [1]. Ventilation systems play an important role in poultry and livestock production by removing contaminants from the premises that are detrimental to the growth of livestock. Ventilation systems must be reliable, since malfunctions in the ventilation systems of animal premises lead to mass mortality [2].

The use of microprocessor-based tools to control the air composition of animal habitats in production facilities will help improve air quality and ensure increased product yield in enterprises. Based on microprocessor systems, namely a programmable logic controller (PLC), optimization and automation of various technological processes in the agricultural sector are possible.

Automatic monitoring systems based on wireless communication networks are now being developed in both dairy and pig farms to replace the traditional manual collection of environmental data and manual control of fans on livestock farms [3].

2 Materials and methods

To control the air composition in livestock buildings, a system has been developed, the structural diagram of which is shown in Figure 1. Thanks to this control system, it is

* Corresponding author: apevdokimov@yandex.ru

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possible to achieve an optimal energy-efficient process for removing harmful gases from the air environment of industrial premises.

Fig. 1. Block diagram of the air composition control system.

All the main control elements of the circuit, including the programmable logic controller, frequency converter and operator panel used for this system, are manufactured by the Russian company EKF.

The F100-12A-R programmable logic controller is an electronic device used to control technological processes in an enterprise. The use of a programmable logic controller allows you to create an almost completely autonomous control system that carries out its work taking into account the parameters, characteristics and state of the controlled object. The programmable logic controller includes all the necessary functional blocks for computing, storing and transmitting information, as well as digital and analog input/output ports. Various sensors can be connected to these ports, from which the values of the measured parameters can be obtained.

A VT100-0R4-1(B) frequency converter is used in conjunction with a programmable logic controller. To power it, a single-phase network with a voltage of 220 V and a frequency of 50 Hz is required. It is designed for a rated motor power of 0.4 kW. The frequency converter has 5 discrete inputs, 2 analog inputs and quite wide capabilities for programming and implementing fan control programs.

The operator panel is designed to create compact local control panels and indicate technological processes. This device eliminates the need to use a large number of indicators, buttons, switches and other equipment. The PROScreen RSC-10E panel used in the system has the following characteristics: screen size – 10.1 inches, four-wire resistive TFT LCD display, USB, RS-232/485/422, Ethernet interfaces, dust and moisture protection degree IP65.

The ventilation unit includes a radial fan with an AOL 22-4 U2 engine. A fan is necessary to circulate air in the room and, accordingly, regulate the composition of the air environment. It has the following technical characteristics: rated power – 0.4 kW; rated voltage – 220/380 V; phase connection diagram - triangle/star; rotation speed – 1500 rpm; rotor type - squirrel-cage. For operation, a triangle connection diagram and a supplied voltage of 220 V are used. The cross-sectional area of the fan duct is $F_{\text{sec}} = 0.0484 \text{ m}^2$.

To monitor the status of changes in air pollution by a particular gas, gas sensors are used, listed in Table. 1.

The signal received from the sensor, entering the controller, is compared with the specified values set by software. If there is a deviation from these standards, the programmable logic controller generates a digital output signal. This signal changes the frequency of the sinusoidal voltage produced by the frequency converter, and therefore changes the speed of the fan itself. After the content of harmful gases in the air environment of the poultry house returns to normal values, the programmable logic controller sends a
digital control signal through the outputs to restore the nominal fan speed. The program for the programmable logic controller was written in the LD language in the PRO-Logic master V2.2.11 programming environment.

Table 1. Technical characteristics of the gas sensors used.

<table>
<thead>
<tr>
<th>Sensors</th>
<th>Detectable gas</th>
<th>$U_{\text{init}}$, B</th>
<th>Current consumption, mA</th>
<th>Measuring range, ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor MQ-137</td>
<td>Ammonia, $NH_3$</td>
<td>5</td>
<td>150</td>
<td>5-500</td>
</tr>
<tr>
<td>Sensor MQ-136</td>
<td>Hydrogen sulfide, $H_2S$</td>
<td></td>
<td>150</td>
<td>1-200</td>
</tr>
<tr>
<td>Sensor MQ-7</td>
<td>Carbon monoxide, $CO$</td>
<td></td>
<td>120</td>
<td>10-1000</td>
</tr>
<tr>
<td>Sensor MG812</td>
<td>Carbon dioxide, $CO_2$</td>
<td></td>
<td>70</td>
<td>350-10000</td>
</tr>
</tbody>
</table>

An experiment was conducted on the developed stand to study the influence of the rotation speed of a radial fan on the speed of the air flow it creates. Using a frequency converter, the required frequency was set, then the anemometer was placed in the air flow at the outlet of the air duct for 10-15 seconds, in accordance with the requirements of the device’s operating instructions. At the same time, the operating mode of the anemometer and the timer were turned on for 1 minute. The received data was transferred to a programmable logic controller and displayed on the operator panel screen. The rotation speed of the radial fan electric motor was regulated using a frequency converter.

3 Results

To control the entire system, a program was compiled in LD language for a programmable logic controller. LD is a graphical programming language; a program written in it for the designed system is shown in Figure 2. The left side of the figure shows a program fragment containing comparison blocks (CMP), in which the input signal of the AI0 block (analog input of the sensor) is compared with the set threshold values (100 - 700 conventional units). If the value is greater than the set threshold, then a logical one is transmitted to the upper output of the block. If the value is equal to this threshold, then a logical one is output to the middle output of the block, and if the value is less than the set threshold, a logical one is output to the lower output of the comparison functional block.

The right side of the figure shows a connection of open contacts, the closure of which provides the required speed. The logic of their operation is as follows: each range of sensor signal values has its own combination of output values. For example, with a signal from 200 to 300 conventional units, there is only one logical unit at the output - Y1; with a signal over 700 conventional units, all three outputs Y0, Y1, Y2 take the value of a logical unit.

The frequency converter operates in multi-stage control mode (Table 2). When using three coils Y0, Y1, Y2, the maximum number of control stages is 8. In certain ranges of sensor readings, the software-set rotation speed of the ventilation unit electric motor was set. To turn on a certain rotation speed, a signal must arrive at the terminals of the frequency converter according to the Table 2.

With parameters FD-00 – FD-07 you can set a certain percentage of the frequency supplied to the fan motor. Coils Y0, Y1, Y2 provide a digital control signal from the programmable logic controller to the frequency converter, and their combination sets the rotation speed of the electric motor. Coil Y3 is used to start the electric motor in the forward direction of rotation.
Table 2. Parameters of multi-stage motor speed control.

<table>
<thead>
<tr>
<th>Y2</th>
<th>Y1</th>
<th>Y0</th>
<th>Control stage number</th>
<th>Parameter</th>
<th>Converter output frequency, Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>0</td>
<td>FD-00</td>
<td>10</td>
</tr>
<tr>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>1</td>
<td>FD-01</td>
<td>20</td>
</tr>
<tr>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>2</td>
<td>FD-02</td>
<td>25</td>
</tr>
<tr>
<td>OFF</td>
<td>ON</td>
<td>ON</td>
<td>3</td>
<td>FD-03</td>
<td>30</td>
</tr>
<tr>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>4</td>
<td>FD-04</td>
<td>35</td>
</tr>
<tr>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
<td>5</td>
<td>FD-05</td>
<td>40</td>
</tr>
<tr>
<td>ON</td>
<td>ON</td>
<td>OFF</td>
<td>6</td>
<td>FD-06</td>
<td>45</td>
</tr>
<tr>
<td>ON</td>
<td>ON</td>
<td>ON</td>
<td>7</td>
<td>FD-07</td>
<td>50</td>
</tr>
</tbody>
</table>

The data obtained during the experiment to study the influence of the rotation speed of a radial fan on the speed of the air flow created by it are given in Table. 3.

Table 3. Obtained experimental data.

<table>
<thead>
<tr>
<th>Fan rotation speed, rpm</th>
<th>0</th>
<th>75</th>
<th>150</th>
<th>225</th>
<th>299</th>
<th>374</th>
<th>404</th>
<th>434</th>
<th>449</th>
<th>494</th>
<th>524</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air flow speed, m/s</td>
<td>0</td>
<td>0.7</td>
<td>1.4</td>
<td>2.2</td>
<td>3.0</td>
<td>3.8</td>
<td>4.0</td>
<td>4.3</td>
<td>4.5</td>
<td>4.9</td>
<td>5.3</td>
</tr>
</tbody>
</table>
4 Discussion

As is known, the flow rate of blown air $L$ depends on the average air flow speed and the cross-sectional area of the air duct:

$$L = 3600 \cdot v_{av} \cdot F_{sec}$$  \hspace{1cm} (1)

Where $v_{av}$ – average air flow speed, m/s; $F_{sec}$ – cross-sectional surface area of the air duct, m$^2$.

Thus, to regulate air flow at a constant cross-sectional area of the air duct, it is necessary to know the dependence of the air flow velocity $v$ on the rotational speed of the radial fan $n$, which was found by the method of approximating experimental data. Using the Excel spreadsheet processor, the following equation was obtained:

$$v(n) = 9.9 \cdot 10^{-3} \cdot n$$  \hspace{1cm} (2)

With confidence $R^2=0.9998$.

A graph of the dependence of the air flow velocity $v$ on the rotational speed $n$ of the electric motor of the ventilation unit is shown in Figure 3.

![Graph](image)

**Fig. 3.** Dependence of air flow speed on fan speed with approximating curve.

Note that the fan rotation speed range is limited to 1500 rpm at the converter output frequency of 50 Hz, since the ventilation unit uses an asynchronous motor with two pairs of poles. Practice shows that the air flow rate fully satisfies the requirements for installations of this kind.

5 Conclusion

The developed regulatory system helps create a reliable and energy-efficient process for ventilation and removal of harmful substances from the indoor air at livestock enterprises. Moreover, this automated system has ample opportunities for reprogramming.
Acknowledgement

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