Control system of gas exhausting in tank truck

Shanren Ji¹, Haijian Zhong², Yeqing Sun¹, Xinhua Xia² and Qing Li*¹

¹ College of Mechanical and Electrical Engineering, China Jiliang University, Hangzhou, China
² Special equipment inspection and Research Institute of Zhejiang Province, Hangzhou, China
* Author to whom correspondence should be addressed; E-Mail: lq13306532957@163.com

Abstract: In order to solve the problem of exhausting gas on the cleaning process of tank trucks in our country, a set of control device for exhausting gas based on Single Chip Microcomputer is developed. The device is composed of Driving Structure, Feedback Signal and Signal Processing. The Displacement Sensor, Tension Sensor, Water Level Sensor and Methane Sensor are used to generate signals, which are processed and judged by the Single Chip Microcomputer, and the corresponding instructions are sent out according to the judgment results to control the operation of the Driving Structure. Compared with the traditional Steam Fumigation Method and High-pressure Water Cleaning Method, the system is more efficient and more environmentally protection

1. INTRODUCTION
With the development of China's industrial production, tank trucks have become the main means of transportation of chemical products. However, most of the products transported by tank trucks are flammable and explosive. So the research about tank trucks is unfolded accordingly. The improvement of cleaning technology[1] and the development of cleaning devices are also important research fields. The cleaning condition of tank trucks will have a great impact on the quality of products transported in the later stage, and improper cleaning will also lead to safety accidents. Therefore, it is necessary to clean the tank trucks after the transportation, to prevent unnecessary losses to the enterprise. At present, Steam Fumigation Method and High-pressure Water Cleaning Method are widely used[2].

2. Introduction to Exhaust System
This system is an control system[3]. It is designed for water injection and exhaust. It is developed for the control and signal detection of tank exhaust. This project takes the tank truck of Methane[4] as the research object, takes clean water as the cleaning medium, develops a set of control system with Single Chip Microcomputer as the core, Displacement Sensor, Tension Sensor, Water Level Sensor and Methane sensor as feedback device. The motor is driving mechanism. Solenoid Valves are control parts of exhaust pipes. The device adopts the concept of explosion-proof design, and all electrical equipment, valves and pipelines meet the national explosion-proof requirements [5]. And the device is common-ground with the tank to prevent the possibility of explosion and combustion during the cleaning operation. Fig.1 shows the state of connection between the device and the tank.
3. The Specific Structure Design of Each Part of The System

3.1. Open Device
The Opening Device acts on the safety valve on the top of the tank in order to open the safety valve so that the gas can be discharged from the safety valve port. The device is composed of three sleeves. The top-sleeve contains Two-phase Four-wire Stepping Motor and coupling. The middle-sleeve has a ball screw pair[6], and the bottom-sleeve has a quick connector. In the open state, the motor will transmit the force to the ball screw pair through the coupling, and the ball screw pair will transmit the force to the quick connector through the connecting sleeve. So that the quick connector can move up. Finally, the quick connector will pull up the safety valve to open and make the residual gas overflow. The specific structure is shown in Fig.2.

3.2. The Displacement Sensor.
This device uses Hall Effect to measure the displacement of the quick connector. Based on SS94A1 Hall Sensor[7], a movable magnet is used as a trigger. When the magnet and the sensor have relative displacement, the output voltage signal of the sensor will also change. The power supply voltage of SS94A1 Hall Sensor is 6.6~12.6V, the working temperature is -40~120°C, and the output current is
1mA. The relationship between output voltage and magnetic field intensity is shown in Fig.3:

![Fig.3. SS94A1 output characteristics](image)

It can be seen from Fig.3 that the output signal of SS94A1 is in proportion to the magnetic induction intensity. And the relationship expression between them can be obtained, where $U$ is the output voltage and $B$ is the magnetic induction strength.

$$U = 40B$$  \hspace{1cm} (1)

On the basis of the formula, the relationship between the output voltage and the displacement is tested. Changing the distance between the magnet and SS94A1 by moving the magnet. The output voltage corresponding to the displacement is detected by the MCU. The relationship between the displacement and the output voltage is obtained as shown in Tab.1.

| Displacement (mm) | Output voltage (V) |
|-------------------|-------------------|
| 0                 | 1.999             |
| 0.5               | 1.935             |
| 1                 | 1.871             |
| 1.5               | 1.814             |
| 2                 | 1.759             |
| 2.5               | 1.690             |
| 3                 | 1.634             |
| 3.5               | 1.603             |
| 4                 | 1.571             |
| 4.5               | 1.529             |
| 5                 | 1.486             |
| 5.5               | 1.443             |
| 6                 | 1.407             |
| 6.5               | 1.368             |
| 7                 | 1.337             |
| 7.5               | 1.302             |
| 8                 | 1.275             |
3.3. Exhaust Control Device

3.3.1. The part of Exhaust Control Device.
The Exhaust Control Device is composed of box shell, exhaust pipe, solenoid valve and U-bolt. The box shell is made of 2mm stainless steel plate. There are five inlets and outlets in the exhaust pipe, which are respectively connected to the atmosphere, the air outlet of the opening device, the drainage outlet, the overflow pipe and the gas recovery container. The whole structure is shown in Fig.4.

Fig.4. Exhaust Control Device

3.3.2. Explosion-proof Solenoid Valves.
The solenoid valve adopts 2S-250-25 Normally-closed Explosion-proof Solenoid Valve. Its specific structure and components are shown in Fig.5. It is driven by 24V DC power. The rated power is 19W, the applicable aperture is 25mm, the working temperature is -5~80℃, and the working pressure is 0~700KPa. The solenoid valve adopts a direct acting piston structure, which uses the force generated by spring deformation to keep the piston in the position of air outlet, and isolate the air inlet from the air outlet and keep it closed for a long time. As shown in Fig. 6. When the current passes through the coil, the magnetic field is generated, and the electromagnetic interaction force (Like poles repel, unlike poles attract) is used to promote the upward movement of the piston, so that the air inlet and outlet are connected to ensure that the gas can flow in the solenoid valve. As shown in Fig.7. In addition, the explosion-proof mark of the solenoid valve is Ex mb IMb Ex mb II T4 Gb DIP A20 TA T4, which is suitable for the places where explosive gases frequently appear or exist for a long time. It is very suitable for the explosion-proof conditions required of the device.

Fig.5. Normally-closed Explosion-proof Solenoid Valve
4. Circuit Part

4.1. The Overview of Circuit
As shown in Fig. 8 is the circuit block diagram of the exhaust control system. The circuit of the exhaust control system is mainly composed of five parts, which are operation amplifier circuit, solenoid valve driving circuit, motor driving circuit, tuning fork liquid level meter feedback circuit, voltage conversion circuit and two control switches.

4.2. Voltage Conversion Circuit
The voltage conversion circuit uses B2405S chip to convert +24V voltage to +5V, and then uses AMS1117-3.3 chip to reduce the +5V voltage to +3.3V to supply power for the single-chip microcomputer. The +5V voltage is converted into -5V through LMC7660 to supply power for Hall Sensor. The voltage difference between the output voltage of Hall sensor and the negative electrode collected by single chip computer AD is 0~3.3V. Fig.9 shows a buck circuit in a voltage conversion circuit.
4.3. Solenoid Valve Driving Circuit
The five solenoid valves of the exhaust control device are all controlled by the single chip microcomputer. The opening state of each solenoid valve in different modes is different. Therefore, we use TLP281 photoelectric coupler[8] as trigger device. The specific working process of the circuit is as follows: first, let the I/O port of MCU output high level, so that the internal infrared light-emitting diode of TLP281 works, and the light emitted by infrared light-emitting diode makes its internal photosensitive triode turn on, and uses 10V Zener Diode. The voltage between the gate and source of MOS transistor is stabilized at 10V. The MOS transistor is connected, the solenoid valve is opened, and the switch diode is paralleled with the solenoid valve to form the solenoid valve protection circuit. Fig.10 is a circuit diagram of the drive circuit of the solenoid valve.

![Fig.10. The Drive Circuit of Solenoid Valve](image1)

4.4. Operation Amplifier Circuit
The output voltage of BSLM-3 tension sensor used in this device is in mV. The voltage signal is very weak, so it is difficult for single chip microcomputer to collect the change of voltage. Therefore, an operational amplifier circuit is needed to amplify the signal to 0 ~ 3.3V. The device uses AD620 amplifier chip[9], which is a low-cost, high-precision (maximum nonlinearity of 40ppm), low power consumption (the maximum working current is only 1.3mA). It only needs an external resistor to set the gain multiple, and the gain range is 1-10000 times. The formula of gain G is

\[ G = \frac{49.4K\Omega}{R_G} + 1 \]  \hspace{1cm} (2)

The operational amplifier circuit of the device selects 100Ω peripheral resistance. According to the gain formula, the gain multiple G is 495 times. The voltage signal output from the tension sensor is amplified by 495 times, which is just within the voltage collection range of the single-chip microcomputer of the device. Fig.11 shows the specific circuit of the signal amplification circuit.

![Fig.11. The Signal Amplification Circuit of Tension Sensor](image2)

5. Summary
Our system uses single chip microcomputer to solve the problem that the gas can not be exhausted in the cleaning process of tank truck, and does not need repeated water injection. The volume of water used is the same as that of tank, which greatly reduces the consumption of water resources, and the exhaust effect is better than Steam Fumigation Method and High-pressure Water Cleaning Method. In
addition, the device has the advantages of small size, mobility and easy disassembly and assembly. One set of device can be used by multiple tank trucks, which reduces the cost of enterprises.

Acknowledgment

(1) National key R & D project: Research on measurement method of new methane ventilation and dust prevention safety instrument in mine, subject No.: 2017yff0205501
(2) Key R & D project of Zhejiang Province: online monitoring and early warning technology and application of multi hazard factors in production and operation sites, project plan No.: 2018c03035

References

[1] Yan Min, Zhong Yong, Min Jun, Yang Songyue. Research and application of tank car cleaning technology for hazardous chemicals transportation [J]. Industrial safety and environmental protection, 2019,45 (07): 40-43+101.
[2] Zhang Wenqi, Xi Danli. Research on cleaning technology of hazardous chemicals transportation tank truck [C]. Shanghai Society of chemistry and chemical industry. Shanghai Society of chemistry and chemical industry: Shanghai Society of chemistry and chemical industry, 2007:288-289+284.
[3] Zhang Yinghua. Design and implementation of intelligent control system for single chip microcomputer [J]. Volkswagen standardization, 2020 (13): 39-40.
[4] Xingchun Wang, Yiling Xu, Sujing Wang, Qiang Xu, Thomas C. Ho. Comprehensive study on boil-off gas generation from LNG road tankers under simultaneous impacts of heat leakage and transportation vibration[J]. Fuel,2020,275.
[5] Zhang Xianli, introduction to explosion proof electrical [M]. China Machine Press, 2014.
[6] Pu Lianggui, Ji Minggang. Mechanical design (8th Edition) [M]. Beijing: Higher Education Press, 2012, 360-385.
[7] Liu Rongxian, Li Fan, Cui Shouji. Design of hall type linear small displacement sensor [J]. Journal of Yangzhou University (NATURAL SCIENCE EDITION), 2013, 16 (04): 47-50.
[8] Zhang Shengyan, Rong Gang, Wang Kangkang, Liu Fei. Design of solenoid valve drive circuit based on interlocking double command control [J]. Astronautics measurement technology, 2018,38 (06): 91-95.
[9] Chang Xing. Design of ECG monitoring amplification signal based on AD620 [J]. Electronic quality, 2016 (10): 30-32.