Design and Research of a Certain Type of Automatic Alarm Equipment

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Abstract: Rapid detection of oxygen leaks in pipelines is crucial to prevent catastrophic accidents. This paper presents the design of an oxygen leakage detection and alarm instrument that converts ultrasonic signals, generated by gas escaping through small holes, into audible frequencies for headset use. This instrument is particularly suitable for ensuring the airtightness of oxygen supply systems for flight crews, engine startup supplemental oxygen systems, and four-station oxygen supply equipment. The design integrates ultrasonic principles, signal processing, computer control, and anti-jamming technologies to detect even minor leaks from a distance. The modular design includes components such as ultrasonic sensors, preamplifiers, filtering circuits, and microcontrollers, ensuring high detection sensitivity and reliability. The alarm system features light and sound alerts, enhancing maintenance efficiency and safety. This modern precision testing instrument significantly improves upon traditional leak detection methods like soapy water tests.

Keywords: Air Leakage, Alarm Instrument; Signal Conversion, Design Study, Gas Tightness

1. Introduction

In order to strengthen the inspection of the sealing of the oxygen supply system for flight crews, the engine start-up oxygen replenishment system and the four-station oxygen supply equipment, it is proposed to develop a set of testing equipment for inspecting the sealing of the oxygen supply system for flight crews, the engine start-up oxygen replenishment system and the four-station oxygen supply equipment, to reform the means of maintenance, to improve the scientific nature of the inspection method, and to reduce the workload of the aircraft maintenance personnel.

2 Technical Programs and Work Processes

2.1 General Design Ideas

The general design idea behind the development of a certain type of oxygen leakage detection alarm is:

(1) Research and analyze the working rules of the pilot oxygen supply system, [1] engine start-up oxygen supplement system and four-station oxygen supply equipment, common leakage parts and the size of the leakage, and then determine the test method, test sensitivity, test process and failure criteria.

(2) According to the working rules of aircraft oxygen supply system, common leakage parts and leakage size, test process and the requirements of the inspection items stipulated in the maintenance regulations of pilot oxygen supply system and engine start-up oxygen supplement system, a certain type of oxygen leakage detection and alarm instrument is designed and developed. [2] The main basis for development is the aircraft maintenance regulations and aircraft oxygen system testing process requirements.

2.2 Overall Layout

A certain type of oxygen leakage detection and alarm instrument consists of display panel, mounting bracket and so on. The display, sensitivity adjustment knob and so on are fixed on the panel, the power charging socket, earphone socket and laser are fixed on the shell of the detector, and the circuit board, power supply and so on are fixed on the mounting bracket. The power supply is fixed on the bottom left side of the bracket. For the convenience of maintenance, the panel is separated from the rack.

2.3 Principles and Techniques

When oxygen leaks from a pipe, the turbulence created by the gas will generate ultrasonic waves at the small holes, which can be detected by a certain type of oxygen leakage detector from several meters away. The Oxygen Leakage Detection Alarm converts these signals, which are inaudible to the human ear, into frequencies that can be easily heard through headphones.[3] The laser generated by the Oxygen Leak Detection Alarm's laser will point to the exact location of the leak several meters away, and even small leaks in very small holes can be detected. In the development of a certain type of oxygen leakage detection and alarm instrument will be comprehensive use of ultrasonic principles, computer control, signal processing, anti-jamming technology, structural optimization and design technology, error compensation technology and environmental adaptability technology design, and in the environmental adaptability to meet the requirements of the national military standards.

A certain type of oxygen leakage detection and alarm instrument adopts intelligent modular design method to design various modules according to different functions, mainly including 1) initialization module; 2) serial communication module; 3) data acquisition module; 4) data preprocessing module; 5) digital filtering module; 6) self-testing module, etc. The main program is used to connect them effectively to become a complete system. The main program is used to connect them effectively to become a complete system. After the working power is turned on, the main program will run automatically, firstly start the self-test program, when a certain type of oxygen leakage detector and alarm works normally, then carry out the calibration of the warning value, collect the output information of the ultrasonic sensors, and then calculate the amount of oxygen leakage through the processing of the MCU, and store and output it; otherwise, output and display the fault code.

2.4 Hardware Components and Fundamentals

The block diagram of a certain type of oxygen leakage detection and alarm instrument is shown in Figure 1. It mainly consists of ultrasonic sensors, sampling and holding circuits, preamplification circuits, filtering and anti-interference circuits, false alarm recognition circuits, A/D conversion circuits, microcontroller, D/A conversion circuits, power amplification circuits, light alarm devices, voice alarm devices and other components.

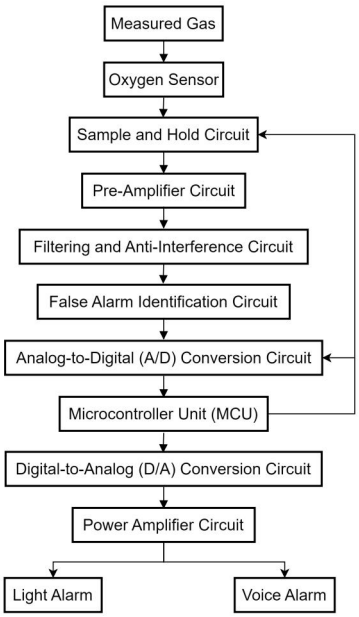

Figure 1. Oxygen Leakage Detector and Alarm Principle Block Diagram

2.4.1 Ultrasonic sensors

When oxygen leaks from the pipeline, the turbulence generated by the gas will produce ultrasonic waves at small holes, which can be detected by ultrasonic sensors. A certain type of oxygen leakage detector and alarm converts these ultrasonic signals, which are inaudible to the human ear, into a frequency that can be easily heard through headphones.

2.4.2 Sample holding circuit

Coordinated by the microcontroller to control the holding rate of the sampling and holding circuit, the ultrasonic sensor produces an audio signal proportional to the amount of oxygen leakage through the pre-amplifier circuit amplified output

2.4.3 Preamplifier circuit

Ultrasonic sensor output audio signal amplitude is very small, the use of operational amplifiers as the main body of the pre-amplifier circuit to amplify the signal, the trial proved that the circuit can work properly in a harsh environment. Ultrasonic sensor output audio signal amplitude is very small,

the use of operational amplifiers as the main body of the pre-amplifier circuit to amplify the signal, the trial proved that the circuit can work properly in a harsh environment

2.4.4 Filtering and anti-interference circuits

Firstly, the interference sources were identified, active and passive interference models were established respectively, and tracking and elimination were carried out for specific interferences. Electrical shielding, frequency selective amplification and signal averaging techniques are used to eliminate all kinds of interference that may be brought in. The main components of the filtering and anti-interference circuit include high-impedance op-amps, resistors and capacitors, and other separation of the original, the circuit design is mature;[4] due to the ultrasonic transducer output signal is very small, in order to facilitate the effective realization of the A/D conversion, we take the filtering circuit and the amplifier circuit to work together to achieve the overall signal logarithmic amplification and filtering, effectively enhance the input signal, inhibit the interference of high-frequency noise.

2.4.5 False alarm recognition circuit

Verification shows that the equipment in practical applications may appear audio signal over the warning value and false alarms and other false alarms, the main reason is the power supply spike voltage, environmental noise and other interfering factors, in order to reduce the rate of false alarms, we have designed a false alarm recognition circuit; the specific idea is that when the rate of change of the signal voltage is more than the maximum predetermined value or greater than the warning value, under the control of the microcontroller, the false alarm recognition circuit, which has the core of DSP, opens the signal pathway to recognize the signal, and filters out the wrong information to avoid the warning device from being triggered by mistake.[4] Under the control of the microcontroller, the DSP-based false alarm recognition circuit opens the signal path, recognizes the signal, filters out the wrong information, and avoids the false triggering of the warning device.

2.4.6 A/D conversion circuit

Based on the consideration of focusing on improving the detection accuracy and coordinating the speed of signal processing, the sampling rate of the designed A/D conversion circuit is 10KHz and the number of sampling bits is 12 bits.

2.4.7 Microcontroller circuit

The microcontroller is in a control and management position, responsible for receiving the oxygen leakage signal output from DSP filtering calculation, carrying out simple signal processing, coordinating the real-time work of ARM+LCD circuit and driving the D/A circuit to give alarm information, etc. It has the advantages of mature technology, easy to realize, high reliability, and is also conducive to the quantitative production of the instrumentation; due to the short development cycle, we will improve the design in the future and consider using a high-performance processor to further improve reliability and reduce costs. [5] Due to the short development period, we will improve the design in the future and consider adopting a high-performance processor to further improve the reliability and reduce the cost.

2.4.8 D/A conversation circuit

The final output of the microcontroller is converted into an analog voltage to drive the alarm device to work.

2.4.9 Power amplifier circuit

The power amplifier circuit is used to drive the light and voice alarm devices and consists of separate components such as emitter outputs, while heat sinks are used to improve circuit reliability.

2.4.10 Light and sound warning devices

Lights and sound alarm device receives the oxygen leakage alarm instruction at the same time, the basic principle is similar to the police equipment, through the different brightness of the light flashes, the size of the alarm volume real-time response to the size of the oxygen leakage to achieve the fault instructions at a glance, easy to recognize.[6]

The power supply circuit is mainly used to turn the AC 220V/50Hz voltage into +12V DC to ensure that the alarm instrument power.

2.5 Software Composition and Fundamentals

A certain type of oxygen leakage detection and alarm instrument adopts distributed control network technology based on CAN bus, and its software writing mainly includes the programming of CAN bus protocol and

the programming of each node function in two major parts. According to the control characteristics of the microcontroller, the software adopts the mixed programming method of C language and assembly language, which not only improves the development efficiency, but also improves the real-time performance of the system. The programming of the CAN bus protocol is mainly composed of the SJA1000 initialization module, the data receiving module, the task sending module, and the error handling module, etc. The programming of each node function is in accordance with the "SJA1000" principle, and is based on the "SJA1000" principle. The programming of each node function in accordance with the "top-down, layer-by-layer subdivision" design principle, the software system is divided into a number of functional modules, according to the different functions of the design of each module, including 1) initialization module; 2) serial communication module; 3) data acquisition module; 4) data pre-processing module; 5) digital filtering module; 6) self-test module and so on.) self-test module, etc. Each functional module is both interconnected and independent of each other, so that the software system has a clear structure and a clear division of labor, which makes it easy to use the main program to effectively connect them into a complete system. After the working power supply is turned on, the main program runs automatically, firstly, the ultrasonic sensor is initialized and exercised, and then the self-test program is started, such as the oxygen leakage detection alarm is normal, then the warning value is calibrated, and the output information of the ultrasonic sensor is collected, and then it is processed and calculated by the monolithic computer to get the information of oxygen leakage amount and stored and output; otherwise, the output and fault code are displayed.[7]

In the process of writing the program, first of all, we should understand the hardware resources of the system, and make a reasonable allocation of each piece of ROM and RAM to avoid conflicts; then we should understand the function module of each node and give a unified definition; finally, we should write the program code, debugging and modification until the software design meets the requirements of the system.

2.6 Alarm Working Process

When oxygen leaks from a pipe, the turbulence created by the gas generates an ultrasonic wave at the small hole, which can be detected by a certain type of Oxygen Leak Detection Alarm from a distance of several meters. The Oxygen Leak Detector converts these inaudible signals into frequencies that can be easily heard through headphones. The laser generated by the Oxygen Leak Detector's laser will point to the exact location of the leak several meters away, and even small leaks in very small holes can be detected. When detecting the oxygen leakage from the aircraft oxygen system, the alarm instrument can quickly give an alarm, requiring the maintenance personnel to take immediate measures to avoid the occurrence of vicious accidents. [8] The alarm is suitable for detecting the airtightness of the pilot oxygen supply system, engine start-up oxygen supplement system and four-station oxygen supply equipment of all types of airplanes in service. Compared with the traditional way of measuring leakage with soapy water, a certain type of oxygen leakage detection alarm instrument shows the superiority of modern precision testing instrument.

3. Main Technical Difficulties and Solutions

In the development process of "a certain type of oxygen leakage detector and alarm", the main technical difficulties encountered are: single-board computer control circuit design, LCD interface circuit design, improve detection sensitivity and anti-interference circuit design.

3.1 Microcontroller Computer Control Circuit Design

Correct data transmission and real-time modular program control are very important for oxygen leakage checking. Considering the rapidity and accuracy of parameter transmission, it is proposed to use serial SDLC synchronous data communication and program control using interrupts and DMA, etc., which is implemented as a main control unit with a microcontroller with superior industrial control performance.[9]

Microcontroller control circuit consists of microcontroller, reset circuit, clock circuit and

address decoding circuit.

The P0 port of the microcontroller is used as a data bus, the P1 and P3 ports are used as control lines, and the P2.0 and P2.1 ports are used as read data selector and write data selector through the decoder U3A and U3B.

3.2 LCD Interface Circuit Design

LCD interface circuit using a direct access interface circuit, through this interface, ARM processor to the LCD read and write operations do not need to realize the complexity of the timing control through the software, as long as it is treated as an ordinary I / O interface operation can be realized simply and effectively. But the LCD is still different from the LED, LED display requires the microcontroller to transmit a smaller amount of data, so it will not take up too much processor time, but the LCD display is rich in content, so it needs to transmit a larger amount of data, but in fact, each time the content of the change is not too much, so it can be updated for different situations on the LCD, thus saving the processor time spent on the LCD. The LCD interface circuit is shown in Figure 2.

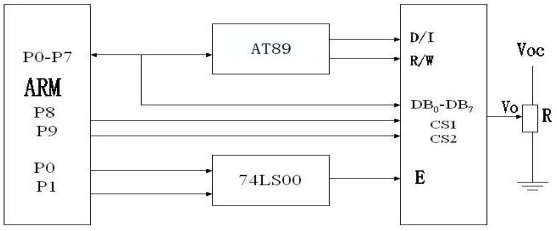

Figure 2. LCE Interface Circuit

3.3 Improvement of Detection Sensitivity

The solubility of oxygen dissolved into the atmosphere is very strong, after the leakage of the oxygen supply system of the airplane, the oxygen will be rapidly dissolved into the atmosphere, and the external atmospheric system is an infinite space, which brings great difficulties to the leakage detection. In order to solve this difficulty, on the one hand, we chose a high amplifier with high magnification, on the other hand, we used two sensors working in series to improve the sampling sensitivity.

3.4 Anti-Interference Measures

After taking measures to improve the detection sensitivity, it is a good solution to the problem of too slow leakage detection, but at the same time, it also brings a new problem, that is, the instrument's ability to resist interference has become very poor, and the working environment is slightly changed, the LCD indicator's indication value keeps jumping and cannot indicate a stable value.

Interference signals include active and passive interference, i.e.

$$J_{RF}^{k}(t) = J_{IRF}^{k}(t) + J_{ARF}^{k}(t) \tag{1}$$

where $J_{IRF}^{k}(t)$ is the passive interference signal and $J_{ARF}^{k}(t)$ is the active interference signal.

(1) Passive Interference Signal Model

Only the mathematical model of the passive interference signal is given here. The signal expression for the interference is given as:

$$\begin{aligned} J_{IRF}^{k}(t) &= K_{RF} \bullet \sqrt{\frac{P_t \bullet L_s}{(4\pi)^3}} \bullet \frac{g_{vt}(\theta_{Jc}) \bullet g_{vr}(\theta_{Jc})}{R_{Jc}^2(t)} \bullet \lambda \bullet \sqrt{\sigma_{kJc}(t)} \\ &\bullet \exp\left[j\omega_c (t - \frac{2R_{Jc0}}{c} - kT)_r \right] \bullet \exp\left[j\pi b (t - \frac{2RJc(t)}{c} - kT_r)^2 \right] \\ &\bullet \exp\left[j\omega_k (t - \frac{2R_{Jc1}(t)}{c} - kT_r) \right] \bullet R_{ect}\left[\frac{t - \frac{2R_{Jc}(t)}{c} - kT_r}{T_p} \right] \end{aligned} \tag{2}$$

(2) Active Interference Signal Model

Let the interfering signal be a noise signal J_t with transmit power P_J , center power and bandwidth BW_J . Then the model of the active interference signal with a bandwidth of BW_J can be expressed as:

$$J_r(t) = \left[\frac{\lambda^2 P_J L_J L_r B W_r}{(4\pi)^2 R_j^2(t) B W_j} \right]^{1/2} \bullet g_v(\theta_J) \bullet g_J \bullet A_{J(t)} \bullet \exp\{j[\omega_1 t + \phi_J(t)]\} \bullet k_{RF} \bullet G_{IF} \bullet L_{IF} \tag{3}$$

There are two main sources of interference: one is brought in by the power supply, the other is through the coupling between the various devices into. The coupling between the various devices into the electrical interference, the main use of electrostatic shielding method to be eliminated; from the power supply into the interference, the main use of the power supply filtering method and the following measures to be eliminated: ① in the detection of the signal amplifier circuit using frequency amplification technology, in order to filter out the 50Hz frequency and its 100Hz multiplier interference and the interference may be brought into the foreground, frequency amplifier circuit of the center frequency The center frequency of the frequency selection amplifier circuit is located

at, and the bandwidth is 10Hz.

Here, in order to stabilize the frequency of the output signal of the sampling circuit at 80Hz for frequency selection and amplification, a tuning fork precision clock oscillator is used and a frequency division of 2,000 is carried out by software; (2) signal averaging is used to average the signals in order to further eliminate possible interference. In addition, the hardware circuit design of the entire instrument is divided into digital and analog signal two parts of the realization. These two parts communicate through their respective data interfaces, this method greatly reduces the interference of analog signals to the digital signal processor (DSP), to provide a good working environment for the DSP system, to ensure that the instrument in a variety of environments can work properly.

The alarm instrument is intrinsically safe and is intrinsically safe and explosion-proof composite type.[10] The alarm instrument adopts the latest microelectronic technology and automatic control technology in the circuit design, which makes its detection precision high, simple operation and good reliability. The alarm instrument is small in size, light in weight, high in detection sensitivity, strong in adapting to the environment and long in service life. In addition, the unique extended sampling device and laser facilitate the use of personnel to detect the equipment that should not be directly accessed, for the oxygen supply system, the engine start-up oxygen replenishment system and the four-station oxygen production and supply equipment sealing of the daily test, provide a means of maintenance and improve the scientific nature of the inspection method.

References

[1] ShuliJi. Application of virtual instrument technology in electronic measurement. Engineering Technology Research, 2023,04:98-99.

[2] Yan Zhou. Application mode and prospect analysis of virtual instrument technology in petrochemical testing. Contemporary Chemical Research 2017,02:43-44.

[3] Liu Suzhen, Rao Nuoxin, Li Hua, Xu Guizhi. Design of electrical and electronic experimental platform based on virtual instrument technology. Experimental Technology and Management, 2016,12:121-124.

[4] Ji-Li Xie. Liquid pressure measurement and control based on virtual instrument. Science and Technology Innovation and Productivity, 2017, 03: 109-111.

[5] Zhang Huimin. Research on virtual instrument design and fault diagnosis method of vibration and test system. North China Electric Power University, 2022.

[6] Ma Nanfeng. Research on virtual instrumentation for rotor system condition monitoring. Nanjing University of Aeronautics and Astronautics, 2021.

[7] Lu Yifang; Lan Jinhui; An introduction to the experimental reform of instrumentation science and technology, Educational Teaching Forum, No. 028, 2024:101-104.

[8] Wang, X.J.; Shih, W.G.; Laser engineering measuring instrument, Mine Measurement, Vol. 4, 2002, 18,25.

[9] Dingli Zhu, Introduction of a program control measuring instrument-PKM630 type polar coordinate measuring instrument. Measurement Technology. 2020, Issue 009: 67-70.

[10] Roger Blake, Saphore. A psychometric comparison of an electronic and classical survey instrument. 2019.

