Infrared Detection Technology-Based Safety Monitoring of Oxygen Cylinder Filling Process

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Abstract. During the process of filling the oxygen cylinder, if the flammable gases such as H₂ and C₂H₂ are also filled into the cylinder, there may be an explosion, which may threaten the production safety. In order to prevent this, a real-time detection of cylinder temperature plays a vital important role in the filling process of oxygen cylinder. This paper designs a temperature early warning system and error correction method. The system is mainly composed of a STM32 microprocessor, a MLX90614 infrared temperature measurement module and a LCD display. By measuring the temperature which reaches the limit of alarming, the cylinder temperature obtained by the real-time detecting of infrared temperature measurement module will be transferred to the single-chip microcomputer for further processing. In the end, data will be transmitted to the LCD display and the buzzer from the single-chip microcomputer.

Introduction

Infrared ray is located in the middle of electromagnetic spectrum i (red lateral), all objects with temperature above absolute zero (- 273 °C) radiate the infrared energy. This is the basis of infrared temperature measurement technology. Therefore, the temperature of object surface can be measured according to the size of infrared energy radiated. The infrared detector, such as infrared temperature measurement module is designed on the basis of this theory. Nowadays, the temperature measurement module is widely used in military, metallurgy, mining and other industries. Based on the non-contact technical requirements of the oxygen cylinder temperature monitoring, an infrared cylinder thermometer is designed using the MLX90614 infrared detector as the temperature measurement module, and the single chip microcomputer STM32 as the core module.

Principle of Infrared Thermometry

The temperature measurement principle of infrared thermometer is the black body radiation law, however in daily life, there is no ideal black body existing, therefore people use grey body to describe all objects in daily life. The monochromatic radiation of the gray body is smaller than that of the black body. The ratio can be expressed in monochrome black degree, and the corresponding numerical expression is:

\[ \varepsilon(\lambda) = \frac{M(T)}{M_b(\lambda T)} \]  (1)
System Hardware Design

Infrared thermometer cylinders hardware is mainly composed of the STM32 processing unit, the infrared temperature measurement module, the LCD display module, the buzzer, the stepper motor and the peripheral circuit. The structure of the hardware connection is as Figure 1 shown.

![Figure 1. Structural connection diagram of the hardware part of the infrared thermograph.](image)

Microprocessing Module

As the processing core of the infrared thermograph, we choose STM32F103RC chip manufactured by ST company as the microprocessor, which is a low power and high performance ARM single chip microcomputer. The core part of this chip is the cortex-m3 CPU, with a memory of up to 64K bytes of SRAM, and a flexible static memory controller with four chip options. In addition, this chip owns up to 112 fast I/O ports, 11 timers and 13 communication serial ports, which fully meets the functional requirements of our design.

Crystal Oscillator. The crystal oscillator is the “heart” of the single chip microcomputer and the benchmark of the working time cycle of SCM. STM32 has a different criteria for the crystal vibration frequency and the configuration. Generally, the minimum microcontroller system requires both external High Speed Clock (HSE) with a crystal vibration frequency between 4-26 MHZ, and Low Speed Clock (LSE) with a frequency of 0~100KHz. For the HSE, the internal phase-locked loop results in a frequency multiplication to formulate the working frequency of peripherals, while LSE can provide the baseline for the real-time clock.

BOOT Startup Mode Selection. STM32 has three startup modes. When BOOT0=0 and BOOT1=0 or 1, STM32 starts from Flash on the chip, which is also the most commonly used starting mode. When BOOT0=1 and BOOT1=1, STM32 starts from internal memory, and this method is mostly used for debug test phase. When BOOT0=1 and BOOT1=1, STM32 starts from the system memory, which is often used in the simulation phase. BOOT pin 1 or 0 is achieved by using 10K resistance to connect to VCC power or by pulling up or down GND.

Reset Circuit. The reset of STM32 is active-low, means at the moment of RST grounding STM32 is reset. The reset circuit consists of a 10k resistor connected by VCC and a 0.1uF capacitance connected by GND, and a series connection between the two components. A button between the resistor and capacitance can be used to reset both electricity and button.

Infrared Temperature Measurement Module

Temperature collection is the most critical part of the infrared thermograph, which requires the reliability and accuracy. Our design is a kind of non-contact sensor which can measure the target and environment temperature. The size and distribution of wavelength of the infrared radiation energy are closely linked to the surface temperature. Therefore, by measuring the infrared radiation of the object itself, the surface temperature can be accurately determined, which is the principle of the infrared temperature measurement. The infrared energy focuses on the photoelectric detector and finally transformed to the electrical signal. Via an amplifier and a signal processing circuit, the signal is calculated and converted into the temperature of measured object after the correction of target emission rate.

The MLX90614 infrared temperature sensor is selected as the infrared temperature measuring module. MLX90614 has 4 pins, which are ground end VSS, digital signal output end SDA, power
supply end VDD and clock signal input end SCL. The IIC bus controller of the selected microcontroller STM32F103RC is compatible with the SMBus, therefore we connect the MLX90614 SCL with the clock line and data line of IIC bus controller. Meanwhile, in order to ensure the high level of SDA &SCL when the bus controller is not in use, two pull-up resistors is also connected to the power supply \(^1\).

**The Power Supply Circuit**

The infrared cylinder measuring thermometer uses 5V and 3.3v power supply. The former one is used for powering LCD display, and the latter one is to power the microprocessor. As a result, we choose MP2359 to convert the external current to 5V dc, and then convert the 5V power supply to 3.3v through the AMS1117-3.3 power conversion chip.

**LCD Module**

Infrared thermometer cylinders uses a 320 * 240 pixel color LCD display module, the display function can ensure the collected temperature data, system running status, and other information to be displayed in the LCD screen concretely and conveniently.

**System Error Correction**

**Temperature Determination of Oxygen Cylinders When Warning Occurs**

Infrared temperature measurement system is monitoring the temperature on the surface of oxygen cylinders, so the result would have certain difference compared to the actual gas temperature of the gas. in order to accurately set the alarming limit of temperature and improve the alarming accuracy, a detailed study is needed on the relationship between inside gas temperature and the outer surface temperature of the cylinder.

Difference of internal and external wall temperature of cylinder also needs to be considered. Assume that at a certain moment of oxygen filling, the cylinder temperature is \(t_f1\), the air temperature is \(t_f2\), the coefficient of thermal conductivity is \(\lambda\), the oxygen and air wall surface heat transfer is \(h1\) and \(h2\) respectively, the cylinder thickness is \(\delta\). Now we need to calculate the inner and outer surface temperature \(t_{w1}\) and \(t_{w2}\)\(\[^2\]\).

Because the thermal conductivity of the cylinder wall and the surface thermal conductance on both sides of the cylinder are the range values, the final result should also be a temperature range. Use \((\lambda, h1, h2)\) for calculation.

According to formula, the heat transfer coefficient \(k\) is:

\[
\begin{align*}
    k &= \frac{1}{\frac{1}{h_1} + \frac{\delta}{\lambda} + \frac{1}{h_2}} \\
    &\quad \text{(2)}
\end{align*}
\]

According to below formula, the heat loss per cylinder unit area, in another saying, the heat flux density during the heat transfer process via the cylinder wall, can be calculated:

\[
    q = k(t_{f1} - t_{f2}) \\
    &\quad \text{(3)}
\]

According to below formula, to the surface temperature of the inner wall of the cylinder can be calculated:

\[
    t_{w1} = t_{f1} - \frac{q}{h_1} \\
    &\quad \text{(4)}
\]

External surface temperature can be calculated:
\[ t_{w2} = t_{f2} + \frac{q}{h_z} \]  \hspace{1cm} (5)

**Distance Factor**

As a non-contact temperature measurement method, there are many factors that can lead to incorrect results in Infrared temperature measurement, which can be found during the use of the measurement sensor. All infrared measuring temperature sensors have D: S coefficient K, known as the distance coefficient. The measuring area is a circle with a diameter as D, and the distance coefficient represents the ratio of the diameter of the measurement area to the measured distance. It works like a flashlight. Different from the flashlight which casts a conical light on the object being measured, the infrared thermometer is measuring the temperature of the conical area. So it can be observed that the distance between the sensor and the object to be measured is one of the important factors which may cause the measurement error. The farther the distance, the bigger the conical area and the greater the influence of regional atmospheric radiation would be. According to the actual situation, the surface temperature of the cylinder at different distances can be measured with the infrared sensor and compared to the corrected surface temperature in Chapter 4.1. The modified compensation formula is obtained by using least square method for data fitting in the end. The \( x, y \) expression is then obtained based on multiple data points \((x_i, y_i)\)\(^3\).

\[ y = \varphi(x) \]  \hspace{1cm} (6)

In order to minimize the error of sum of squares, the expression is as below:

\[ Q = \sum_{j=1}^{N} \delta^2 \]  \hspace{1cm} (7)

Means, the value of expression No.7 is the smallest.

The fitting can be carried out by MATLAB software, and finally the compensation algorithm is written into the STM32 microprocessor.

**Summary**

In this paper, the infrared temperature sensor with STM32 as the microprocessor and MLX90614 as the core element realizes the function of the non-contact oxygen cylinder highest-limit temperature alarming. A set of measurement error correction method is proposed as well. The whole system fulfills the basic requirements of oxygen cylinder filling operation, which is stable, accurate and reliable.

**References**

