Design and develop of functional safety temperature transmitter for fault status

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Abstract. According to the requirements of the functional safety temperature transmitter high reliability, this paper selects the micro-power voltage reference, the reset monitor, the D-type flip-flop and the OR gate to design the functional safety temperature transmitter protection circuit for fault status. The protection circuit takes power from the data line of HART fieldbus by micro-power voltage references. According to the control signal of the functional safety transmitter, the protection circuit utilizes the state latch of D-type flip-flop, and realizes the functional safety temperature transmitter protection circuit for fault status.

Introduction

The functional safety temperature transmitter is specially designed to work under the harsh conditions or security applications. The functional safety transmitter is applied in industry as a highly reliable and safety protection facilities, and usually used in petrochemical and dangerous chemicals and so on\cite{1}. When the functional safety temperature transmitter fails, it must be fast and accurately respond to the failure, and avoid accidents or reduce the risk of accidents to the equipment and personnel\cite{2}.

This paper uses the 1oo1D(1-out-of-1 and Diagnosis) architecture to design the functional safety temperature transmitter. The functional safety temperature transmitter has a data acquisition channel and a diagnostic channel as shown in Fig. 1. The two channels are independent and not redundancy. The functional safety temperature transmitter uses the diagnostic circuit to improve the diagnostic coverage\cite{3} \cite{4}.

The functional safety temperature transmitter protection circuit for fault status is an important part of safety transmitter. When the functional safety temperature transmitter occurs dangerous failure, the protection circuit makes the power circuit of the functional safety temperature transmitter from normal working state to safety state, and the functional safety temperature transmitter stops power supply to avoid the error output. The protection circuit provides an important guarantee for the whole control system, and improves system security and reliability.
Design of Functional Safety Temperature Transmitter Protection Circuit for Fault Status

The functional safety temperature transmitter provides an important guarantee for industrial safety production. When the accident occurs, the functional safety transmitter can accurately and quickly enter into the safety state, and closes some functions or all functions, and performs security functions [5].

This paper takes the functional safety temperature transmitter on HART fieldbus as research object to design the protection circuit for fault status. The functional safety temperature transmitter protection circuit for fault status consists of power circuit and protection circuit, the principle diagram is shown in Fig2. The power circuit takes power from the HART fieldbus, and supplies power to the protection circuit; the protection circuit determines the state of functional safety temperature transmitter according to the security control signal of the main controller.

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A. Power circuit

The power circuit takes power from the HART fieldbus to simplify connection mode of the functional safety temperature transmitter protection circuit for fault status. The operating current range of HART fieldbus is 4~20mA, and add the digital signal to the operating current. The power circuit selects the micro-power voltage references LM285. The operating current of LM285 is 10 μA~20mA, and the dynamic impedance is 1Ω. According to the above parameters, the micro-power voltage references LM285 can work normally in the operating current range of HART fieldbus [6].

The power circuit uses the micro-power voltage references to generate 5V voltage, and supplies power to the protection circuit. The power circuit uses dividing resistor and PNP transistor to provide the reference voltage. The zener diode is paralleled with the output end of the power circuit to prevent from damaging to the other circuits by high output voltage. The decoupling capacitor is paralleled with the output end of the power circuit to reduce the noise voltage and improve the quality of power supply. The specific circuit is shown in Fig3.

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Fig.2 The functional safety temperature transmitter protection circuit for fault status diagram

Fig.3 The power circuit diagram
B. Protection circuit

According to the functional safety temperature transmitter of working conditions (initial power, normal work and failure conditions), this paper designs the protection circuit with the dual D-type flip-flop structure. The protection circuit is consisted of the control signal input circuit, the signal processing circuit and the executive circuit (as shown in Fig 4). When the functional safety temperature transmitter occurs dangerous failure, the protection circuit enters into the safety state, and uses the state memory function of D-type flip-flop to latch the output state. The protection circuit provides an important guarantee for the functional safety temperature transmitter, and improves system security and reliability.

![Fig.4 The power circuit diagram](image1)

### Device layout

The protection circuit is consisted of the D-type flip-flop, the reset monitor and the OR gate and so on, and the specific circuit is shown in Fig 5. The reset monitor controls the supply voltage of the protection circuit, and provides the protection circuit with the reset signal during the power-on or power-down. The protection circuit uses the diode and the transistor to realize the double-end control, the reset pin of the main controller and the control signal of the main controller are connected respectively with the two ends of diodes. Any pins’ low level of the diode will generate a shutdown signal to make the transistor in the shutdown state. The reset pin connects respectively with the set pin of the D-type flip-flop A and the reset pin of the D-type flip-flop B. So the output of D-type flip-flop is determined by the reset pin of the reset monitor when the D-type flip-flop powers on.

![Fig.5 The protection circuit](image2)

### Operating mode

The operating mode of protection circuit is consisted of initial power-up conditions, normal operating conditions and failure conditions, the details are as follows.

1. Initial power-up conditions

   The reset monitor outputs low level when the protection circuit power on initially. The set pin of the D-type flip-flop A and the reset pin of the D-type flip-flop B are low level, the reset pin of the D-type flip-flop A and the set pin of the D-type flip-flop B are connected to the positive terminal of
power circuit. According to the logical function table (table 1) of the D-type flip-flop, the /Q pin of the D-type flip-flop A and the Q pin of the D-type flip-flop B output the low level. Since the two input pins of the OR gate are low level, the OR gate outputs low level according to the truth table. Since the gate of P-channel and depletion type MOSFET is low level, the MOSFET is in conducting state, and the functional safety temperature transmitter can works normally. If the main controller can’t work normally, the reset pin of reset monitor outputs low level, and the transistor is in off state when the reset monitor changes from the power-on reset state to the normal operating conditions. The set pin of D-type flip-flop A and the reset pin of D-type flip-flop B are high level, the reset and set pins of D-type flip-flop A and the reset and set pins of D-type flip-flop B are high level, and the clock input pin of D-type flip-flop B changes from low level to high level by RC delay circuit. According to the logical function table, the Q pin of D-type flip-flop B output the high level. The OR gate outputs high level according to the truth table of OR gate, so the MOSFET is in off state and the functional safety temperature transmitter is in safe state.

Table 1. The D-type flip-flop logical function table

| Pins | Set pin SD | Reset pin CD | Clock pin CLK | Data pin D | Out pin Q | Out pin /Q |
|------|------------|--------------|---------------|------------|----------|-----------|
| State | L          | H            | X             | X          | H        | L         |
|       | H          | L            | X             | X          | L        | H         |
|       | L          | L            | X             | X          | H        | H         |
|       | H          | H            | ↑             | H          | H        | L         |
|       | H          | H            | ↑             | L          | L        | H         |

Note: L —— Low voltage level
H —— high voltage level
X —— don’t care
↑ —— low-to-high clock input transition

When the protection circuit works normally, the reset and set pins of D-type flip-flop A and D-type flip-flop B are high level, and the data input pin of D-type flip-flop A and D-type flip-flop B are low level, and the clock input pin of D-type flip-flop A is low level, and the clock input pin of D-type flip-flop B is high level. Since the clock input pin of D-type flip-flop does not generate the rising edge, the output of D-type flip-flop is the same as the protection circuit power on initially according to the logical function table of D-type flip-flop, so MOSFET is in conducting state, and the safety transmitter work normally.

2. Normal operating conditions

When the functional safety temperature transmitter occurs safe failure, the control end receives the shut-off signal (low level) or reset signal (low level) of the main controller. The Transistor changes from the conducting state to the off state, and the clock input pin of D-type flip-flop A changes from low level to high level, and the clock input pin of D-type flip-flop B does not change. According to the logical function table of D-type flip-flop, the /Q pin of D-type flip-flop A outputs the opposite of the data input pin, and the Q pin of D-type flip-flop B does not change. So the /Q pin of D-type flip-flop A outputs high level, and the Q pin of D-type flip-flop B outputs low level. The OR gate outputs high level according to the truth table of OR gate, so MOSFET is in off state and the functional safety temperature transmitter is in safe state.

3. Failure conditions

Once the control end of protection circuit receives the shut-off signal, the protection circuit shuts down the power circuit. If the data input pin of D-type flip-flop does not change, the protection circuit
outputs shut-down signal according to the state latch of D-type flip-flop whatever the status of clock input pin is. So it prevents effectively the functional safety temperature transmitter from generating an error output, and improves the functional safety temperature transmitter reliability.

C. Experimental verification

In order to verify the accuracy and rapidity of the functional safety temperature transmitter protection circuit for fault status, this paper makes respectively the control end and the reset end output the shut-off signal, and observes the output state of the protection circuit with the oscilloscope. The experiments are as follows

1. The control end shut-down experiment

The control end of main controller outputs the shut-off signal. The oscilloscope observes the output states of the control end of main controller and the protection circuit, and records the signal waveform (as shown in Fig6). The output state of MOSFET can respond quickly to the control end, and the response time is less than 1ms.

![Fig.6 The experimental results of the control end outputs low level](image)

2. The reset end shut-down experiment

The reset end of main controller outputs the shut-off signal. The oscilloscope observes the output states of the reset end of main controller and the protection circuit, and records the signal waveform (as shown in Fig7). The output state of MOSFET can respond quickly to the reset end, and the response time is less than 1ms.

![Fig.7 The experimental results of the reset end outputs low level](image)

As the Fig6 and Fig7 show, the functional safety temperature transmitter protection circuit for fault status can response accurately and rapidly according to the main control end and the reset end of the main controller, and improves the functional safety temperature transmitter security and reliability.
Conclusion

This paper designs the functional safety temperature transmitter protection circuit for fault status. When the functional safety temperature transmitter occurs safe failure, the protection circuit turns from normal working state to safety state, and stops power supply for the transmitter. Using the state latch of D-type flip-flop, the protection circuit prevents the safety transmitter from generating an error output when occurring safe failure. The protection circuit improves system security and reliability, and provides important guarantee for the functional safety temperature transmitter. It has the following advantages:

- Circuit simple and reliable. The functional safety temperature transmitter shutdown protection circuit for fault status is consisted of the micro-power voltage references, the reset monitors, the D-type flip-flop and the OR gate. The circuit is simple, low cost of hardware, high reliability, easy to implement.
- Wide universality. The protection circuit for fault status is not only the functional safety temperature transmitter but also other industrial control equipments.

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