DESIGN PRINCIPLES FOR A TEMPERATURE TRANSMITTER

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Annotation

This article discusses the **design principles of a temperature transmitter**, an essential device used in industrial measurement and control systems for converting temperature signals into standardized electrical outputs. The study explains the operating principles of temperature sensors such as thermocouples and resistance temperature detectors (RTDs), which serve as the primary sensing elements. Special attention is given to signal conditioning circuits, amplification, linearization, and analog-to-digital conversion processes that ensure accurate and reliable temperature measurement. The paper also analyzes important design factors including sensitivity, stability, response time, accuracy, and noise reduction.

Key words: Temperature transmitter, analog signal conversion, digital signal processing, industrial temperature measurement, signal linearization, electrical isolation, process control, amplifier.

Introduction

The transmitter is a measuring instrument which converts an analog input signal into a scaled, analog or digital output signal. Dependent on the requirements, this signal is then available in the measuring chain for further processing in a controller and/or for indication.

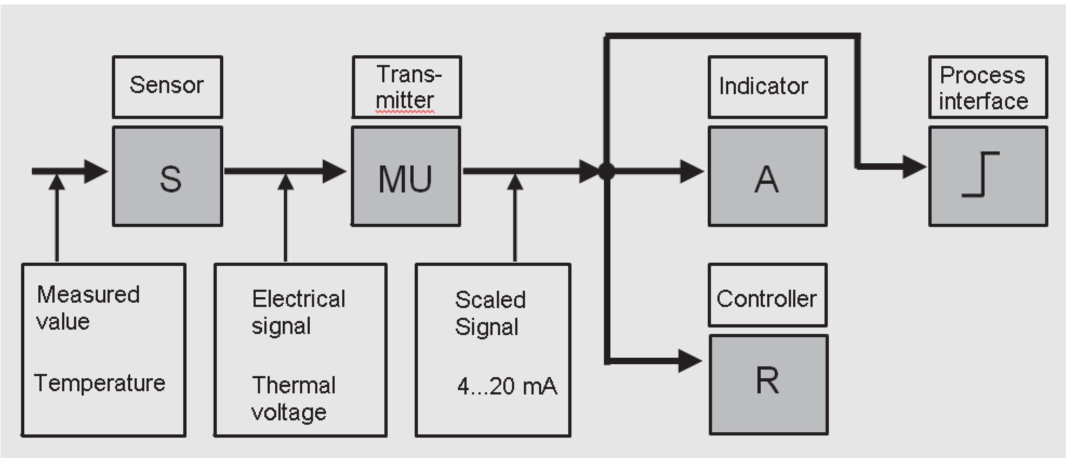

Figure 1. The components in an industrial temperature measuring chain.

Temperature transmitters operate based on the current measuring process (Lindeck-Rohte, better stated as a current cross coupled amplifier) which outputs a load independent current of 4...20 mA DC. The curves for the resistance thermometers or thermocouples are not linear. An additional function of the transmitter is to linearize the input signal in order to output a temperature proportional signal. Additional require-ments for a temperature transmitter

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include selectable measuring ranges, sensor failure monitoring, measuring circuit signal contact and the electrical isolation between input, output and power supply.

Temperature Transmitter in Four-Wire Technology

The transmitter shown in the following figure is designed to either measure the mV-signals (thermocouples) or make the resistance measurements (Pt100). It converts the input values into a proportional, load independent DC current signal of 0...20 mA or 4...20 mA or into a voltage signal of 0...10 V. The adaptation to the measured value type is accomplished by a selection made at the temperature transmitter or by using exchangeable measuring range modules.

The temperature transmitter in four-wire technology consist of a switched controller (1), which rectifies and stabilizes the supply power. A electrically isolated voltage (2) is supplied to the in- and output circuits. Additional circuit sections are the amplifier (3), measuring range module (4), electrical isolation (6), output stage (7) and alarm signalling (8).

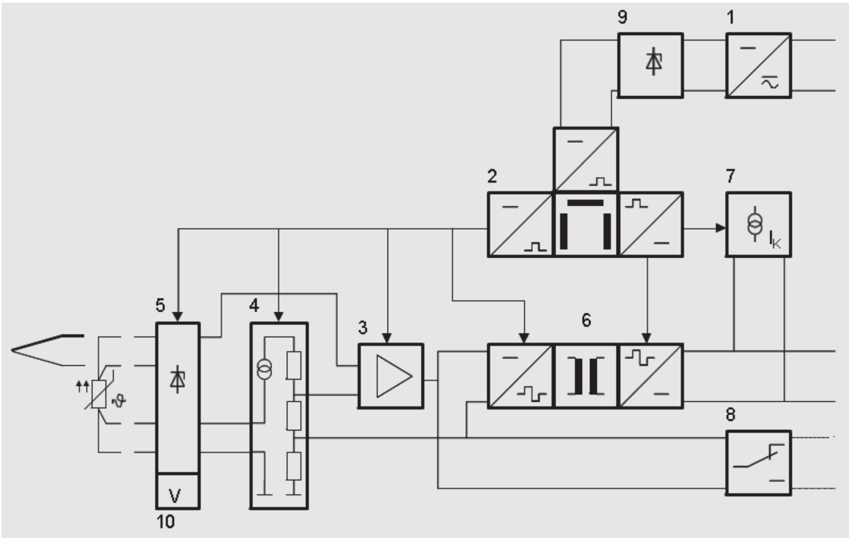

Figure 2. Schematic of a temperature transmitter in four-wire technology.

Transmitters in explosion proof designs incorporate a circuit limiter (5) for the Intrinsic Safety of the input circuit, a power supply limiting circuit (9) and electrical isolation (6). A different explosion proof design has intrinsically safe in- and outputs as well as elec-tronic current and voltage limiters in the output current circuit. In this design a electrical isolation between the input and output is not required.

The input signal is fed through the measuring range module (4) to the amplifier (3) whose output is a load independent DC signal. When a electrical isolation (6) circuit is installed, the DC current signal is chopped, decoupled by an isolating repeater and converted back to a load independent DC current in a rectified circuit with a load converter. This signal is unipolar. For conversion to a bipolar current signal or voltage an output stage (7) is required.

The reference junction correction (10) for thermocouples, monitors the temperature at the connection terminals of the temperature transmitter and accounts for its value in the measurements.

The alarm signal transmitter (8) has an adjustable switching point which can be either normally open or normally closed. For a purely analog operating temperature trans-mitter, this switch point can be set using a potentiometer. For digital temperature trans-mitters, the switch point, the temperature measuring ranges, the connected sensor and its connection circuit can be set using programming software.

Temperature Transmitter in Two-Wire Technology

In regard to their electrical functions, these transmitters, viewed from both connection terminals, can be considered to be passive, equivalent resistance circuits. The trans-mitter behaves as a variable resistor whose resistance changes until the current in the measuring circuit corresponds to the measured value. As a basic component, the 4 mA current, provides the power supply for the electronic circuits in the transmitter. The current is a load independent current with a signal range of 16 mA, which contains the measured value information.

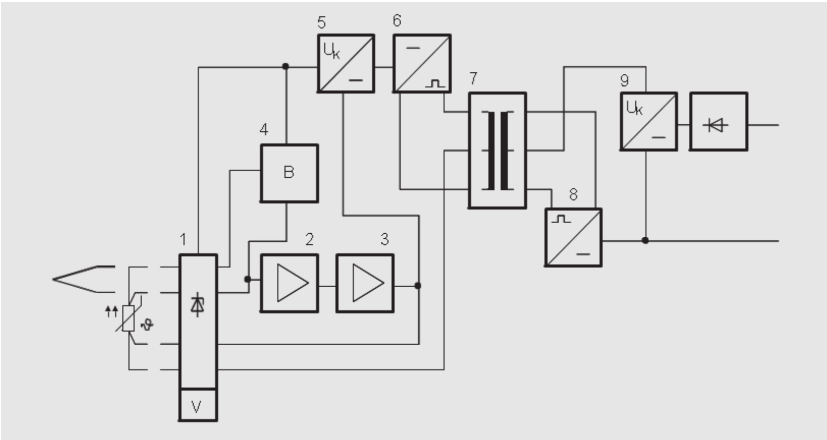

Figure 3. Schematic of a temperature transmitter in two-wire technology.

This transmitter is designed for the same input signals as the four-wire transmitter. It converts the input single values into a load independent DC current signal of 4...20 mA. The selection of the measured value type is made at the factory by adjustments made in the temperature transmitter.

Slope and zero values are also set at the factory in the temperature transmitter using precision resistors. The elimination of the potentiometer and the complete encapsula-tion of the electronics with potting material assure an unexcelled, rugged construction with long term stability. Transmitters for resistance thermometers or for thermocouples are built using this design.

The input signal is fed from the input circuit (1), configured based on the measuring method and measurement range, to the amplifier (2) and converted in a final stage (3) into a load independent DC current. The constant voltage source provides the circuit components with a stabilized voltage.

Error Monitoring

Error monitoring is an important function of the transmitter. Sensor failure, sensor short circuit and reacting when measured values are outside of the range setting must be recognized. These error conditions can also be signalled over the 4...20 mA output. Today the power supply required by the transmitters can be provided by a basic current < 3.5 mA. As a result, transmitters can be designed in which information can be trans-mitted outside of the 4...20 mA range. In the error monitor circuit (4) the output signal during a short circuit or measuring circuit interruption condition can be selected to be signalled at a current value either above or below the 4...20 mA range.

Measured values outside of the measuring range end values are error conditions, indicating an undesirable status of the process. Sensor failure or sensor short circuit in comparison are error conditions indicating that the sensor should be checked or repaired to rectify this condition. The NAMUR (International User Association of Auto-mation Technology in Process Industries) has published a recommendation defining current ranges, outside of the 4...20 mA measuring range, which provide an adequate separation, for the indication of a measured range error and for a temperature sensor error (Fig. 4). This allows the appropriate corrective measures to be initiated quickly.

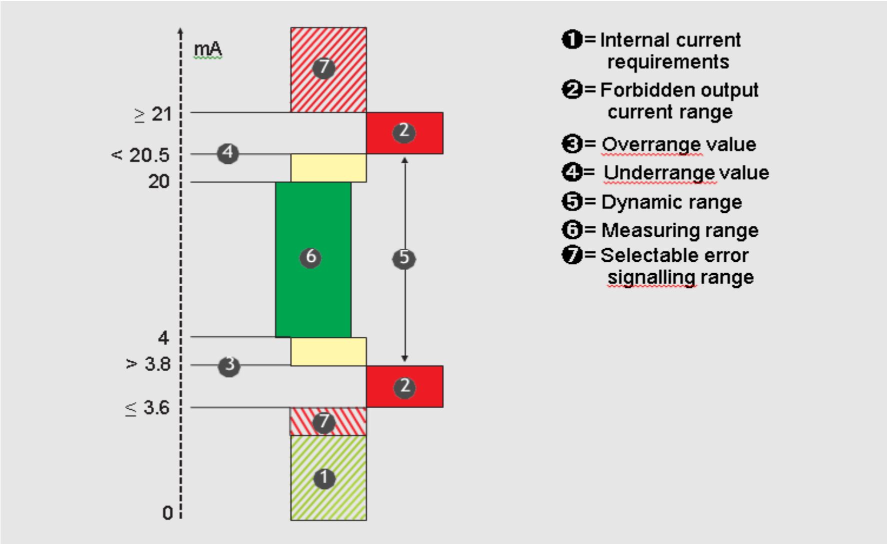

Figure 4. NAMUR limits for error signalling of a transmitter in two-wire technology (NAMUR-Recommendation NE 43).

Basically the range > 21 mA, as well as the range < 3.6 mA can be utilized for error signaling. Ideally, the behavior during an error condition should be selected so that during an error condition the alarm monitors connected to the output signal will not be effected. In addition, in programmable transmitters, different error conditions can often be user assigned. For example, an error condition which can turn a system off can be set if the current value is > 21 mA. Error conditions, which should only trigger and alarm, can be set if the current value < 3.6 mA. It should be noted, that during a power outage or a break in the 4...20 mA loop (not to be confused with a sensor failure) the current value is always 0 mA. A signalling of this error condition must be made using the analog input of the monitor.

Linearization

The curves for thermocouples and resistance thermometers are generally not linear. The linearity error is usually larger than all other errors (hysteresis, amplification, aging etc.). Since the curve shapes are known, the measuring error can be compensated using an inverse function. In practice it has been sufficient to approximate the curve shape using straight segments. How to select the straight segments depends on the particular curve shape. In Fig. 5-12 the curve U_A (T) is approximated first using a straight line and then two straight lines between equidistant temperature intervals and lastly with three straight lines between optimized temperature intervals for which the deviations from the curve are minimized.

For analog transmitters, the method uses an operational amplifier with a defined amplification for each straight section. It is possible using this approach to reduce the total error of the temperature transmitter to approx. 0.1 % of the range.

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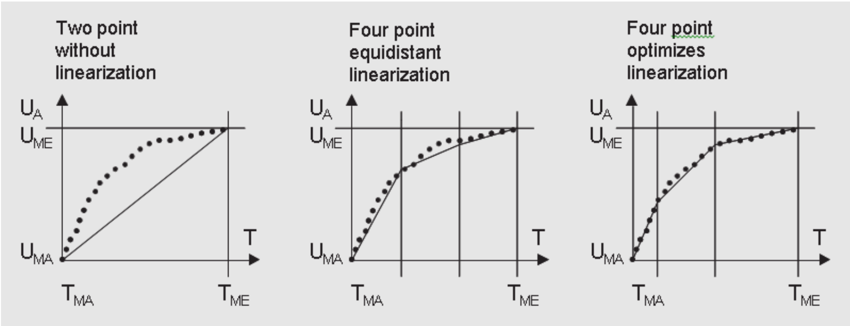

Figure 5. Circuit diagram of a three-wire circuit.

For digital temperature transmitters with a microcontroller, the curve can be linearized using software (Firmware) by calculating an inverse function polynomial directly from the curve of the standard temperature sensor. As a result of this technology, the linear-ization error for digital transmitters is less than for analog ones.

Conclusion

In conclusion, temperature transmitters play a crucial role in industrial temperature measurement systems by converting sensor signals into standardized output signals for monitoring and control. Their ability to process signals from thermocouples and resistance thermometers ensures accurate and reliable temperature measurement in various industrial applications.

The implementation of both two-wire and four-wire technologies provides flexibility depending on system requirements, while features such as signal linearization, electrical isolation, and error monitoring improve measurement precision and operational safety.

Modern digital transmitters with microcontroller-based firmware offer higher accuracy and better stability compared to traditional analog transmitters. Therefore, understanding the design principles of temperature transmitters is essential for improving efficiency, reliability, and safety in industrial automation and process control systems.

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