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TEMPERATURE MEASUREMENT BY CONTACT SMART SENSORS

MĚŘENÍ TEPLOTY KONTAKTNÍMI INTELIGENTNÍMI SENZORY

Abstract

The paper deals with actual state of intelligent temperature sensors. There are characterized standard principles and properties of contact smart temperature transducers with an accent on the new trends in this area. There are described even traditional principles of temperature sensors, further quick developing group of noncontact smart temperature sensors. Briefly there are characterized a knowledge and application experiences from this area obtaining on the Department of Control Systems & Instrumentation VŠB-TUO.

Abstrakt

V příspěvku je popsán současný stav inteligentních snímačů pro měření teploty. Jsou zde charakterizovány standardní principy a vlastnosti kontaktních smart teploměrů s důrazem na nové trendy v této oblasti. Jsou uvedeny tradiční principy teplotních snímačů, dále prudce se rozvíjející skupina bezkontaktních inteligentních teplotních senzorů. Stručně jsou charakterizovány poznatky a aplikační zkušenosti z této oblasti získané na KATŘ VŠB-TUO.

1 INTRODUCTION

Temperature is one expression for the kinetic energy of the vibrating atoms and molecules of matter. This energy can be measured by various secondary phenomena, e.g., change of volume or pressure, electrical resistance, electromagnetic force, electron surface charge, or emission of electromagnetic radiation. The most frequently used temperature scales are Kelvin, Celsius and Fahrenheit, which divide the difference between the freezing and boiling points of water into 100° and 180°, respectively.

The thermodynamic scale begins at absolute zero, or 0 degree of Kelvin, the point at which all atoms cease vibrating and no kinetic energy is dissipated (0 K = –273.15°C = –459.67°F). Big differences exist between different temperature sensor or temperature measurement device types. Using one perspective, they can be simply classified into two groups, contact and non-contact. Both contact and non-contact sensors require some assumptions and inferences in use to measure temperature. Many, many well-known uses of these sensors are very straightforward and few, if any, assumptions are required. Other uses require some careful analysis to determine the controlling aspects of influencing factors that can make the apparent temperature quite different from the indicated temperature.

Temperature measurement can be divided into two categories: contact and noncontact. Contact thermocouples, RTDs, and thermometers are the most prevalent in temperature measurement applications. They must contact the target as they measure their own temperature and they are relatively slow responding, but they are inexpensive. Noncontact temperature sensors measure IR energy emitted by the target, have fast response, and are commonly used to measure moving and intermittent targets, targets in a vacuum, and targets that are inaccessible due to hostile environments, geometry limitations, or safety hazards. The cost is relatively high, although in some cases is comparable to contact devices.

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The selection of what type of temperature transducer to be used affects many other aspects of the design and installation of the equipment in the plant such as:

- Θ What type of wire needs to be run?
- Θ What type of instrument will be in the control room on the other end of that wire?
- Θ RTD's for their high accuracy and linearity?
- Θ Or thermocouples because of their lower cost and familiarity?
- Θ Will there be local junction boxes with terminal strips or transmitters, and if so, what types of transmitters are required?
- Θ Do any special piping considerations need to be made to protect the sensor or provide the required response time?

These are just some of the details, and we have not even touched on the actual selection and design of the sensor itself. We have all read articles on this subject before, but as long as there are questions out there, more information will be provided to help make wise and informed decisions regarding each specific application.

2 CONTACT TEMPERATURE TRANSDUCERS

Resistance thermometry is a widely employed method of measuring temperature, and is based on using a material whose resistivity changes as a function of temperature. Resistance Temperature Detectors (RTD's) have fast response time, provide absolute temperature measurement (since no reference junctions are involved), and are very accurate. Their measurement circuits are relatively simple, and the sensors, when properly installed, are very stable over years of use.

Resistance temperature sensors are constructed much like wide-temperature-range strain gages. The standard sensors utilize nickel or nickel/manganin grids, although special-purpose gages are also available in Balco® alloy or copper foil grids. These temperature sensors are bonded to structures using standard strain gage installation techniques, and can measure surface temperatures. Because of their extremely low thermal mass and the large bonded area, the sensors follow temperature changes in the structural mounting surface with negligible time lag.

The International Temperature Scale (ITS-90) defines temperatures between 13,8003 K and 1234,93 K (961,78°C) by use of Platinum Resistance Thermometers (PRT's) calibrated at specified sets of fixed points. While this is fine in a laboratory, you are not likely to find an industrial grade RTD that will cover this entire range adequately. ASTM defines the Platinum RTD for use over the range -200°C to 650°C. This is a good guideline to follow, even though IEC extends the upper limit to 850°C. Industrial grade Platinum RTD's can be manufactured for use to 850°C, but it is not an easy task that can be taken on by just anyone. Also, you may find that standard warranties are not valid for this type of service. Fortunately, over 90% of all contact temperature measurements made in industry are below 650°C. On the Figure 1 we can see comparison of thermo resistor transducers transfer characteristic for most common purposes (Pt-100, Ni, thermistors NTC and PTC).

Like the RTD, the thermistor is also a temperature sensitive resistor. While the thermocouple is the most versatile temperature transducer and the PRTD is the most stable, the word that best describes the thermistor is sensitive. Of the three major categories of sensors, the thermistor exhibits by far the largest parameter change with temperature.

Thermistors are generally composed of semiconductor materials. Although positive temperature coefficient units are available, most thermistors have a negative temperature coefficient (TC); that is, their resistance decreases with increasing temperature. The negative T.C. can be as large as several percent per degree Celsius, allowing the thermistor circuit to detect minute changes in temperature which could not be observed with an RTD or thermocouple circuit. The price we pay for this increased sensitivity is loss of linearity. The thermistor is an extremely non-linear device which is highly dependent upon process parameters. Consequently, manufacturers have not standardized thermistor curves to the extent that RTD and thermocouple curves have been standardized.

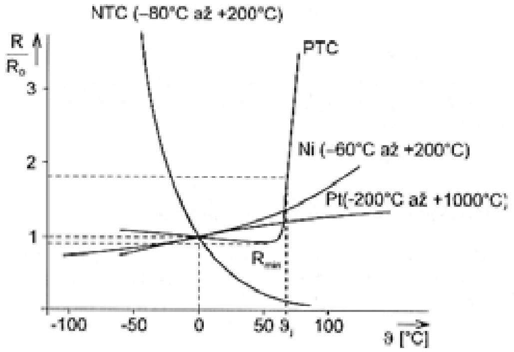

Fig. 1 Comparison of thermo resistor transducers transfer characteristic

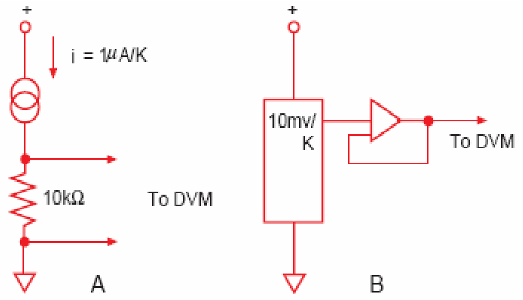

Fig. 2 Integrated silicon circuit temperature transducer in both voltage (A) and current-output (B) configurations.

An individual thermistor curve can be very closely approximated through use of the Steinhart-Hart equation:

$$\frac{1}{T} = A + B.\ln R + C.(\ln R)^3$$

, where T - temperature [K], R - resistance of thermistor [Ω], A,B,C - fitting constants

The high resistivity of the thermistor affords it a distinct measurement advantage. The four-wire resistance measurement is not required as it is with RTD's. For example, a common thermistor value is 5000 ohms at 25'C. With a typical T.C. of 4%/ºC, a measurement lead resistance of 100 produces only a .05°C error. This error is a factor of 500 times less than the equivalent RTD error.

2.1 Monolithic linear temperature sensor

A recent innovation in thermometry is the integrated circuit temperature transducer. It is available in both voltage and current-output configurations. Both supply an output that is linearity proportional to absolute temperature. Typical values are 1 mA/K and 10 mV/K. They offer a very linear output with temperature and these devices share all the disadvantages of thermistor devices(they have a limited temperature range). The same problems of selfheating and fragility are evident, and they require an external power source. These devices provide a convenient way to produce an analogue voltage proportional to temperature. Such a need arises in a hardware thermocouple reference junction compensation circuit

Thermocouples as a second most common used temperature transducers also have temperature limitations based on what type is specified, and what gage wire it is constructed of. International Organization ASTM E-608 recommends the following temperature limits for such base metal thermocouples; Type T 370°C, Type J 720°C Type E 820°C, Type K 1150°C

Now just because ASTM says these thermocouples can be used at these temperatures doesn't mean that they are going to last forever. The higher the application temperature, the sooner they will begin to drift, and the shorter the life. Above these temperatures, we must step up to precious metal Thermocouples: either Platinum-Rhodium Alloys, or Tungsten- Rhenium Alloys. These do tend to get expensive, but when you've got to measure temperature above about 1000°C, it really is the way to go. The life expectancy is much longer, and they are not as prone to drift. There are suggested upper temperature limits for Types R and S Platinum- Rhodium Thermocouples as 1480°C, and for Type B as 1700°C. On the Figure 2 is integrated silicon circuit temperature transducer in both voltage (A) and current-output (B) configurations. On the Figure 3 and Fig. 4 there are practical connection of thermocouple with hardware compensation of "cold end" and Static characteristics of various thermocouples used in industry.

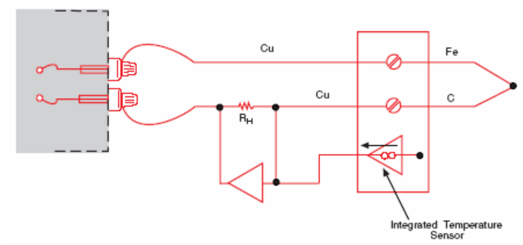

Fig. 3 Practical connection of thermocouple with hardware compensation of “cold end”

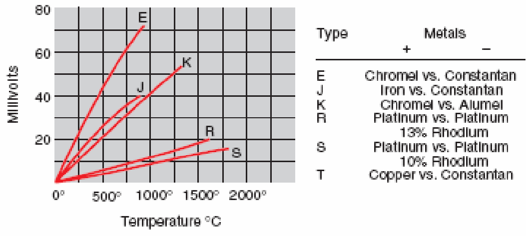

Fig. 4 Static characteristics of various thermocouples used in industry

2.2 Sensitivity

Here the RTD's are very simply; Superior. Take if you will, a Platinum 100 Ohm RTD with 0,00385 Temperature Coefficient. From 0°C to +100°C its resistance changes from 100,00 to 138,50 Ω, a difference of 38.5 Ω. If we had been using 1 mA sensing current (which is quite typical to avoid self-heating effects), Ohm's Law (V=iR) tells us that we would see a difference of 38.5 mV over this range. By comparison, a Type E Thermocouple, which provides the highest sensitivity of all recognized thermocouples, will show only a change of 6.317 mV. This is only about one sixth of the sensitivity of the RTD. If your environment might provide electrical interference, the thermocouple will be at least 6 times more sus-ceptible to it. And this is when using a type E, other types have sensitivity as low as .33 micro-volts per degree Celsius. If you want even higher sensitivity, you may opt for a Pt 500 Ohm RTD to provide 5 times the sensitivity of the Pt 100, or a Pt 1000 Ohm to give you 385 ohms over that 100 degree range.

2.3 Digital i/o temperature sensors

About five years ago, a new type of temperature sensor was introduced. These devices include a digital interface that permits communication with a microcontroller. The interface is usually an I2C or SMBus serial bus, but other serial interfaces such as SPI are common. In addition to reporting temperature readings to the microcontroller, the interface also receives instructions from the microcontroller. Those instructions are often temperature limits, which, if exceeded, activate a digital signal on the temperature sensor IC that interrupts the microcontroller. The microcontroller is then able to adjust fan speed or back off the speed of a microprocessor, for example, to keep temperature under control (see Fig. 5 and Fig. 6).

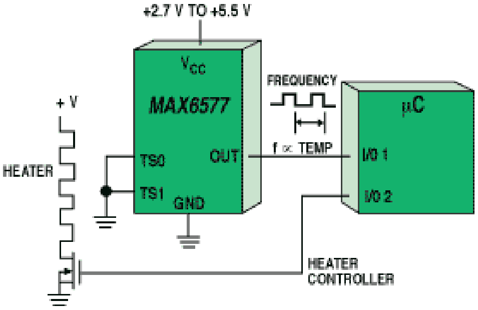

Fig. 5. A temperature sensor with square wave frequency signal (part of a heater controller circuit).

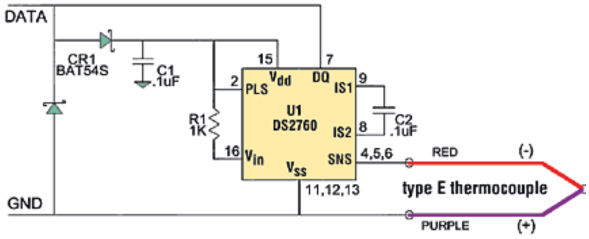

Fig. 6. Electrical net of temperature sensor - thermocouple

This type of device is available with a wide variety of features, among them, remote temperature sensing. To enable remote sensing, most high-performance CPUs include an onchip transistor that provides a voltage analogue of the temperature (only one of the transistor's two p-n junctions is used.). When an actual temperature reading is needed, and a microcontroller is available, sensors that transmit the reading on a single line can be useful. With the microcontroller's internal counter measuring time, the signals from this type of temperature sensor are readily transformed to a measure of temperature.

The sensor in Figure 7 outputs a square wave whose frequency is proportional to the ambient temperature in kelvins.

IC temperature sensors provide a varied array of functions and interfaces. As these devices continue to evolve, system designers will see more application-specific features as well as new ways of interfacing the sensors to the system. Finally, the ability of chip designers to integrate more electronics in the same die area ensures that temperature sensors will soon include new functions and special interfaces.

3 NON CONTACT TEMPERATURE SENSORS

IR Radiation - infrared is that portion of the electromagnetic spectrum beyond the visible (blue to red, 0,4-0,75 µm) response of the human eye. IR wavelengths extend from 0,75 µm to 1000 µm. Because IR radiation is predominantly generated by heat, it is called thermal radiation. Radiation thermometer there is noncontact thermosensor determines the surface temperature of an object by intercepting and measuring the thermal radiation it emits (see Fig. 7).

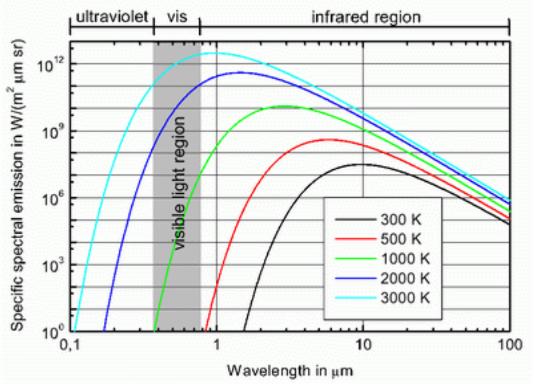

Fig. 7 Radiation characteristic of absolute blackbody

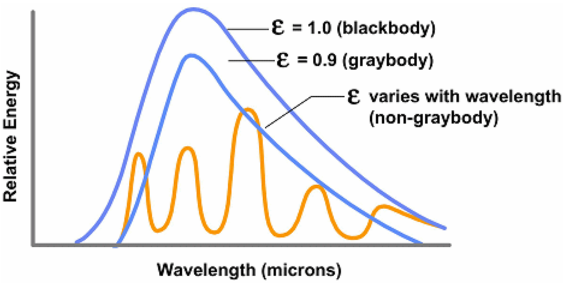

Fig. 8 A graph of emissivity vs. wavelength

Emissivity there is a quality defines the fraction of radiation emitted by an object as compared to that emitted by a perfect radiator (blackbody) at the same temperature. Emissivity is determined in part by the type of material and its surface condition, and may vary from close to zero (for a highly reflective mirror) to almost 1 (for a blackbody simulator).

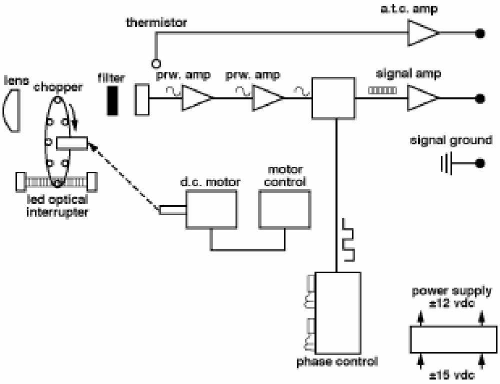

Fig. 9 Schematic representation of a typical contemporary infrared thermometer

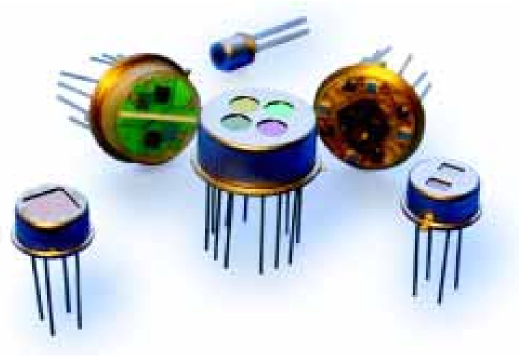

Fig. 10 Examples of non contact temperature sensors

Emissivity is determined in part by the type of material and its surface condition, and may vary from close to zero (for a highly reflective mirror) to almost 1 (for a blackbody simulator). Emissivity is used to calculate the true temperature of an object from the measured brightness or spectral radiance. Because an object's emissivity may also vary with wavelength, a radiation thermometer with spectral response matching regions of high emissivity should be selected for a specific application (see Fig. 8). Emissivity values are listed in the literature for a variety of materials and spectral bands, or these values can be determined empirically.

Figure 9 shows a schematic representation of a typical contemporary infrared thermometer - IRT. Probably the most important advance in infrared thermometry has been the introduction of selective filtering of the incoming IR signal, which has been made possible by the availability of more sensitive detectors and more stable signal amplifiers. Whereas the early IRT's required a broad spectral band of IR to obtain a workable detector output, modern IRT's routinely have spectral responses of only 1 micron. The need to have selected and narrow spectral responses arises because it is often necessary to either see through some form of atmospheric or other interference in the sight path, or in fact to obtain a measurement of a gas or other substance which is transparent to a broad band of IR energy (see Fig. 10).

4 LABORATORY EXPERIMENTS

On the Department of Control Systems & Instrumentation there were realized many of measurement plants for testing of contact and non contact On the Figure and Figure are examples of a measurement plant for testing of non contact sensor with thermocouple detector OMEGA and example of experimental results (see Fig. 11 and Fig. 12).

Fig. 11 Photo of measurement stand for testing of non contact sensor with thermocouple detector OMEGA

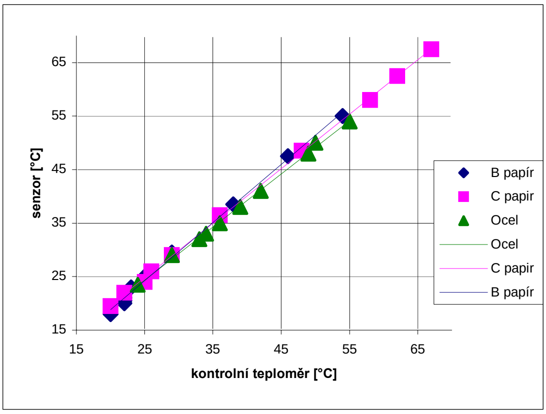

Fig. 12 Experimental measurement of static characteristic of infrared thermocouple detector OMEGA

5 CONCLUSIONS

The main presumption of correct temperature measurement there are right selection of sensor principle and type, and their right location. Until recently, all the temperature sensors on the market provided analogue outputs. Thermistors, RTDs, and thermocouples were followed by another analogue-output device, the silicon temperature sensor. In most applications, unfortunately, these analogue-output devices require a comparator, an ADC, or an amplifier at their output to make them useful.

Thus, when higher levels of integration became feasible, temperature sensors with digital interfaces became available. These ICs are sold in a variety of forms, from simple devices that signal when a specific temperature has been exceeded, to those that report both remote and local temperatures while providing warnings at programmed temperature settings. The choice now isn't simply between analogue-output and digital-output sensors; there is a broad selection of sensor types, one of which should match your system's needs.

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