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PRECISE MEASUREMENT OF PROCESS TEMPERATURE DIFFERENCES

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Abstract

The precise measurement of process temperature differences is an important factor in the quantitative determination of productivity in nuclear reactors. The paper describes the equipment and methods which may be used in providing the necessary precision of measurement, matching and calibration of elements, compensation of leads, and other factors.

Introduction

Measurement of power in a nuclear reactor system is comparable to measurement of yield in a chemical plant, or to measurement of throughput in a paper mill process. In most reactor systems, power is determined by measurement of heat transferred to the coolant.

In this study, reactor coolant heat-rise was determined by the differential-temperature measuring circuitry of a power calculator which computed and recorded reactor power.

Measurement techniques involved in determining the differential temperature are presented in this paper, and may be of parallel interest to instrument engineers in other process fields.

Primary Elements

The measuring system employed selected industrial four-wire 10-ohm copper resistance thermometers because of their intrinsic accuracy and consistency. The linear response of copper elements makes them especially valuable for temperature difference measurements, since they provide difference signals which are independent of absolute temperature.

Typical responses for perfectly matched pairs of elements for varying differential temperatures are shown in the following table. Data are taken from standard calibration tables and curves for the elements shown. Note that only copper resistance thermometers provide responses which are the same for differential temperatures at varying signal levels; ie, they provide difference signals which are independent of absolute temperature.

Element Temperature, °C		ΔT, °C	Resistance Thermometer, ohms		Thermocouple, mv		
No. 1	No. 2		Copper	Nickel	Iron, Constantan	Copper, Constantan	Platinum, Platinum-Rhodium
20	40	20	0.770	7.03	1.04	0.82	0.121
40	60	20	0.771	7.39	1.06	0.86	0.130
60	80	20	0.770	7.73	1.07	0.89	0.136
80	100	20	0.770	8.12	1.07	0.92	0.143
20	50	30	1.155	10.66	1.56	1.24	0.184
70	100	30	1.155	12.03	1.61	1.37	0.211
20	70	50	1.926	18.24	2.63	2.11	0.318
50	100	50	1.926	19.61	2.68	2.25	0.346

The desired limit of error for temperature difference measurements using matched resistance thermometer pairs was 0.05°C. The vendor provided copper elements of excellent linearity through careful annealing and precise control of the length and diameter of the copper used. Normal accuracy for a single element was 0.25°C, and elements were supplied with individual corrections to standard tables at three calibration points. To satisfy the requirement for difference measurements of 0.05°C accuracy, the vendor selected from standard elements those with 0.1°C accuracy.

Matching of Elements

Matching of elements of 0.1°C accuracy to provide response to differential temperatures precise to 0.05°C entailed further selection. An initial study established the requirements for matching. Since the differential temperature of these elements was to be measured automatically, a standard calibration for the measuring circuitry was determined. The calibration for a standard resistance thermometer was the logical choice, and was used. This meant that the circuitry would measure a temperature difference signal as if it were the output of a resistance thermometer at a temperature equal to the temperature difference.

The requirements for matching, then, were that elements have calibration slopes identical to the standard, and that corrections were the same at respective calibration points. For example, an element with corrections of +0.1°C at upper and lower calibration points was matched with another element of +0.1°C corrections at those points. The corrections of the two canceled in the differential measuring circuitry, independent of the operating temperature of either element. An element with corrections of +0.1°C was not matched with one of -0.1°C corrections, despite the fact that the slopes were equal, because one element operated at a high temperature and the other at a low temperature, and the difference signal would vary from the measuring circuit calibration by the combined amounts of the corrections, or 0.2°C.

From the elements chosen for individual accuracy, pairs were selected which had corrections of the same magnitude and direction at all calibration points.

These specifications for precision of accuracy and matching added considerably to the cost of the primary elements. In addition, a spare matched set was supplied at each differential measurement location, to be used if either of the operating elements failed.

Thermal Lag and Time Constant

The question of thermal lag and time constant was one of necessity. Though not critical from the standpoint of control, thermal lag in this application can mask gradual transient conditions encountered in reactor systems, and even obscure the more rapid changes. So efforts were made to insure maximum response in all resistance thermometer installations.

The design of the elements provides good response. The wire is wound on copper forms soldered to the top of the one-piece brass tube. The tip of the tube is assured a good metal-to-metal contact with the well by the compression bushing of the element assembly, which also effects a vapor seal for the element in the well. Lead-wire conduits are provided with a vulcanized seal to prevent breathing at low temperatures.

At one time it was considered advisable to improve the thermal response by bonding the element to the thermowell to insure metal-to-metal contact. Techniques were developed to produce bonds with Wood's metal, a low melting-point eutectic mixture. Due to difficulties experienced, bonding was discontinued.

Bonding provided no improvement in time response unless the element and well were tinned in the bonding process. Tinning the stainless steel wells proved very difficult and the procedure for heating resistance thermometer jackets for tinning was potentially hazardous to the element. Untinned bonding was unsatisfactory due to 1) the shrinkage of Wood's metal, and 2) the formation of the double oxide film between the alloy and the surfaces of the well and the thermometer.

A real disadvantage of bonding was the immobility of elements in the wells, since it was necessary to drain process lines prior to removal of wells for calibration or replacement of elements.

Circuitry

The measuring and indicating circuitry of the power calculator (see figure 1), was designed by L. C. Bancroft and J. W. Adams, and is described in the paper, "Reactor Power Calculator," presented at the March 1958 AIChE Nuclear Congress in Chicago, Illinois. (Reprints may be obtained from the American Institute of Chemical Engineers, 25 West 45th Street, New York, N. Y.)

There are several outstanding features of the circuitry as applied to the precise measurement of temperature differentials.

- Inherent cancellation of lead-resistance effects. The potential leads of the four-wire thermometers are fed into precision ratio-transformers. The high impedance (150,000 ohms) of the transformers minimizes lead-wire effects so that lead resistances up to several hundred ohms have little significance in the measurement.

- Exceptional precision of measurement. The ratio transformers have a ratio accuracy of 0.01%. The integrity of the thermometer resistance is maintained throughout the measuring circuitry.

- Insensitivity to supply voltage variations. The measured temperature differential is proportional only to the resistance of the matched resistance thermometers. This means that the supply voltage, the impedance of the supply transformer, and the current leads of the thermometers can vary over a wide range of their values without affecting the measured temperature differential.

- Insensitivity to lead-in connector contact resistances. This is particularly advantageous where auxiliary temperature measurements with portable instruments are made periodically, and where measuring circuitry is calibrated with precision resistors.

Because of the above characteristics the differential temperature measurement circuitry may have extensive application in other fields.

Calibration

Accuracies of the systems are assured through periodic calibration checks of resistance thermometers.

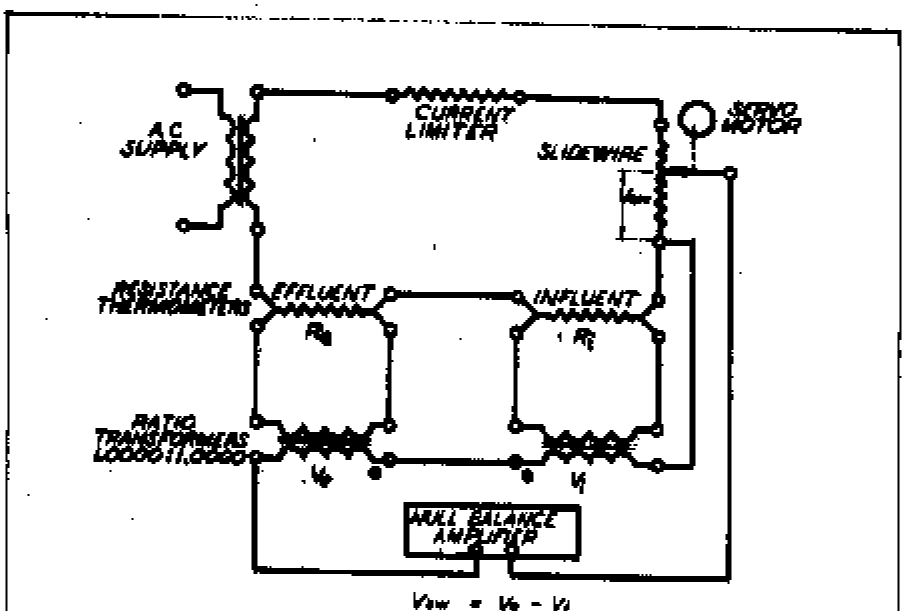
Laboratory-type precision thermometers and Mueller bridges are employed for temperature and resistance measurements. Accuracy of measurement is 0.02°C and 0.001 ohm. In addition, the laboratory is equipped with a precision Kelvin resistance standard and bridge, and several secondary standard resistance thermometers. Measurements with this equipment are accurate to 0.01°C and 0.00001 ohm.

The calibration procedure is standard for the precision required, and includes all practical compensations and corrections. The elements are checked at five or seven points between 0 and 100°C. Readings are taken after the elements have been in the bath at each temperature for a minimum period of 25 minutes, and when the laboratory thermometer attached to the element shows a change of not more than 0.1°C in 10 minutes. At least two measurements are made at each temperature to reduce deviations due to reading errors. Lead error is eliminated by measurement and compensation. Thermometer stem correction is applied when required, although use is generally made of partial immersion thermometers which are graduated and standardized for definite depths. Thermometer calibration corrections are applied where they exist.

Calibration data are plotted and verified. Readings of questionable points are repeated until accuracy is assured. The calibration is considered precise when the deviation of the experimental points from the least squares straight line through the points is not more than 0.2°C. Data are compared with earlier calibrations. If considerable differences exist, the resistance thermometer is no longer used in the differential temperature application because of the doubt associated with an element of changing calibration.

Conclusion

The differential temperature measuring system was designed for accuracy, stability, sensitivity, speed of response, and usable life. Initial cost and maintenance costs were necessarily secondary considerations in the provision and assurance of these specifications. However, the equipment has long life and may be expected to amortize the high initial costs. The maintenance procedures are exacting, but do not represent extensive expenses after personnel have been trained.



$V_{sw} = V_e - V_i$
$\Delta T \propto R_e - R_i$
$V_e - V_i \propto R_e - R_i$
$V_{sw} \propto \Delta T$

Figure 1. DIFFERENTIAL TEMPERATURE MEASURING CIRCUIT

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