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A Novel Method for Linearization of Copper-Constantan Thermocouple by Composite Sensor Circuit

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Abstract: A method for linearizing thermocouple output is proposed with particular reference to measurements of small temperature differences over a large range of mean temperatures from - 100 to + 200 degree centigrade. The linearization is obtained by using composite sensors including copper or platinum resistors which, added to an appropriate external resistance, provide a linear current or voltage output. The linearizing resistors do not need to be at the exact temperature of the junctions. The linearity attained is to better than ± 0.2 degK within a span of 200 degK for copper-constantan thermocouples.

Key words: linearization, thermocouple, zero load, calibration, measurement and control.

I. INTRODUCTION

A set-up for linearization of copper-constantan thermocouple voltages within the temperature range of -50 to +50°c has been performed. It uses subtraction of the nonlinear term by a voltage obtained from an additional thermocouple, which feeds a bridge comprising a temperature sensitive resistor. For each junction in a copper-constantan thermocouple the e.m.f. at ambient temperatures follows very closely the laws.

$$e_1 = at_1 + bt_1^2$$
$$e_2 = at_2 + bt_2^2$$

Where a and b are constants and t_1 and t_2 the temperatures with respect to the reference temperature at which the constants *a* and b have been determined.

The resulting e.m.f. from the two junctions is

$$\begin{aligned} e_1 - e_2 &= a(t_1 - t_2) + b(t_1^2 - t_2^2) \\ &= a(t_1 - t_2)\{1 + b/a(t_1 + t_2)\} \end{aligned}$$

The output will thus depend not only on the difference in temperature but also, to a less

extent, on the sum of temperatures. The nonlinear term (b/a) $(t_1 + t_2)$ is particularly troublesome if both temperatures vary over large limits, since calibration of the device will then depend on the mean temperature of the two junctions, which must be determined separately so that an appropriate correction can be applied. For a copper-constantan thermocouple the slope of the voltage-temperature curve will vary by as much as 20% for a shift in mean temperature of 100degK.

II. COMPENSATION METHOD

For nonlinear compensation,

Each junction may be in near thermal contact with two temperature sensitive resistors R1 and R2**,** which both follow a linear law.

$$R_1 = R_0(1 + At_1)$$
$$R_2 = R_0(1 + At_2)$$

If these resistors are connected in series with a resistor R3 that is insensitive to temperature, the resulting resistance will be

$$R = R_1 + R_2 + R_3 = (R_3 + 2R_0)\left\{1 + \frac{R_0}{R_3 + 2R_0} A(t_1 + t_2)\right\}$$

The resistance of the thermocouple wire may be considered as included in ***R3.***

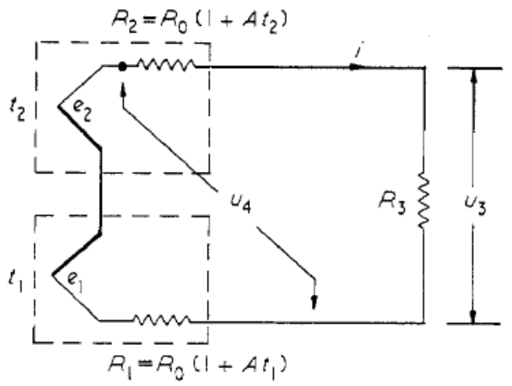

Fig 1. Basic composite sensor circuit for linear temperature difference measurements

The current through and the voltage over ***R3*** are thus both linear functions of t_l- t_2 provided

$$b/a= R_0A/R_3+2R_0$$

For a copper-constantan thermocouple, ***b*** =0.044 μv degK^{-2} and *a* =38 μv degK^{-1}.

A temperature difference as high as 1 degK between the junction and its resistor will in fact only give a proportional error of 0.1 % in the case of copper-constantan thermocouples. It may also be found that the matching of the characteristics of the linearizing resistors is not critical. The tolerances of industrial platinum resistance elements made according to BS 1904 (grade I or 11) will thus give proportional errors less than ± 0.02 %.for temperature differences of 100 degK between the two junctions.
The current may be measured or recorded by a highly linear galvanometer, the internal resistance of which as well as all lead resistances should be included in the value of R3.

III. ZERO LOAD CIRCUIT

Temperature differences t_1-t_2 may be measured practically without thermocouple current using the compensation circuit. One of the compensating resistors must in this case be electrically disconnected from its junction. The Series resistor R_S is chosen very high compared with R_1+R_2+R_3 so that the feedback current is unaffected by resistance variations in R_1 and R_2. At null balance the adjusted output voltage is then

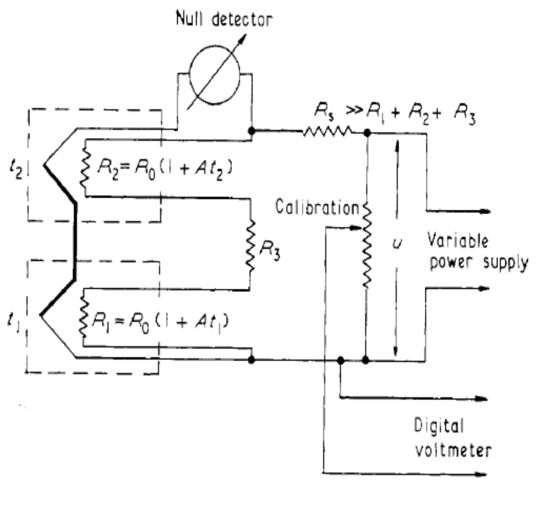

Fig 2. Zero load circuit for linear measurement of temperature differences.

$$u = (R_S/R_3+2R_0) * a(t_2-t_1)$$

Where R3 should include lead resistances to the linearizing resistors. The circuit represents a very convenient means for recording temperature differences if the power supply is fitted with fine
Adjustment of voltage.

IV. EXPERIMENTAL SET UP FOR LINEARITY

The method was tested on copper-constantan junctions by using as a linearizer a miniature platinum resistance element. The model chosen was a low-inertia immersion type E 712 D with ice resistance R_O = 100 Ω. The copper-constantan wire was type 9BIT4-9BlE8.All connections were welded by condenser discharge. The wires were insulated by ceramic double-bore tubing and introduced in a closed-end glass tube which was immersed to 35 cm in stirred, precision thermostatically controlled liquid baths.

The set-up is shown in Fig 3. The measurements of the output voltage for each temperature were made on a calibrated potentiometric compensator for two positions of the thermo free switch: without a load resistor and with a load resistor R_L=200 Ω. The total lead resistance due to the length of the thermocouple wires was R_q=27 Ω and was practically constant throughout the measurements.

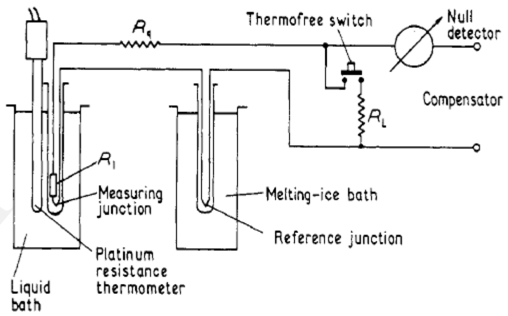

Fig 3. Schematic diagram of set-up for linearity tests

V. CONCLUSION AND RESULTS

Linear range is almost as good as for copper-constantan. Due to its high output the copper-constantan thermocouple may be the most attractive to use for differential temperature measurements.

Summary of computed performance of thermocouple with platinum resistance linearizer

Thermo couple	*Range ("c)*	*Linearity deviation*	*c*	R_{co}	***u3***
Copper-constantan	-75 to +70	≤ ±0.2	0.30	327	14.9
	-40 to +110	0.2	0.28	347	16.2
	-10 to +150	0.2	0.26	377	18.2

c, ratio of linearizer resistance to total circuit resistance at *0"c*
Rco, total circuit resistance at *0"c* for linearizer with Ro= 100 Ω
u3, maximum differential voltage output per degree according to figure 1 (lead resistance neglected).

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