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PROGRESS ON A PdCr WIRE STRAIN GAGE

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The principal activity under the HOST effort to improve the state-of-the-art in high-temperature static strain measurement has been a contract under which a palladium-chromium (PdCr) alloy was developed. The contract effort is continuing with the goal of developing a thin-film high-temperature static strain gage system. In addition to this effort, we have contracted with Battelle-Columbus Laboratories to draw the PdCr alloy into wire and have been working here at Lewis to gain experience with this alloy as a wire strain gage. The progress of this work is reported herein.

THE PALLADIUM-CHROMIUM WIRE STRAIN GAGE SYSTEM

The plans for the strain gage system have been shaped by the known characteristics of the PdCr alloy. The specific characteristics that have had the greatest influence to date on these plans are the relatively high temperature coefficient of resistance (TCR) and the tendency for chromium to oxidize out of the alloy, causing the TCR to increase and the resistivity to decrease. Because of the oxidation problem, we will start working with rather large diameter wire (45 μm) and test its capability at temperatures up to 1250 K before we attempt to work with wire sizes in the range of 25 μm diameter. In addition, because of the relatively high TCR (175 ppm/K), a temperature compensation system will be used.

The temperature compensation technique chosen for this application uses a temperature-sensitive resistor in an adjacent leg of the bridge circuit. This technique has been used previously, especially with platinum-tungsten (PtW) gages, and has been described in texts on experimental stress analysis (e.g., ref. 1). The circuit, along with the nomenclature used here, is shown in figure 1. It can be shown that, if the effective temperature coefficient of the uncompensated strain gage is given by α_G, the effective temperature coefficient of the compensated circuit is given by

$$\left(1 - \frac{R_c}{R_c + R_B} \frac{\alpha_c}{\alpha_G}\right) \alpha_G$$

Temperature compensation is achieved by making

$$\left(1 - \frac{R_c}{R_c + R_B} \frac{\alpha_c}{\alpha_G}\right) = 0$$

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The price one pays for this compensation is a reduced sensitivity to strain. The reduction in gage factor is given by

$$\left(1 - \frac{R_c}{R_c + R_B} \frac{G_c}{G_G}\right)$$

Optimum compensation is achieved by choosing a compensating resistor material with a very high TCR compared with that of the strain gage.

Preliminary Tests

Some preliminary tests were made to get experience with this technique; these were done using PtW strain gages mounted with ceramic cement to a constant strain beam which had been coated with flame-sprayed NiCrAlY and alumina. A 25-μm-diameter platinum (Pt) wire was used for the compensating resistor. The installed gages were soaked for 16 hr at 770 K before testing. Measurements of the effective temperature coefficients yielded 2990 ppm/K for the compensating resistor and 294 ppm/K for the strain gage. These values compare with handbook TCR values of 3940 and 240 ppm/K, respectively. The differences are due to differential thermal expansion (which should be a small effect), self-heating of the wires, and, in the strain gage, oxidation of the tungsten in the PtW alloy. The self-heating effect seems to be the major effect for the compensating resistor; therefore, measurement of temperature coefficient should be done with the same level of current that will be used in the bridge circuit.

A compensated bridge was set up based on the measured temperature coefficients. The resulting apparent strain over the temperature range to 770 K was within ±750 microstrain. The uncompensated apparent strain for this strain gage would have been approximately 140 000 microstrain at 770 K.

Tests on Palladium-Chromium Wire

Compensated strain gages have been made with the 45-μm-diameter PdCr wire. The strain gage shown in figure 2 is 8.2 mm long and 10.6 mm wide and has a nominal resistance of 81 Ω. The compensating resistor is Pt wire 25 μm in diameter, and the grid is 7.1 mm long and 3 mm wide. This gage is larger in size and lower in resistance than might be desirable because of the diameter of the wire used.

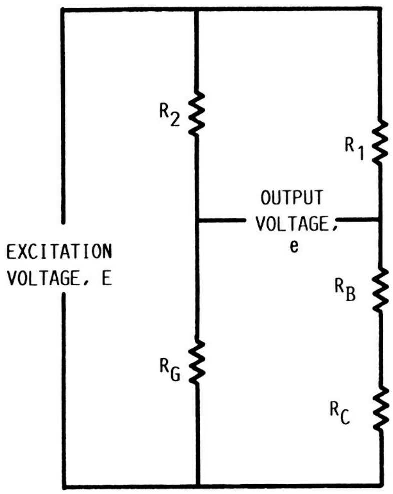
The test plan for these gages emphasizes testing for thermal stability and temperature compensation. Measurements of gage factor, strain range, etc., will be delayed until the temperature range over which we have acceptable repeatability is established. For this testing, the strain gages with Pt compensating elements are mounted on Hastelloy-X plates using Bean-H cement over flame-sprayed alumina (a base coat of flame-sprayed NiCrAlY is used under the alumina). An alternative mounting procedure will use plasma-sprayed alumina for both the insulating layer and for mounting the strain gage (i.e., no ceramic cement). The sequence of testing will start with a heat soak for stress relief followed by thermal cycles to permit measurement of the installed temperature coefficients and their repeatability. A temperature-compensated bridge will be established using the installed temperature coefficients, and a series of apparent strain and no-load drift tests will be run. For tests in which the gages are mechanically loaded, the gages will be mounted on Inconel 718 constant strain beam.

Test results to date indicate that the installed temperature coefficients after a 3-hr soak at 1230 K in air are 224 ppm/K for the strain gage and 1620 ppm/K for the platinum compensating resistor.

REFERENCES

1. Dove, R.C.; and Adams, P.H.: Experimental Stress Analysis and Motion Measurements. C.E. Merrill Books Inc., Columbus, OH, 1964.

TEMPERATURE COMPENSATED STRAIN GAGE BRIDGE CIRCUIT AND NOMENCLATURE USED IN CIRCUIT EQUATIONS



R_G	STRAIN GAGE $\Delta R_G/R_G = [(TCR)_G + G_G(\Delta TEC)_G]\Delta T + G_G\varepsilon = \alpha_G \Delta T + G_G\varepsilon$
R_C	RESISTANCE THERMOMETER $\Delta R_C/R_C = [(TCR)_C + G_C(\Delta TEC)_C]\Delta T + G_C\varepsilon = \alpha_C\Delta T + G_C\varepsilon$
R_B	FIXED BALLAST RESISTOR
R_1, R_2	BRIDGE COMPLETION RESISTORS
TCR	TEMPERATURE COEFFICIENT OF RESISTANCE
ΔTEC	DIFFERENCE IN THERMAL EXPANSION COEFFICIENTS BETWEEN RESISTOR AND SUBSTRATE
G	GAGE FACTOR
α	EFFECTIVE TEMPERATURE COEFFICIENT, [(TCR) + G(ΔTEC)]
ε	STRAIN

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Figure 1

WIRE STRAIN GAGE MADE FROM 45-μm-DIAM PdCr WIRE WITH 25-μm-DIAM Pt WIRE COMPENSATING RESISTOR

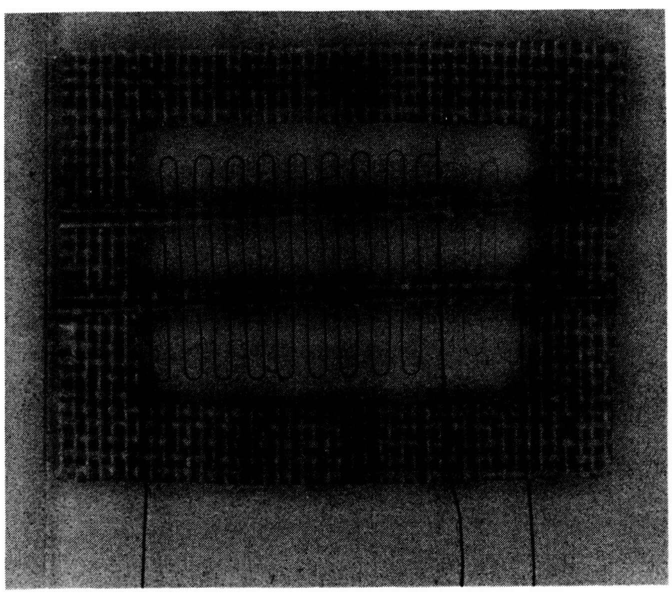

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Figure 2