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A Resistance Strain Gage With Repeatable and Cancellable Apparent Strain for Use to 800 °C

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Abstract

A temperature compensated static strain gage, which is fabricated from palladium-13w/o chromium (Pd13Cr) alloy and a platinum (Pt) compensator, is being developed and has been tested over a temperature range to 800°C at NASA Lewis Research Center. The PdCr compensated strain gage has significantly lower apparent strain to 800°C than other high temperature strain gages. The PdCr compensated gage is protected from oxidation by a flame-sprayed alumina-4w/o zirconia overcoating. Test results to 800°C indicate apparent strain variations of less than 300 $\mu\epsilon$ and reproducibility between thermal cycles within 50 $\mu\epsilon$. The apparent strain of the coated PdCr compensated gage can be predicted and cancelled due to its reproducibility and low value.

Introduction

Although the search for suitable materials for high temperature strain gage usage has been under way since the introduction of the wire resistance strain gage some 50 years ago, none of the strain gage systems meet all of the desired characteristics at high temperatures. The main problems associated with high temperature static strain measurements arise from the structural instability and insufficient oxidation resistance of the gage materials, which results in an unstable and nonrepeatable resistivity of the gage. For example, all of the iron-chromium-aluminum systems, including Chinese 700°C and 800°C gages, Kanthal A-1 gage and BCL3 gage have some kind of order-disorder transition in the temperature range of 350°C-500°C. Their apparent strain data therefore show large cycle to cycle nonrepeatability and zero-shift. The heating and especially the cooling rate of the previous cycle affects the shape of their apparent strain curve. Care is required in using these gages in the unstable temperature region. The commonly used HT-1200 platinum-tungsten alloy gage, with its high temperature coefficient of resistance (240 ppm/°C) and internal oxidation, is also limited as a high temperature strain gage.

Recent work at NASA Lewis Research Center, United Technologies Center, and Pratt and Whitney Aircraft to develop a high temperature static strain gage for airframe and aircraft engine testing has emphasized a palladium-13w/o chromium (Pd13Cr) alloy. This alloy in bulk form appears to have the desired characteristics for high temperature strain gage usage. It is structurally stable, undergoes no phase transformation or order-disorder transition in the temperature range to 1000°C, and it forms an adherent, self-protective Cr_2O_3 scale in air. All these properties of PdCr result in a repeatable, stable resistance versus temperature relationship which is independent of the heating- and cooling-rates (ref. 1).

However, to be able to use PdCr as a high temperature stain gage, a suitable temperature compensation system is required due to its fairly high temperature coefficient of resistance (175 ppm/°C). In addition, experience (refs. 1,3) have shown that the oxidation resistance of fine wires and thin films of PdCr is insufficient to provide the required stability and that a protective overcoat is necessary. This paper will present results of tests over a temperature range to 800°C of the temperature compensated PdCr wire gage with enhanced oxidation protection. The temperature compensation technique used was proposed in the earlier work (ref. 2). The gages tested were coated with a flame sprayed mixture of alumina and four weight percent zirconia since this mixture coating significantly reduced the oxidation rate of PdCr fine wire (ref. 3).

Construction and Fabrication of Gages

The compensated PdCr wire strain gages developed were fabricated from a 25 μm diameter PdCr wire drawn in China. Size of the grid was 7.5 mm long and 6.2 mm wide and had a nominal resistance of 120 ohms. The compensating resistor was platinum wire 25 μm in diameter and with nominal resistance of 15 ohms. The configuration of the compensated strain gage is shown in Fig.1. Notice that the Pt compensator was distributed around the PdCr gage grid in order to minimize the effect of temperature gradients. The lead wires were also PdCr but were 76 μm in diameter. These leads were spot welded to the gage and compensator wires.

The PdCr compensated wire gages were wound and mounted on the Hastelloy X test coupons and IN718 test beams at HiTech Products, Inc. There was one gage on each side of the substrate, so the measurements were conducted on two gages at the same time to improve the reliability. A powder mixture of alumina with four weight percent zirconia was flame sprayed on the gages as a protective overcoat. Flame-sprayed alumina with no zirconia addition was used as a base coat. Fig. 2. shows the bonded gages on the IN718 test beam. A close-up view of the gage on the Hastelloy X plate is shown in Fig. 3. Notice that there were also two thermocouples spot-welded to the substrate to monitor the temperature of the gages and to detect any temperature gradient across the substrate.

Experimental Technique and Procedures

The gage (R_G)and compensating element (R_C) were connected to adjacent arms of a Wheatstone bridge circuit as in Fig. 4. The compensated bridge was set up based on the measured resistance (R) and temperature coefficients of resistance (TCR) of PdCr gage and Pt compensator. The bridge was balanced at room temperature by properly adjusting the value of the ballast resistor R_B ($R_B= R_G(TCR_C-TCR_G)/TCR_G$)), and the bridge completion resistors R_1 and R_2 (ref. 2). The thermal output (e) was measured during several temperature cycles and drift tests at high temperature. Bridge excitation voltage (E) was limited to 1 volt to avoid self heating of the fine wire gage.

The trade-off for the temperature compensation is the loss in the strain sensitivity of the gage (ref. 2). Preliminary experimental results suggest that the gage factor of the PdCr compensated gage is in the range of 1.2-1.3, as compares to an average gage factor of 2 for the most metallic strain gage at room temperature.

All the tests were conducted in air. The strain gage lab is automated to provide computer control of oven temperatures, imposed strain and data collection. This system is described in the reference 4.

Results and Discussion

The change in apparent strain as a function of temperature for a PdCr compensated gage with no preheat treatment is shown in Fig. 5. The gages were installed on the Hastelloy X coupon. It is seen that the variation in apparent strain over the temperature range to 600°C was within 700 $\mu\epsilon$. The apparent strain for the uncompensated PdCr strain gage would have been approximately 65000 $\mu\epsilon$ in the same temperature range. Values of apparent strain of the PdCr compensated gage were calculated assuming a gage factor of 1.2.

In order to improve the reproducibility of the apparent strain between thermal cycles, the gages were soaked at 725°C for 16 hours. The resulting thermal output of this prestabilized gage is presented in Fig. 6. The variation in apparent strain over the temperature range to 600°C was reduced to 250 $\mu\epsilon$. The reproducibility of the apparent strain was improved to within 50 $\mu\epsilon$ between two thermal cycles to 600°C. Note that the shape of the apparent strain versus temperature curves and the value of the apparent strain of a compensated gage simply reflect the nonlinearity of the resistivity versus temperature characteristic of the gage and compensator material. The prestabilization temperature and time affect the repeatability and the shape of the apparent strain characteristics.

Further testing was done at increasingly higher temperatures. A thermal cycle to 700°C caused a uniform 100 $\mu\epsilon$ zero shift in the apparent strain curve which indicated that the sixteen hour preheat process at 725°C was insufficient for gage use to 700°C. Soaking the gage again at 780°C for 50 hours improved the performance of the gage to 700°C; this is shown in the Fig. 7. As can be seen, the variation in apparent strain was less than 600 $\mu\epsilon$ and the reproducibility of the apparent strain was within 50 $\mu\epsilon$ during three thermal cycles to 700°C. Note that the bridge was not rebalanced to zero between cycles. These test results suggest that the reproducibility of the apparent strain and drift of PdCr gage could be further improved by presoaking the gage at an even higher temperature and for a longer period of time.

Fig. 8 shows the change in apparent strain versus temperature of this prestabilized gage during four thermal cycles and some high temperature holds. Notice that the shape of the apparent strain versus temperature curves and the amount of the change in apparent strain over the temperature range to 700°C remained the same even after a one hour and another ten hour soak at 700°C. The drift at 700°C during the ten hour hold of the gage is shown in Fig, 9. The drift was almost linear with an average drift rate of about 80 $\mu\epsilon$/hr. These results indicated that the apparent strain of the PdCr gage can be predicted and cancelled due to its reproducibility and low value, and the gage can be reused after a high temperature hold by rebalancing the circuit.

The use of PdCr wire gage is presently limited to about 800°C because PdCr wire undergoes an undetermined microstructural change at higher temperatures. This is probably caused by the presence of impurities in the wire, mostly silicon and aluminum; however, this is still under investigation. Fig. 10 presents the experimental results of PdCr compensated wire gage tested to 800°C. The gage was mounted on an IN718 test beam and was tested after a 50 hour soak at 800°C. The variation in apparent strain was less than 250 $\mu\epsilon$ and the reproducibility of the apparent strain was within 50 $\mu\epsilon$ during two thermal cycles. Fig. 11 compares the apparent strain versus temperature characteristic of the PdCr compensated gage with that of three Fe-Cr-Al based high temperature strain gages, Chinese 700°C gage, Kanthal A-1 gage and BCL3 gage. The PdCr compensated gage has significantly lower apparent strain to 800°C. Data on the Chinese 700°C gage and Kanthal A-1 gage were adopted from reference 5. Data on the BCL3 gage were obtained here at NASA Lewis.

Development of PdCr thin film strain gages has also started partly because of a temporary shortage in the supply of suitable PdCr wire. Fig. 12 shows the thin film gages on an alumina test beam; they are 8x8 millimeters and 10 micrometer thick. Preliminary tests on these uncompensated uncoated thin film gages have demonstrated linear resistance versus temperature curves to 1000°C (Fig. 13). The reproducibility of the data during a thermal cycle to 1000°C is within 1000 ppm after a fifty hour soak at 1050°C. These results indicate that the PdCr thin film gages have potential usefulness at temperatures to 1000°C. Work is underway to produce compensated thin film gages with overcoatings for oxidation protection.

Conclusions

A PdCr temperature compensated resistance static strain gage is being developed both in the fine wire and thin film form. PdCr wire strain gage coated with a flame sprayed mixture of alumina and 4w/o zirconia has demonstrated the smallest variation in apparent stain and the best repeatability of apparent strain among the existing gages used over the temperature to 800°C. A PdCr thin film gage demonstrated the possibility of extending the use of a PdCr strain gage to 1000°C.

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Reference

1. C. O. Hulse, R. S. Bailey and F. D. Lemkey, High Temperature Static Strain Gage Alloy Development Program", NASA report No. CR-174833, March 1985.

2. D. R. Englund, "The Dual Element Method of Strain Gage Temperature Compensation", Forth Annual Hostile Environments and High Temperature Measurements Conference Proceedings, SEM, p.40-43, 1987.

3. Jih-Fen Lei, "Development and Characterization of PdCr Temperature- Compensated Wire Resistance Strain Gage", NASA report No. CR-185153, 1989

4. H. F. Hobart and H. A. Will, "The Lewis Strain Gage Laboratory- Status and Plans", NASA Conference Publication No.2405, 1985.

5. H. F. Hobart, "Evaluation Results of the 700°C Chinese Strain Gages", NASA Technical Memorandum 86973, 1985.

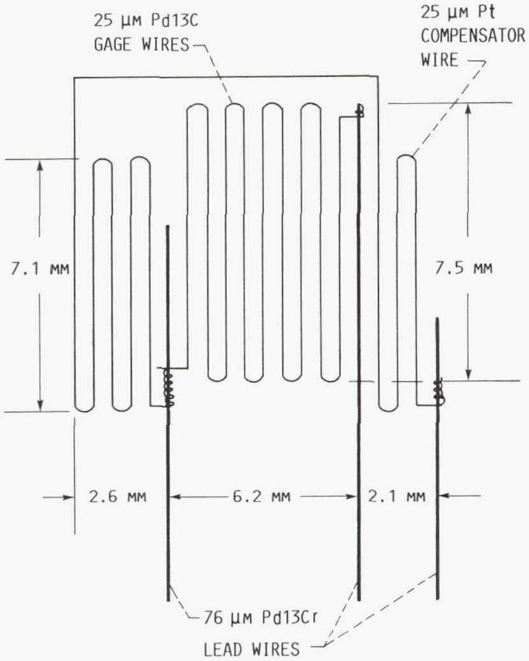


FIGURE 1. - CONFIGURATION OF A TEMPERATURE COMPENSATED PdCr WIRE STRAIN GAGE.

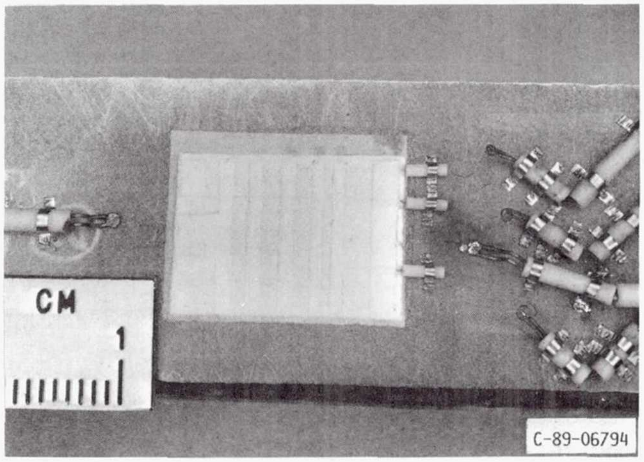


FIGURE 3. - CLOSEUP VIEW OF THE PdCr WIRE STRAIN GAGE ON THE HASTELLOY X COUPON. NOTICE THAT THERE ARE ALSO TWO THERMOCOUPLES SPOT-WELDED TO THE SUBSTRATE.

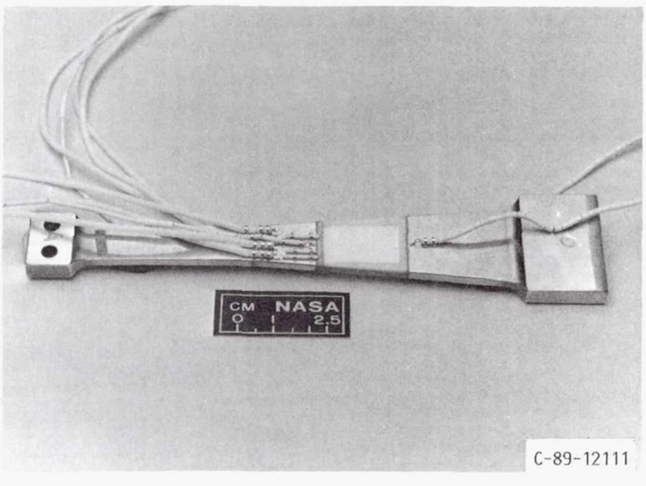
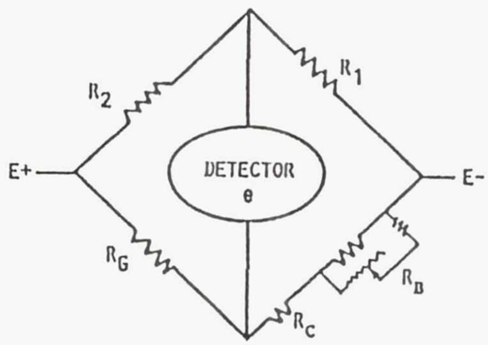


FIGURE 2. - PdCr WIRE STRAIN GAGE ON THE IN718 TEST BEAM. GAGES WERE INSTALLED BY THE FLAME SPRAY TECHNIQUE AND COATED WITH A MIXTURE OF ALUMINA AND ZIRCONIA.



STRAIN GAUGE RESISTANCE, R_G
COMPENSATING GAUGE RESISTANCE, R_C
BALLAST RESISTANCE, R_B
BRIDGE COMPLETION RESISTORS, R_1 AND R_2

FIGURE 4. - WHEATSTONE BRIDGE CIRCUIT FOR TEMPERATURE COMPENSATION OF THE PdCr STRAIN GAGE.

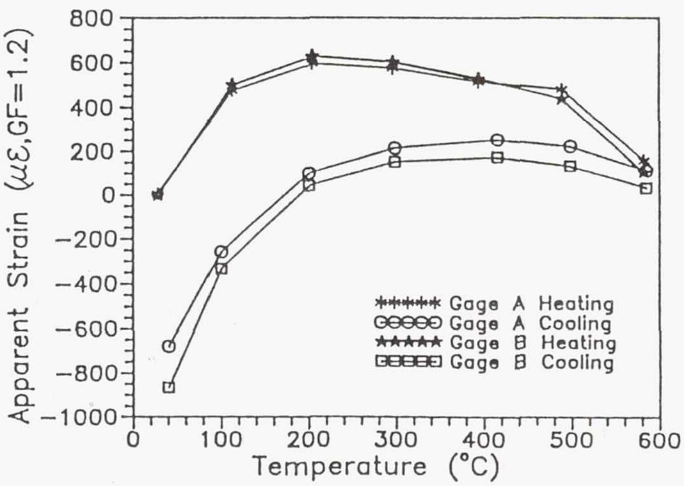


FIGURE 5. - APPARENT STRAIN VERSUS TEMPERATURE OF THE COMPENSATED PdCr TO 600 °C. THE GAGE WAS ON THE HASTELLOY X COUPON AND HAD NO PREHEAT TREATMENT.

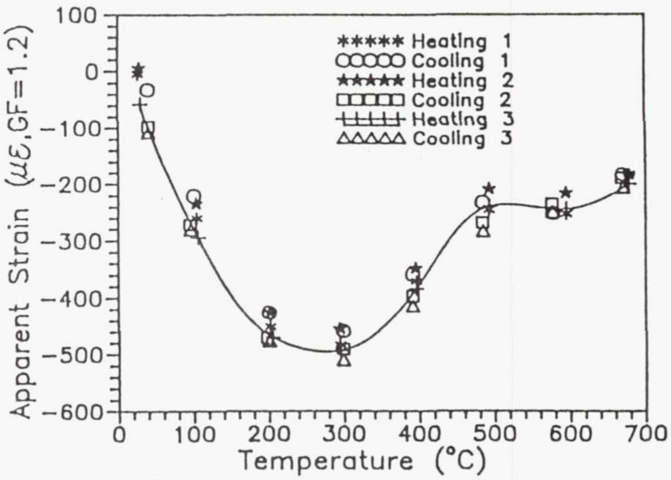


FIGURE 7. - APPARENT STRAIN VERSUS TEMPERATURE OF THE COMPENSATED PdCr GAGE DURING THREE THERMAL CYCLES TO 700 °C. THE GAGE WAS PRESOAKED AT 780 °C FOR 50 HOURS.

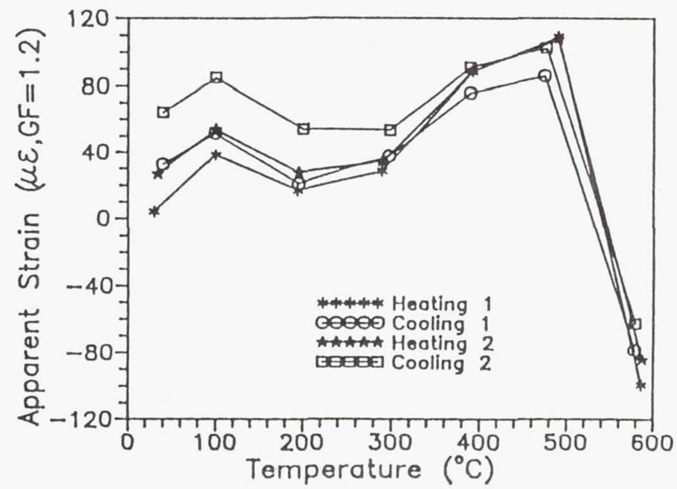


FIGURE 6. - APPARENT STRAIN VERSUS TEMPERATURE OF THE COMPENSATED PdCr GAGE TO 600 °C. THE GAGE WAS PRE-STABLIZED AT 725 °C FOR 16 HOURS.

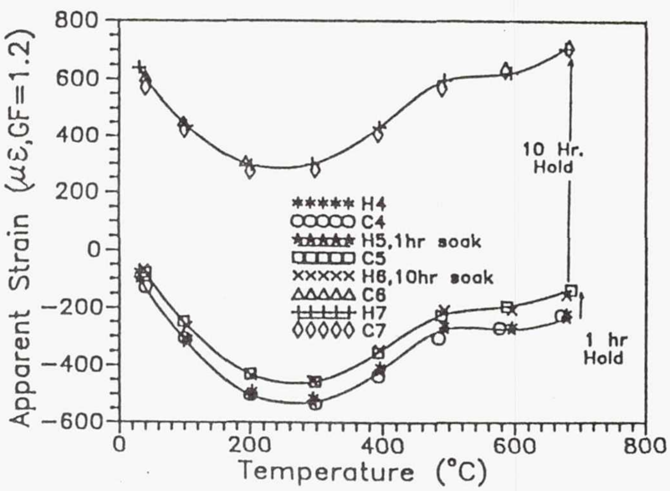


FIGURE 8. - APPARENT STRAIN VERSUS TEMPERATURE OF THE COMPENSATED PdCr GAGE (PRESOAKED AT 780 °C FOR 50 HOURS) DURING FOUR THERMAL CYCLES TO 700 °C AND ONE HOUR AND TEN HOURS SOAKED AT 700 °C.

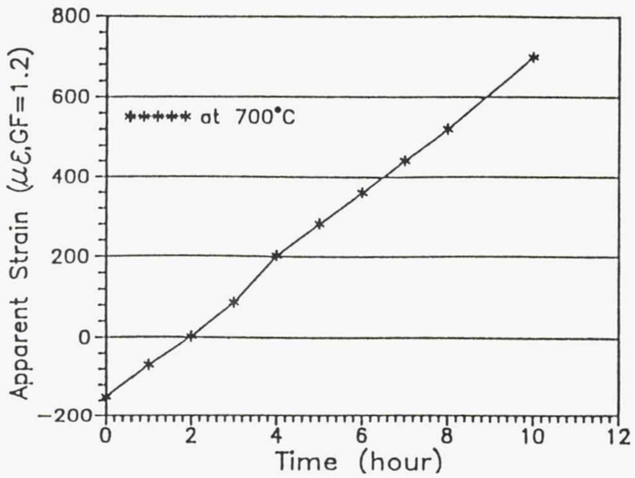
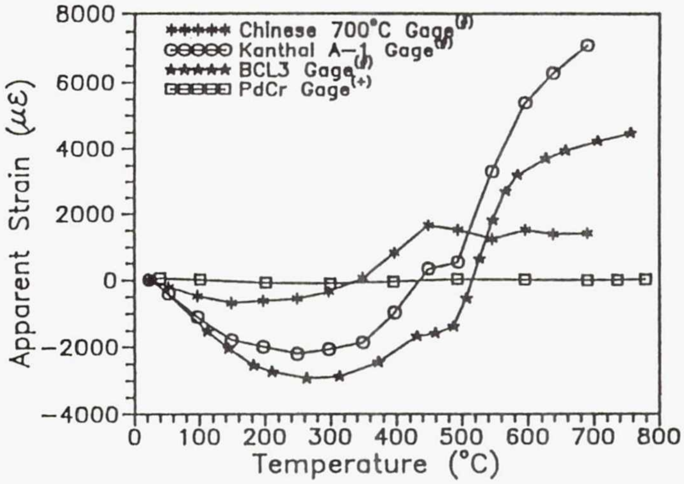


FIGURE 9. - DRIFT OF THE COMPENSATED PdCr GAGE AT 700 °C FOR 10 HOURS.



(#): GF=2; (+): GF=1.2

FIGURE 11. - COMPARISON OF THE APPARENT STRAIN VERSUS TEMPERATURE CHARACTERISTIC AMONG FOUR HIGH TEMPERATURE STRAIN GAGES.

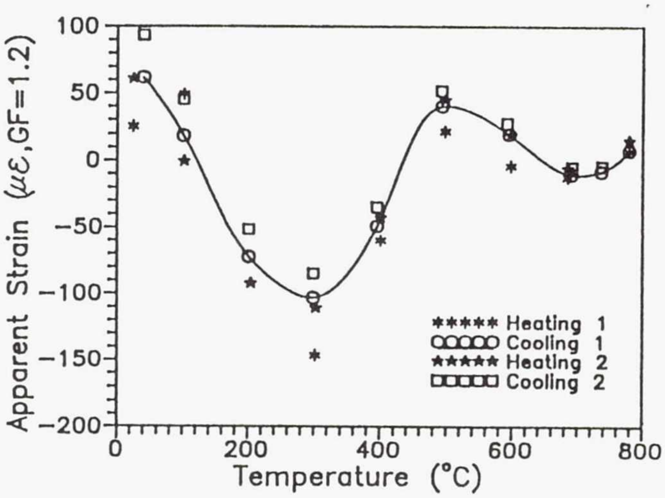


FIGURE 10. - APPARENT STRAIN VERSUS TEMPERATURE TO 800 °C OF THE COMPENSATED PdCr GAGE ON THE IN718 BEAM. THE GAGE WAS PRESOAKED AT 800 °C FOR 50 HOURS.

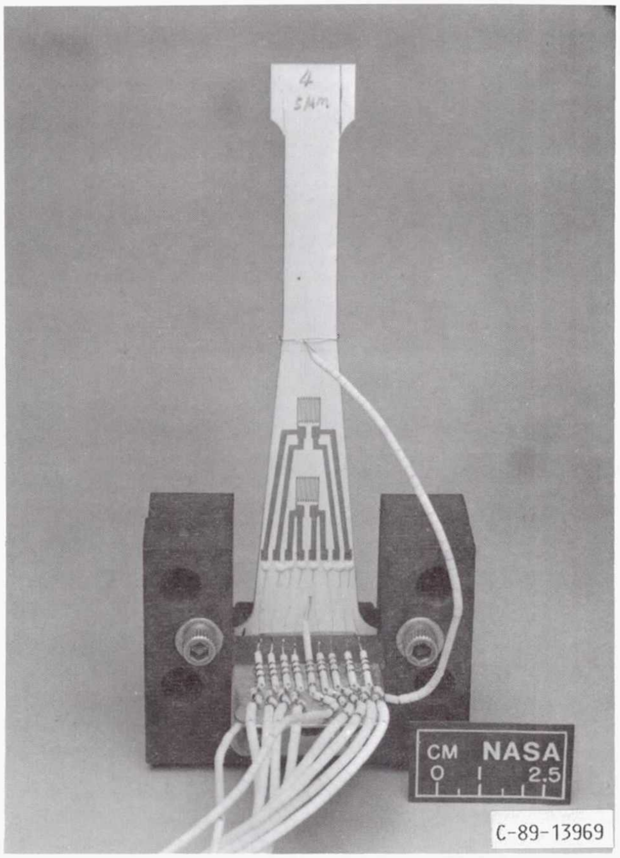


FIGURE 12. - PdCr THIN FILM STRAIN GAGES ON AN ALUMINA TEST BEAM. THE GAGES ARE 8x8 MM AND 10 μM THICK.

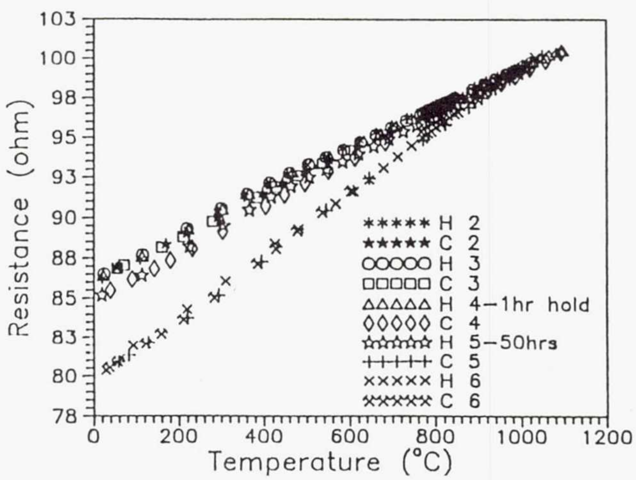


FIGURE 13. - PRELIMINARY RESULTS OF CHANGE IN RESISTANCE VERSUS TEMPERATURE OF PdCr THIN FILM GAGES. THE GAGES WERE UNCOATED AND WITHOUT COMPENSATOR.

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16. Abstract

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