THE DEVELOPMENT OF A HIGH TEMPERATURE STATIC STRAIN GAGE SYSTEM*

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The objective of this program is to develop electrical resistance strain gages which will permit the measurement of static strains on nickel and cobalt superalloy parts inside gas turbine engines running on a test stand. The ability to make measurements of this type is essential to the goals of the HOST program because, without reliable knowledge of the stresses and strains which exist in specific components during engine operation, it will be difficult to effectively determine where improvements in design and materials can be implemented.

The specific goal of this work is to develop a complete system able to make strain measurements up to $\pm 2{,}000$ μstrain with a total error of no more than $\pm 10\%$ over a 50 hour period at 1250K. In addition to simple survival and stability, attaining a low thermal coefficient of resistivity, of the order of 100 ppm/K or less, is a major goal. This need results from the presently unavoidable uncertainties in measurements of the exact temperatures inside gas turbines. The initial part of this work consisted of a strain gage alloy development effort in which a variety of alloys were evaluated after being prepared by drop-casting or splat cooling.

The thermal cycling apparatus shown in figure 1 was used to make resistivity measurements up to 1250K at heating and cooling rates as high as 250K/min. The sample was positioned axially in the center of a split metal tube heater which could be cycled or held at a constant temperature under program control. Platinum leads for use in a four wire resistance circuit and a thermocouple at the center of the sample were attached by spot welding. The heating system also included an external plenum, not shown in figure 1, to permit cooling gases to be introduced at lower temperatures for better temperature control. A variety of circuit and computer program changes have been made to improve the accuracy of the data.

Our previous work (ref. 1) on the properties of various metal alloys prepared by drop casting resulted in the identification of two candidates from two different alloy systems. The first candidate was a FeCrAl alloy called Mod 3 of composition Fe-11.9Al-10.6Al, in weight percent. The effects of a whole series of alloying additions to this candidate were evaluated without discovering any which resulted in significant improvements. This alloy shows a resistivity versus temperature behavior which is very similar to that of the Chinese FeCrAl-base alloy recently described by Hobart (ref. 2), with the difference that it appears able to be used to a higher temperature.

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It was subsequently observed, however, as shown in figure 2, that the resistivity versus temperature curves for this alloy does show a gradual change with increasing times of exposure to 1250K in air. Because of this effect and concern over the oxidation of this alloy, work on this system was discontinued in favor of work on the second alloy candidate.

The best PdCr alloy candidate identified in this second alloy system was Pd-13Cr, in weight percent. The ultimate strength and the 0.02 percent off-set yield strengths determined on bulk samples as a function of temperature are shown in figure 3. The gage factor of this alloy determined at room temperatures using commercial strain gages was 1.78. These properties may be different when evaluated for thin sputtered films which are in intimate contact on both sides with oxides. Although it is more sensitive to temperature than the FeCrAl Mod 3 alloy, the response of the Pd-13Cr alloy to temperature, as shown in figure 4, is linear which indicates that no internal microstructural changes which could be time dependent are taking place. It was decided that this stability was most important for a static gage system and that thermal compensation by the incorporation of a small second grid of a pure precious metal would be the optimum way to proceed. This will be developed in Task 5 of the program.

As a final step in the alloy development process, sputtered films of Pd-13Cr have been prepared on Hastelloy-X substrates. Although the initial plans were to form sputtered films approximately 30 microns (30 micrometers) thick, problems encountered in the removal of the masks after sputtering limited the maximum thicknesses to approximately 6.5 microns. Results to date indicate that the as-sputtered films are very well bonded to the substrate. When these sputtered films are subsequently exposed to air at elevated temperatures, they develop a coating of chromium oxide, Cr_2O_3, which is also extremely adherent. It is difficult even with grit blasting to remove the oxide to expose the underlying metal in order to make electrical contacts.

The measured thermal sensitivies of the resistances of these films after oxidation are approximately ten times higher than for the original as-sputtered alloy because most of the chromium in the alloy has been consumed in order to make the protective oxide coating. Moreover, the observed rates of electrical drift at 1250K suggest that, at this small a dimension, the Cr_2O_3 coating does not provide a sufficient level of stability and protection from oxidation. Experiments to recrystallize the sputtered nodules and thus to remove the enhanced diffusion paths provided by the boundaries between the nodules were successful, but unacceptable levels of drift still remained. These results indicate that the use of an additional overcoating system will be necessary. Current effort on this problem involves sputtering a coating of aluminum on top of the Cr_2O_3 which can then be oxidized in place to form a tight overcoating of Al_2O_3 which should be much more protective. The subject of overcoating will also be examined in a later task of the program (Task 5).

REFERENCES

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2. Hobart, H. F.: "Evaluation Results of the 700°C Chinese Strain Gages," NASA Conference Publication 2339, Turbine Engine Hot Section Technology 1984, NASA Lewis Research Center.

HIGH SPEED THERMAL CYCLE/RESISTIVITY MEASUREMENT APPARATUS

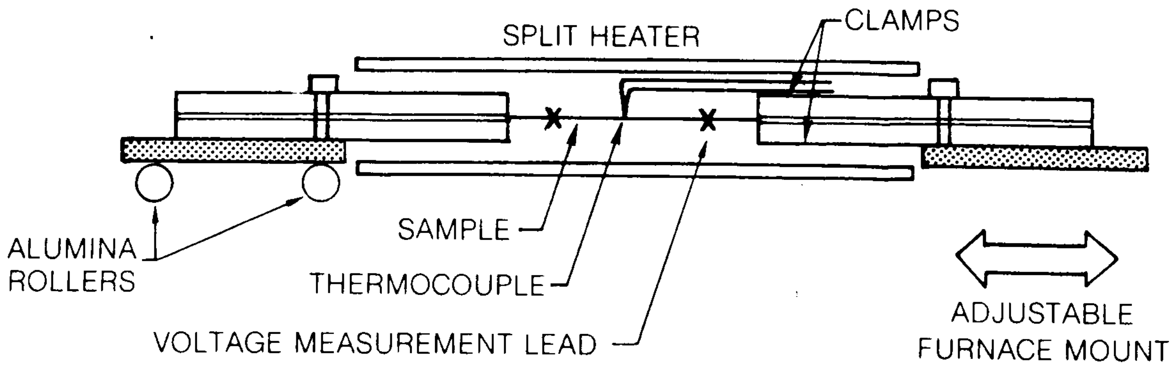

FIGURE 1

CHANGE IN MOD 3 FeCrAl ALLOY RESISTANCE VS TEMPERATURE AFTER DIFFERENT SOAK TIMES AT 1250K

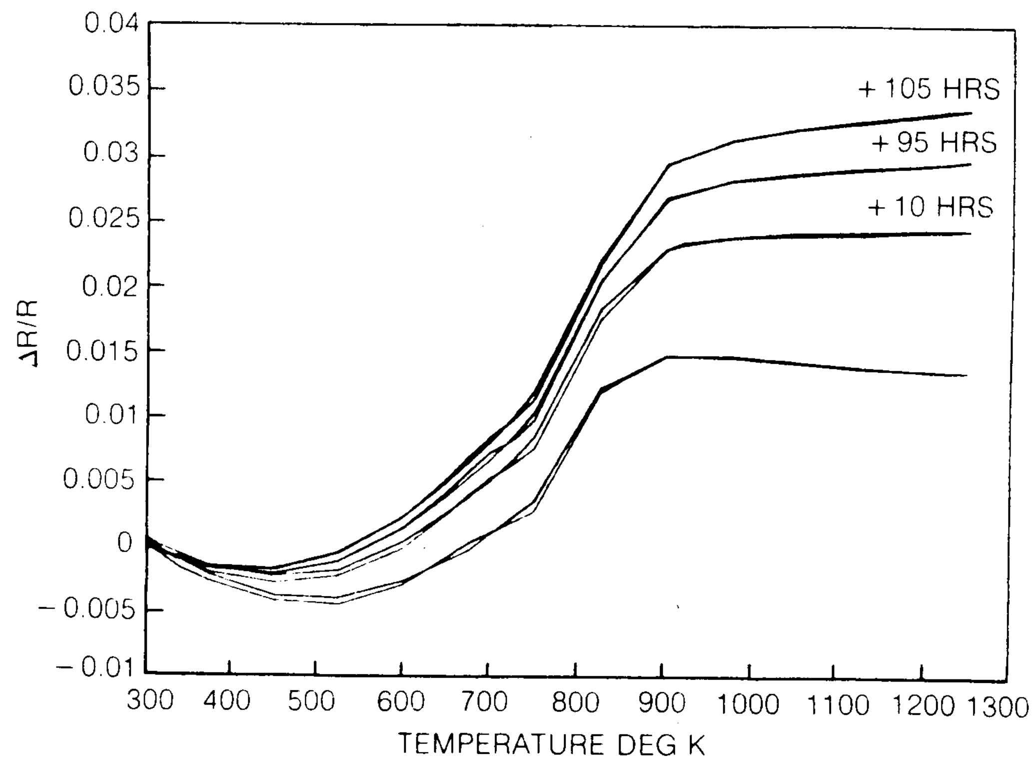

FIGURE 2

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STRENGTH VS TEMPERATURE OF DROP-CAST Pd-13 Wt % Cr

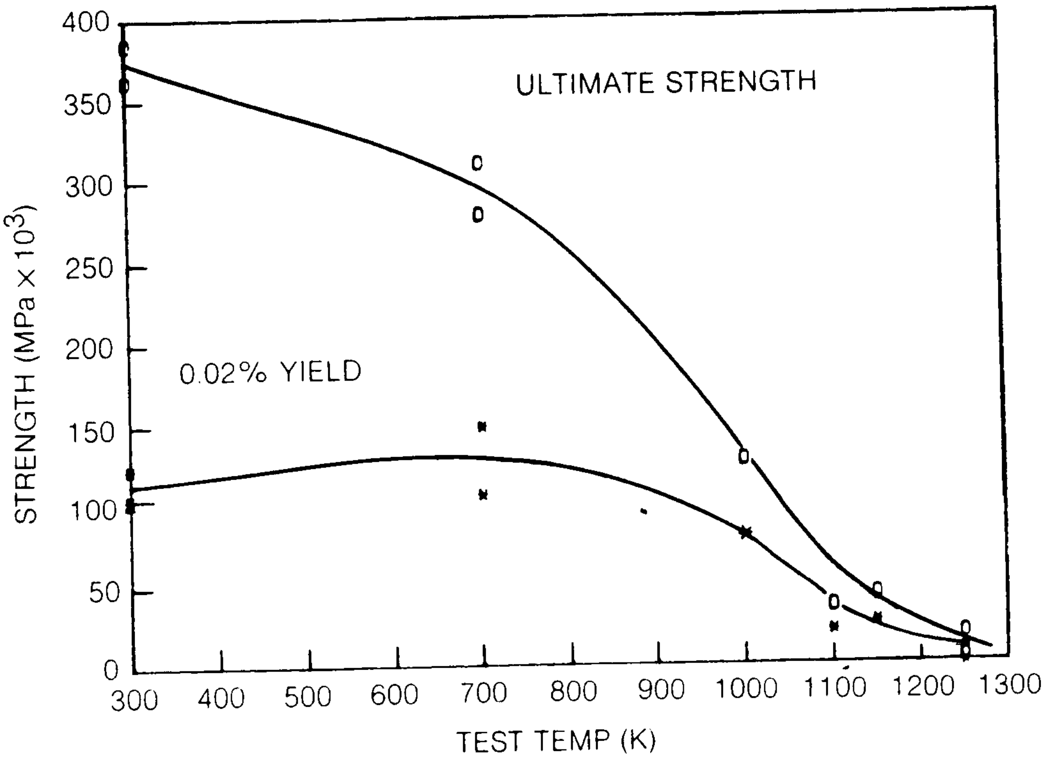

FIGURE 3

RESISTANCE VS TEMPERATURE AT 50 DEG K/MIN (Pd-13 Wt % Cr)

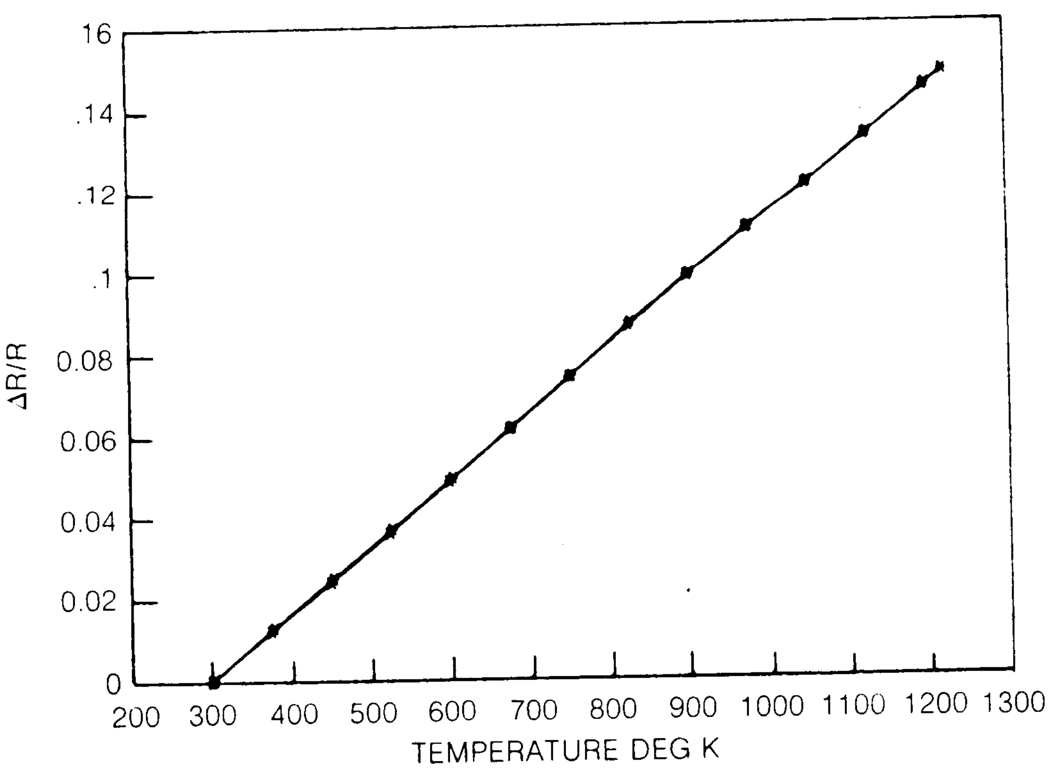

FIGURE 4