N87-11188

# HIGH TEMPERATURE STATIC STRAIN
# GAGE PROGRAM

Charles Hulse and Richard Bailey
United Technologies Research Center

and

Howard Grant
Pratt and Whitney Aircraft

The purpose of this program is to develop electrical resistance strain gages for static strain measurements of nickel or cobalt superalloy parts inside a gas turbine engine on a test stand. Measurements of this type are of great importance in meeting the goals of the HOST Program because, without reliable knowledge of the stresses and strains which exist in specific components, it will be difficult to fully appreciate where improvements in design and materials can be implemented. The first part of this effort consists of a strain gage alloy development program which is to be followed by an investigation of complete strain gage systems which will use the best alloys developed together with other system improvements.

The specific goal for the complete system is to be able to make measurements to ± 2,000 $\mu\varepsilon$ with an error of no more than ± 10% over a 50 hour period. In addition to simple survival and stability, attaining a low thermal coefficient of resistivity, of the order of 100 ppm/K or less, is also a major goal. This need results from the presently unavoidable uncertainty in measurements of exact temperatures in the turbine. The first year of effort resulted in the indentification of an FeCrAl alloy and the Pd-Cr systems as the best candidates. This years effort has been concentrated on additional alloy development, fabrication and alloy evaluation studies.

Although the size and thickness requirements to avoid aerodynamic effects suggest sputtering as the best strain gage fabrication technique, this approach is too slow and expensive for alloy studies. An arc-melting and drop-casting facility, shown schematically in Figure 1, was therefore developed. This has provided a relatively quick and inexpensive way to prepare rod samples which can be subsequently ground and polished to produce flat ribbon samples. A differential pressure in the titanium gettered argon above the molten sample supplies the force to quickly move the molten alloy down into the ceramic casting tube when the bottom film across the hole becomes melted enough to rupture.

As an alternative fabrication approach, palladium alloy were prepared as thin foils about 2.5 in. in diameter using the splat cooling approach. For this purpose, the ram shown in Figure 1 was used to splat a small arc-melted drop on a water-cooled hearth which did not include the casting hole shown in Figure 1.

PRECEDING PAGE BLANK NOT FILMED

These foils were subsequently polished down from thickness of about 0.075 to be about 0.050 mm thick and then cut into strips for testing.

The thermal cycling apparatus in Figure 2 was used to make resistivity measurements up to 1250K by the use of a split metal tube heater which could be cycled or held at a constant temperature under program control. The test samples were positioned axially in the center of this tube with platinum leads for voltage measurements and a thermocouple attached to the center of the test section by spot welding. This system was improved by the addition of an external plenum to permit cooling gases to be introduced at lower temperatures for better control. A variety of circuit and computer program program changes were also made to improve the accuracy of the data.

Our previous work had identified the FeCrAl composition Fe-11.9Al-10.6Cr, in weight percent, as an improved strain gage alloy candidate. The effects on the oxidation of this alloy of a number of alloying additions were examined by weight change measurements made over a 50 hour period in air at 1250K. A total of 12 different samples were examined with different additions of Y, Co, Zr, Hf, Sc and Ni. None of these elements appeared by this measure to provide a significant improvement. It was subsequently observed, as shown in Figure 3, that the resistivity versus temperature curves for this base alloy show a gradual change with increasing times of exposure to 1250K. Because of this effect and concern over the oxidation of this alloy, work on this system was discontinued in favor of work on PdCr alloys.

Efforts were made to examine the effects of alloying additions on the Pd-13 wt % Cr alloy previously developed. Thirty four samples with various amounts of Cr, Gd, Er, La, Nc, Re, Ta, Y, Mo and W were prepared and evaluated to determine the alloying limits. The oxidation behavior of seven alloy compositions were also examined by measurements of weight changes over a 50 hour period in static air at 1250K. Figure 4 shows with electron microprobe data how the chromium becomes concentrated at the surface of the alloy where other measurements confirm that it reacts with oxygen to form $Cr_2O_3$. The electrical behavior of 12 different alloy samples were examined during thermal cycling at different heating and cooling rates and during thermal soaks at 1100 and 1250 K in air and in argon. The results of this work indicated that the original Pd-13 Wt % Cr alloy was still the most desirable condidate. Table I presents data on the reproducibility of resistance and apparent strain from cycle to cycle at 50K/min assuming a gage factor of 2.0. Figure 5 shows electrical drift data for drop-cast rod material at 1100 and 1250 K in air and in argon. These repeatability and stability measurements are close to the program goals for a complete strain gage system.

## TABLE I

## Cycle to Cycle Reproducibility of Pd - 13 wt % Cr

| | | Difference in apparent strain in microstrain from avg. (G.F. = 2.0) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Temp. | Std. Dev. | Cycle #2 | | Cycle #3 | | Cycle #4 | | Cycle #5 | |
| (K) | ( R/R) | Heat | Cool | Heat | Cool | Heat | Cool | Heat | Cool |
| 300 | .000035 | -9 | 22 | -9 | 8 | -9 | -20 | -9 | 29 |
| 450 | .000167 | 66 | -86 | 67 | -97 | 51 | -92 | 108 | -18 |
| 600 | .000134 | 74 | -49 | 54 | -76 | 33 | -80 | 78 | -35 |
| 675 | .000173 | 102 | -76 | 65 | -94 | 54 | -91 | 95 | -54 |
| 725 | .000243 | 137 | -110 | 103 | -131 | 96 | -106 | 117 | -105 |
| 825 | .000117 | 60 | -58 | 37 | -62 | 47 | -54 | 71 | -40 |
| 975 | .000071 | 46 | -26 | 30 | -25 | -4 | -42 | 45 | -24 |
| 1125 | .000061 | 35 | -18 | 20 | -26 | 37 | -48 | 11 | -10 |
| 1225 | .000063 | 27 | -17 | 29 | -16 | 19 | -53 | 33 | -21 |
| 1250 | .000043 | 30 | | -16 | | -15 | | 1 | |

Avg. Std. Dev. = .000130

Runs rezeroed between cycles

# TRI-ARC MELTER SHOWING POSITION OF SPLAT COOLING RAM AND DROP CASTING TUBE

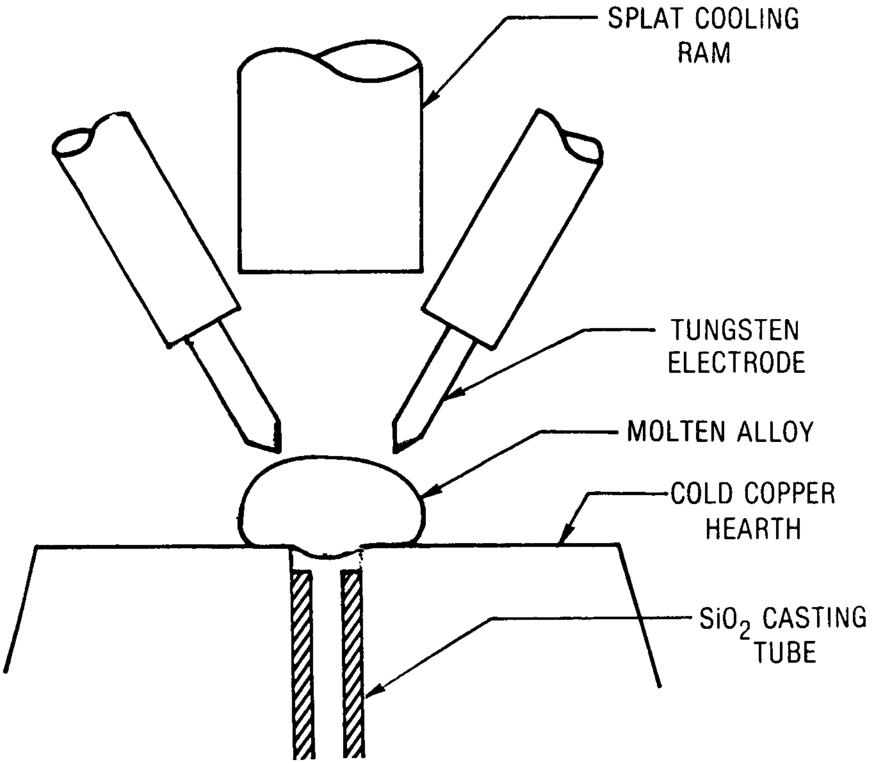

FIGURE 1

84–8–70–1

## HIGH SPEED THERMAL CYCLE/RESISTIVITY MEASUREMENT APPARATUS

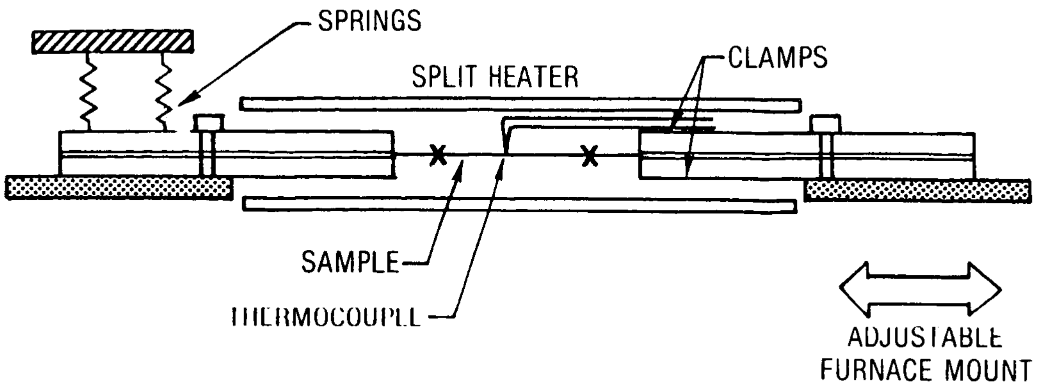

FIGURE 2

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

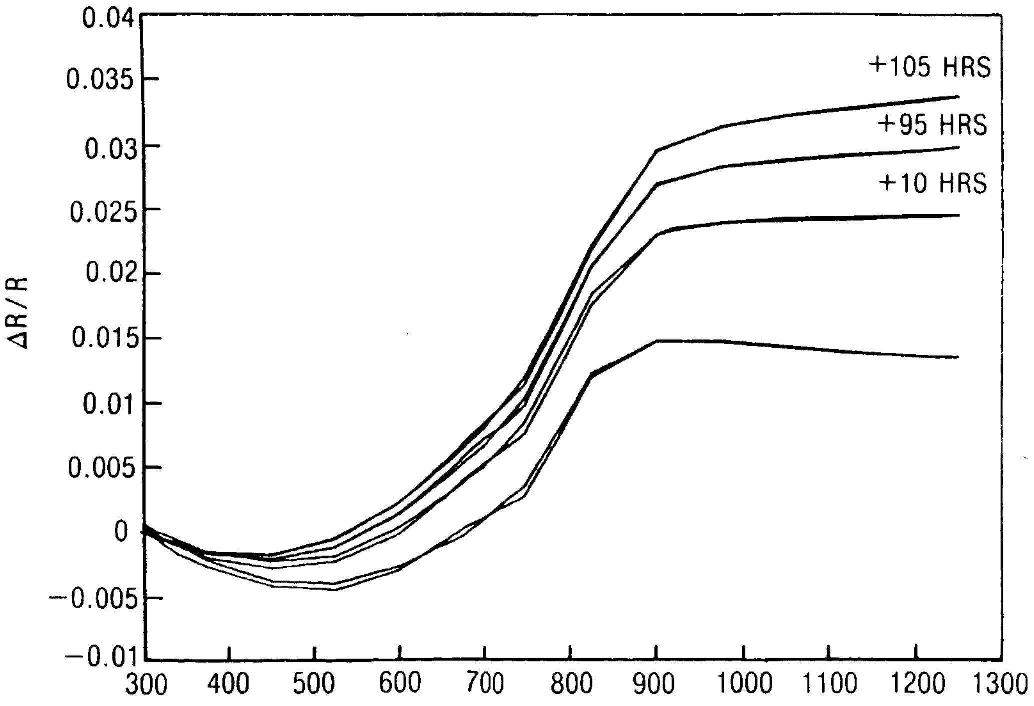

FIGURE 3

84–8–70–2

ELEMENTAL COMPOSITION PROFILES AT THE SURFACE OF Pd-13 WT% CR SAMPLE AFTER 40 HOURS IN AIR AT 1250K

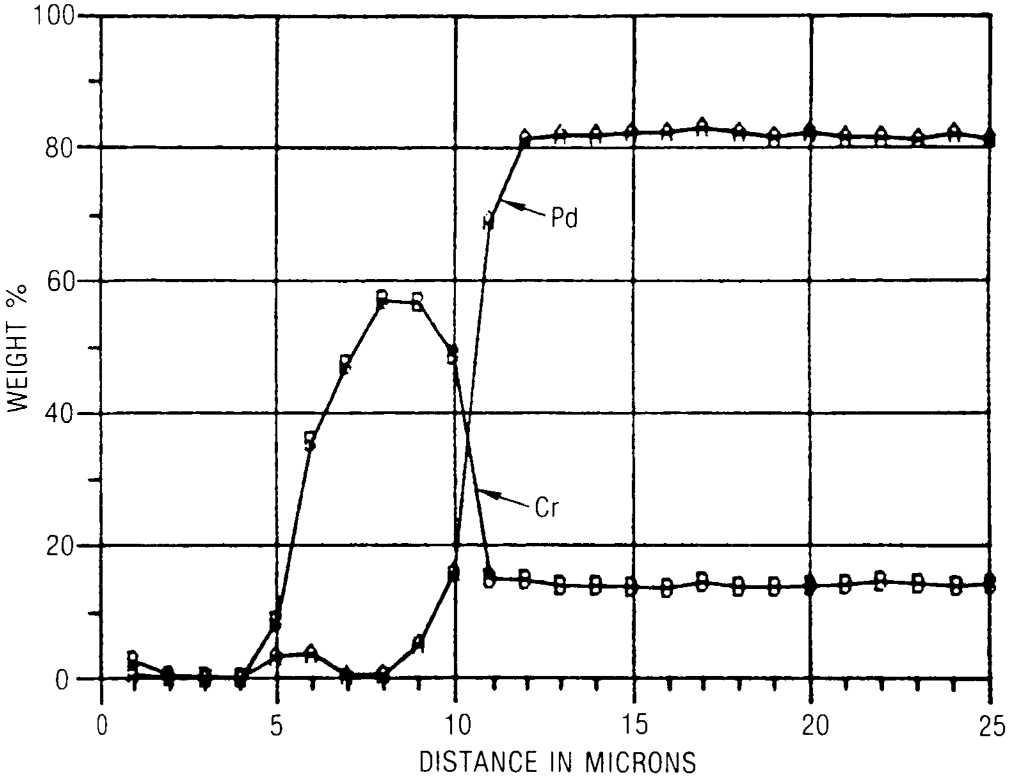

FIGURE 4

DRIFT IN APPARENT STRAIN OF Pd-13 Wt% Cr ASSUMING A GAGE FACTOR OF 2.0

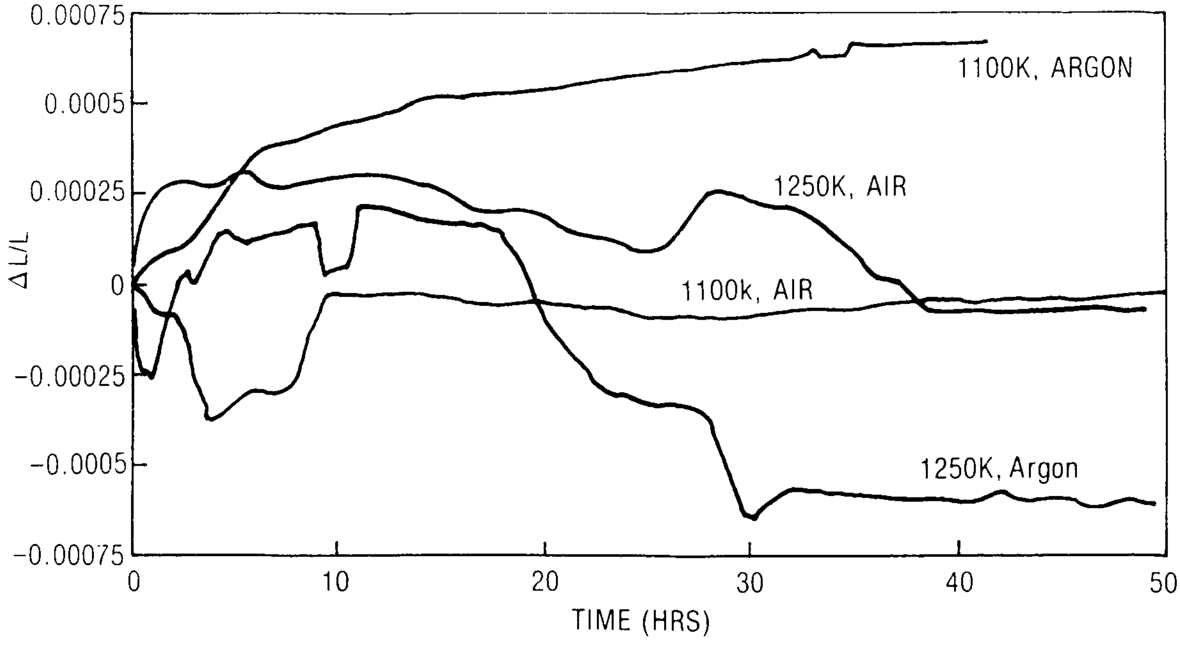

FIGURE 5