High Temperature Strain Gauges for Turbo-Jet Components

ADVANTAGES OF PLATINUM ALLOY RESISTANCE WIRES

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Since 1953 an extensive research programme has been in hand at the Electro-Dynamics Laboratories of Bristol Siddeley Engines Limited on the basic properties of resistance strain gauges (1, 2) in order to develop elements capable of producing alternating strain data within an accuracy of $\pm$ 5 per cent at temperatures up to 1000°C and steady strain data within a similar accuracy but in the temperature range -70 to $+650$°C, mainly from turbo-jet components operating in oxidising atmospheres. A total of fifty-four alloy systems have been examined so far and, more recently, greater emphasis has been given to alloys of the platinum metals (3). This change of emphasis has resulted from the greater amount of effort being devoted to the development of elements suitable for the measurement of steady strains.

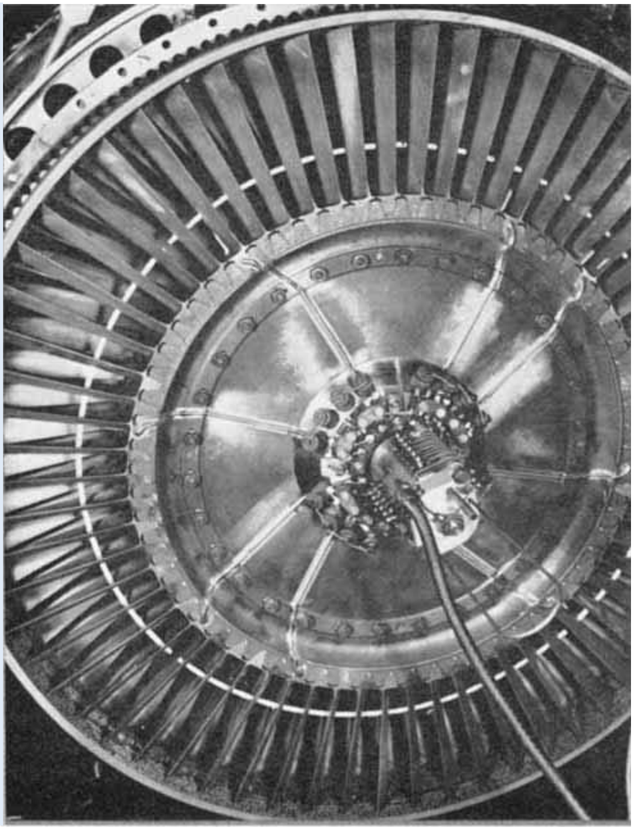
When using resistance strain gauges to detect alternating stresses, temperature- and time-induced resistance changes may generally be reduced to secondary effects by suitable instrumentation. This is not possible when steady strain data are required, since these variations would provide either a shift or complete loss of the original reference zero, so invalidating the results. The maximum value of electrical resistance drift that can be tolerated will depend upon the degree of accuracy required and the general stress level normally encountered. For a steady stress level of 10 tons/sq. in. and a required accuracy of 5 per cent, the maximum acceptable drift from all causes cannot exceed 100 to 150 μ ohm/ohm or must be compensated to better than this value. A high degree of resistance to corrosion and oxidation is therefore essential if the gauge is required to remain stable at high temperatures for long periods of time, since a diametral change of only 0.001 per cent in the strain wire may result in a resistance change in excess of 200 μ ohm/ohm. Some alloys will suffer preferential oxidation under these conditions, resulting in a permanent resistivity change due to depletion of one or more of their constituents. Where the resistivity changes owing to depletion are negative, they may compensate the positive resistance changes due to oxidation and corrosion when

$$\frac{d\rho}{dc} = \rho \frac{D}{D'} 10^{-2}$$

where $d\rho/dc$ is the rate of change of resistivity with composition, ρ the alloy's resistivity, D its density and D′ the density of the preferentially oxidised constituent. Theoretical considerations suggest that such compensation can be more readily achieved with alloys having an oxidation rate of 0.002 g/m²h or less.

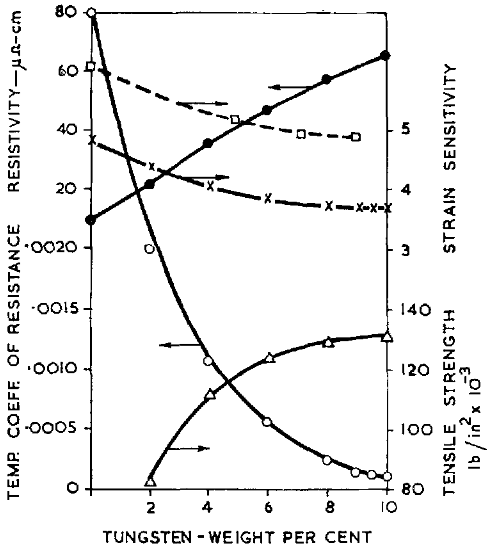
Tests carried out on twenty-one binary and ternary noble metal alloys have clearly indicated that some platinum metal alloys are sufficiently stable: the number of alloys having a suitable $d\rho/dc$ is much more limited and, consequently, very few wires are suitable for the measurement of steady strains at high temperatures. The best characteristics so far have been obtained with binary alloys of the face centred cubic platinum metals with one another or with metals of Group VIA. The

This article reviews an investigation carried out in order to develop a wire resistance strain gauge for the measurement of steady stresses in stationary and rotating turbo-jet components operating at temperatures up to 600°C in oxidising atmospheres. The illustration shows a typical turbine strain gauge assembly using tungsten-platinum alloy wires



work has been hampered by the sluggishness of structural changes in many of these alloys and the large property changes associated with such modifications. For example, the strain sensitivity — that is the electrical resistance change per unit applied strain — of iridium-platinum alloys increases from 4.9 for pure annealed platinum, to 6.5 as the solid solution to duplex alloy transitional composition is approached, falling again, as greater quantities of iridium are added, to 4.2 at the 25 per cent by weight iridium alloy. Exposure of rhodium-platinum alloys to irradiation of the order of 5×10^{20} nvt will modify the strain sensitivity and resistance characteristics by significant amounts, the changes being attributable to neutron capture and the consequent transmutation of rhodium to palladium. Some alloys of the chromium-palladium and tungsten-platinum systems exhibit outstanding long-term stability at high temperature under oxidising conditions. In order that the temperature coefficient of resistance may be acceptably low, suitable alloys must contain at least 20 per cent by weight of chromium or, as shown in the graph on page 130, at least 8 per cent by weight of tungsten. The strain sensitivity of high chromium-palladium alloys is modified by moderate straining and greater effort has therefore been devoted to the tungsten-platinum series of alloys containing between 8 and 10 per cent by weight tungsten.

Typically, an annealed alloy containing 9.5 per cent tungsten will have a room temperature tensile strength of 142,000 lb/ sq. in. falling to 83,000 lb/sq. in. at 600°C, an oxidation rate in still air at 600°C of 0.00085 g/m²h, a resistivity at 20°C of 74.2 μ ohm-cm, a temperature coefficient of resistance (0-1000°C) of 145 μ ohm/ohm/°C and a coefficient of thermal expansion (0-1000°C) of 8.9 μ in./in./°C.



Electrical and mechanical properties of tungsten-platinum alloys. All specimens were in the annealed condition except that represented by the broken line, which was in the hard drawn state.

Strain elements wound from 0·001 inch diameter wire, annealed and stabilised by soaking at 600°C for 100 hours will have a strain sensitivity of 3.74 ± 0.008 (95 per cent confidence limits) with a standard deviation of 0.126. The sensitivity will fall at the rate of 0.042 per cent per °C with increasing temperatures. Exposure to oxidising atmospheres at 600°C for periods of up to 200 hour/ indicates a drift rate equivalent to 14 μ ohms ohm/h; no significant changes in strain sensitivity or temperature coefficient of resistance will result. Successful tests have been carried out using elements of this type bonded to engine rotating parts operating at temperatures up to 600°C, as shown in the photograph. After a five-hour test, the elements were recalibrated: there appeared to be no change in temperature coefficient of resistance, drift rate or strain sensitivity. The permanent resistance change was 70 μ ohm/ohm (equivalent to 700 lb/sq. in. in steel).

It is evident that platinum metal alloys offer significant improvements in strain sensitivity, stability and resistance to adverse environmental conditions and there is little doubt that wider acceptance of such alloys will result in greatly improved techniques.

References

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2 R. Bertodo, Resistance Strain Gauges for the Measurement of Steady Strains at High Temperatures, *Proc. Inst. Mech. Eng.*, 1964, Preprint P34/64

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Corrosion Resistance of Iridium and Ruthenium

ATTACK BY LIQUID METALS

Recent progress in methods of fabricating iridium and ruthenium has focused attention on their special properties of high melting points and resistance to chemical attack. D. W. Rhys and E. G. Price have now reported (*Metal Ind.*, 1964 (August 20th), 243–245) the results of tests designed to show the amount of attack by nineteen liquid metals on sintered specimens of iridium and ruthenium contained in crucibles of the same material. Under the test conditions neither iridium nor ruthenium were attacked by lithium, sodium, potassium, silver, gold, mercury, indium, or lead. Copper, cadmium, tellurium and tin did not attack ruthenium, and bismuth did not attack iridium. Calcium, gallium, and bismuth only slightly attacked ruthenium, and gallium also only slightly attacked iridium.

Some alloying and/or solution occurred with ruthenium for magnesium, zinc, aluminium, and antimony. Iridium was affected by these metals and also by copper, calcium, cadmium, tin and tellurium.

The most severe attack occured with zinc by rapid solution.