

High Temperature Strain Gage Technology for Gas Turbine Engines

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Summary

This report summarizes the results of a six month study that addressed specific issues to transfer Pd-13Cr static strain sensor technology for use in a gas turbine engine environment. The NASA Lewis (NASA) developed Pd-13Cr strain gage was determined by Pratt & Whitney (P&W) to be the only viable static strain sensor operational to 1400°F. Various components of the measuring system were addressed to make the sensor more robust for a gas turbine engine environment, and more compatible with field or test cell applications.

The issues that were studied include: (1) Replacement of the decade resistance boxes that were used in previous laboratory tests with a bridge completion network. This included the evaluation of a miniature variable potentiometer for the ballast resistor. (2) Evaluation of metal sheathed, platinum conductor leadwire for use with the 3-wire sensor. (3) Sensor fatigue characteristics.

Previous P&W and NASA experience had indicated that this sensor is highly dependent on: the purity of the Pd-13Cr wire, the purity of the flamespray powders and the installation technique. Because of its importance to the quality of the output data, the strain gage installation technique (which was developed by NASA and HITEC Corp.) is discussed in detail.

Test results indicated a useful gage system at all temperature levels up to 1350° F. The thermal output behaved extremely well between 950° F and 1350° F with absolute values of e/E (output millivolts per volts of excitation) staying within ± 60 ppm (parts per million). Cyclic repeatability was within 15 ppm and zero repeatability was less than 50 ppm.

Room temperature fatigue testing indicated that the Pd-13Cr strain gage is comparable to the P&W standard strain gage currently used in gas turbine engine testing. Three out of four Pd-13Cr strain gages survived a standard P&W fatigue qualification test.

Introduction

There has been significant emphasis by the military & defense contractors to continually increase gas turbine engine thrust to weight ratio. As such, the requirements for static strain measurement at elevated temperatures has moved to the forefront of instrumentation technology development.

To reduce overall engine weight, structures have become thinner, resulting in higher strain levels. Diffuser and turbine cases, as well as the newly developed vectoring nozzles, can operate under high static strain levels as a result of this lightweight requirement.

To increase engine thrust, combustor and turbine modules are operating at higher temperatures and pressures resulting in increased structural loading. Extremely high aerodynamic loads on airfoils have resulted in abnormally high static stress levels in the blade attachment area of the rotating disk.

It is apparent that measuring the actual stress at high temperature is imperative to component design, however, measurement above 700° F has typically been a challenging if not impossible task. Various sensor concepts and techniques have been developed that under strictly controlled conditions, have operated sufficiently at 1200°F and beyond.

In the hostile gas turbine engine environment strain measurement requirements and environmental conditions vary widely. The strain gage is typically subjected to a variety of extreme conditions such as: high temperatures up to and exceeding 1400°F; varying thermal cycle rates and durations at various temperatures; dynamic strain components coupled with the underlying static strain values; direct exposure to the hot gas stream; and rotational loads (for example, on turbine disks and blades) resulting in forces exceeding 50,000 g's. An engine test may require dozens of static strain measurements, therefore the temperature compensation technique for the static strain gage must be simple and easily applied. The gage should also be usable with commercially available signal conditioners.

An extensive study was recently conducted by P&W (ref. 1) which reviewed a variety of static strain gage candidates for high temperature use (>1000° F). Although this report was intended to address specific NASP (National Aerospace Plane) applications, the results also apply to any high temperature static strain requirement.

It was determined that the Pd-13Cr strain gage was the only viable candidate for high temperature static strain measurement. It was recommended however, that this gage concept be further developed before practical engine application measurements (gas turbine or hypersonic) could be routinely made.

The following application development issues were identified:

1. Replacement of the bare wire Platinum conductor gage hook-up leadwires with Pt conductors in swagewire form (conductors encased in a solid metal sheathing and insulated with packed alumina).
2. Replacement of the decade resistance boxes used for the strain gage bridge completion network and the ballast resistor (R_b) with miniature commercially available units.
3. Elimination or reduction in time of the post installation heat treat required to stabilize the gage output.
4. Identification of a readily available source for the Pd-13Cr bare wire, in an acceptably pure composition.

The first two items above were addressed under this contract. The third and fourth items were addressed by NASA.

The Pd-13Cr strain gage was also viewed as a potential candidate for measurement of dynamic strain in the turbine environment. It is commonly believed that oxidation of the gage grids in a hot gas environment results in premature failure of the strain gage. The Pd-13Cr strain gage relies upon the formation of a very stable chrome-oxide layer around the surface of the gage element for reliable static strain measurements. This stable oxide layer could very well protect the strain gage while measuring dynamic strain loads at elevated temperatures.

Under the limited scope of this program, it was decided to look at the fatigue life characteristics of the strain gage at room temperature only. A follow-on study would include tests at elevated temperatures and the results compared to conventional strain gages.

Testing of the strain gages under this contract was based upon evaluation of the gage "thermal output" (with the exception of the fatigue tests). Thermal output is an undesired component of the gage output at elevated temperature. As temperature changes a strain gage will undergo a resistance change independent of any structural loading. If not corrected for, this would be interpreted as actual strain. It is important that the absolute value of the thermal output remain relatively low, preferably no higher than the level of "real" strain being measured. Another guideline for this magnitude is that the thermal output sensitivity of the gage be less than 1 microstrain/degree F in the entire temperature range (ref. 1).

Correction of the thermal output from actual test data can be justified if it is repeatable with successive thermal cycles, and exhibits low drift. The magnitude of acceptable thermal output will vary with the application and will depend on the accuracy required. A good rule of thumb is a cyclic repeatability within 100 microstrain and a drift value that is less than 100 microstrain/hour at maximum temperature.

Experimental Procedure

The experiment was centered around evaluation of the Pd-13Cr gage thermal output for each change made to the strain gage system. The first change involved switching the bare wire Pt leads with Pt conductors in swagewire form. The second change involved switching out the decade resistance boxes used for completion of the strain gage bridge completion network with a conventional (and commercially available) signal conditioning unit. The third change required identification of a miniature, variable, low drift potentiometer to replace the decade resistance box used for the ballast resistor in the compensation circuit.

A baseline specimen was prepared with a Pd-13Cr strain gage, bare wire Pt conductor extension leads, and decade resistance boxes. Thermal output was obtained on this specimen and used as a benchmark for all experimental changes made to the strain gage system.

Arriving at a baseline specimen with acceptable thermal output data (ie: data that was comparable to that published by NASA) proved to be a difficult task because of silica contamination occurring during strain gage installation. Previous P&W and NASA experience showed that the Pd-13Cr and Pt wires are highly susceptible to silica contamination, resulting in a relatively useless gage. Sources of silica contamination can be found in the flamespray powder and in the strain gage tape (both carrier and masking). For this reason, great attention must be paid to following the proper application technique.

The following section discusses the specific technique that was used to successfully install the Pd-13Cr strain gage. This technique was developed by NASA and Hitec Products, Inc. and was thoroughly reviewed by P&W for conformance to industry standards as well as ease of use.

It should be noted at this point that the Pd-13Cr bare wire for the strain gages used under this contract were laboratory tested at NASA for material purity. NASA experience has shown that trace impurities within the Pd-13Cr wire will drastically affect static gage performance. These impurities can be introduced during the wire manufacturing stage, the gage winding process, and sensor installation. All processes must be tightly controlled to ensure an optimal strain gage assembly.

Strain Gage Installation Technique

Equipment/materials used:

- Hitec Products CR1000 Mini Gun (powder flamespray system)
- Hitec Products High Purity Alumina FA powder and FA powder with 4% zirconia
- Metco Corp 443 powder (nickle-aluminide)
- Vortec, Inc. cold air gun (model 606)
- Acetone, alcohol, MEK (methyl-ethyl-ketone), GN2 (gaseous nitrogen)

The surface of the substrate to which the strain gage will be applied must be adequately prepared to ensure an acceptable bond with the flamesprayed precoat. The prep consisted of grit blasting with #60 alumina grit (**not silica**) delivered by 40 psi clean, dry shop air. After gritblasting, the surface was cleaned with acetone and then flush with alcohol. This was followed by blow drying with GN2. (The acetone and alcohol flush and GN2 dry will subsequently be referred to as being "cleaned and dried").

In the next step, the Metco 443 precoat layer was applied with the Hitec flamespray gun. The thickness of this layer should be between 3 and 4 mils (thousandths of an inch). The area to be masked off for this precoat will vary depending on the application but the width is typically 0.400 to 0.500 inch. Any good quality flamespray masking tape may be used.

After application of the precoat, the surface was lightly wire brushed to remove any peaks, then it was cleaned and dried. (Metco 443 is not critical to the success of the Pd-13Cr gage. Any metallic flamespray material with the appropriate temperature limit may be used as a precoat or "bond" layer. The purpose is to provide an adequate bonding surface for the subsequent alumina basecoat).

A 3 to 4 mil basecoat of the Hitec high purity alumina powder was applied next. The width should be from 0.050 to 0.100 inch less than the precoat layer. A cleaning is not necessary after this step, although loose powder was blown off with GN2.

The Pd-13Cr strain gage was then applied to the basecoat. This should be performed within two hours of the basecoat application to prevent contamination. After the gage was laid, the carrier tape was trimmed as shown in Figure 1.

Additional tape was then applied over the existing carrier tape. This additional tape layer should extend from 5 to 10 mils beyond the edge of the initial carrier tape as shown in Figure 2. This is to prevent overspraying of the alumina onto the tape (bridging) as shown in Figure 2.

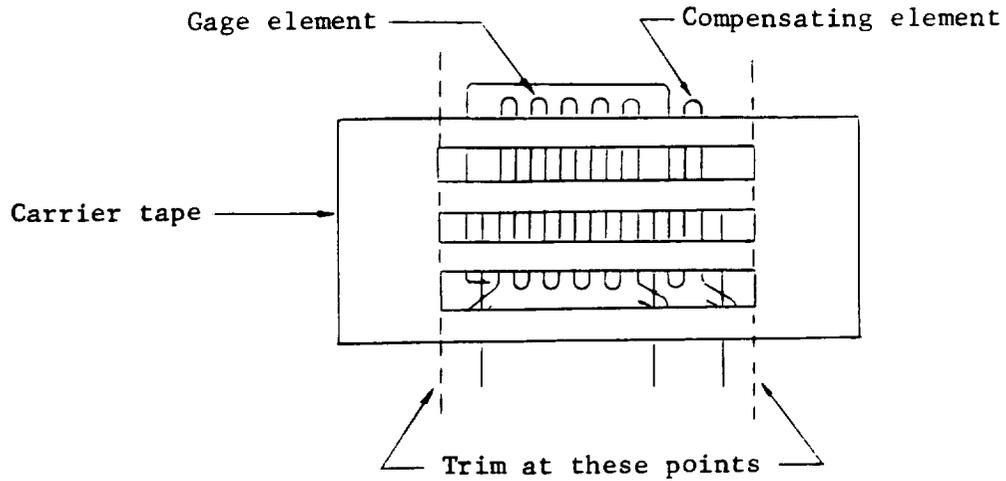


Figure 1: Schematic of the Pd-13Cr strain gage with carrier tape

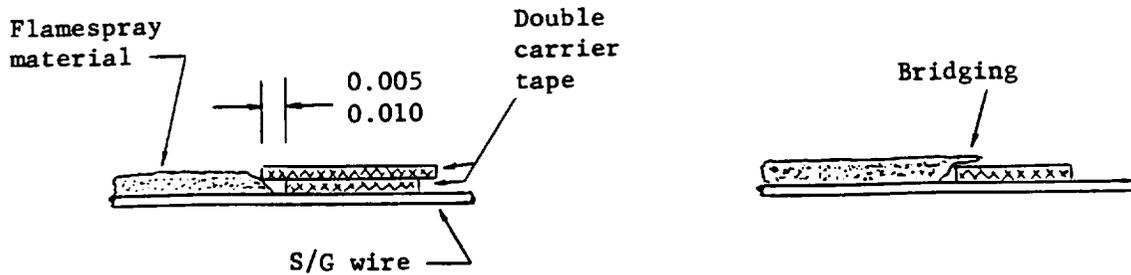


Figure 2: Additional carrier tape and bridging effects

The specimen was then entirely masked around the gage with flamespray tape, exposing only the strain gage grid wires and weld loops. Afterwards, a coat was applied for the gage hold-down using flamesprayed alumina with 4% zirconia. The alumina/4% zirconia powder mix is available from Hitec Products but can be purchased from any qualified flamespray powder manufacturer. It is important to specify however, that the flamespray powder mix contain less than 0.1% silica (SiO). The resulting powder mix should be as free of contaminants as possible.

A compressed air cooler from Vortec, Inc. was used during the flamespray process to prevent the specimen and gage assembly from overheating. It has been found that overheating of silicon based tapes will result in contamination of both the Pd-13Cr gage grid and leadwires. This contamination is difficult to detect (except by destructive testing), and nearly impossible to remove. The cold air gun produces chilled air at approximately 50° F with an input of 30 psi filtered shop air. The nozzle of the cooler should be placed 2-3 inches away from the gage.

The type of flamespray technique that is used for the gage hold-down coat is essential to maintain a low temperature within the gage/tape assembly. The most desirable technique is to perform quick passes of the flamespray gun (torch) with long intervals between passes. The torch is held perpendicular to the strain gage grid and approximately 6 to 8 inches away. After each pass of the torch, the specimen and gage assembly typically heats up to between 150°F and 200°F. The flamespray operator must wait for the gage assembly to cool down to room temperature before proceeding with the next pass. When using the cold air gun, this usually takes a few minutes, depending on the heat sink capabilities of the specimen.

A minimal amount of passes should be made with the flamespray gun for the hold-down coat. The coat should be thick enough so that the gage is held down firmly to allow removal of the carrier tapes, but not so thick that subsequent flamespray coats appear non-uniform. Typical hold-down coat thickness is about 1 mil.

Removal of carrier tapes was performed next using a pure camel hair bristle brush and MEK (methyl-ethyl-ketone). The brush was dipped into the MEK and dabbed adjacent to the carrier tape. This allowed for the MEK to "wick" under the carrier tape. The tape was removed by pulling at a sharp angle with constant application of additional MEK.

The area around the gage assembly was then masked off to allow for application of an intermediate layer of flamesprayed alumina/4% zirconia. This coat is intended primarily to fill in the exposed gage grid area and should also be kept thin, typically 1 to 2 mils. The cold air gun and the same flamespray application technique described earlier was used.

The Pd-13Cr strain gage leadwire (3 mil diameter) was then routed to the splice area. The leads were masked and secured with flamesprayed alumina/4% zirconia using the same steps described for application of the strain gage.

After the intermediate layer was applied to the gage leads, the entire gage assembly was exposed for application of a final flamespray covercoat. The cold air gun was not used for this step. This covercoat layer should be between 2 and 4 mils.

The final overall gage installation thickness should range from 9 to 14 mils. Excessively thick (> 20 mils) flamespray installations can result in delamination in areas of high "g" loading or in a hot gas flow stream. Too thin of an installation can cause loss of electrical insulation resistance and limited erosion protection.

Test Set-Up

Equipment/Materials used:

- Applied Test Systems tube furnace, model #2961
- Syscon temperature controller, model #Rex P-200
- Encore strain gage signal conditioning unit (bridge completion network and power supply), model #610
- 386 AT/25 MHz computer
- Contec Micro Electronics data acquisition/processing cards:
 - 16 channel relay card, DTP-R
 - 16 channel digital I/O, PIO 16/16T
 - 8 channel A/D, ADC30
 - 16 channel mux, ATPM-3
- Labtech Notebook XE data acquisition and control software

The first test involved evaluating the effectiveness of Pt conductor swagewire for use as a leadwire with the Pd-13Cr strain gage. A baseline specimen was prepared using the strain gage installation technique described earlier. The Pd-13Cr strain gage leads were spliced to bare wire Pt conductors (5 mil diameter) that were long enough to extend out of the furnace.

The extension leads were wired into a makeshift Wheatstone bridge as shown in Figure 3.

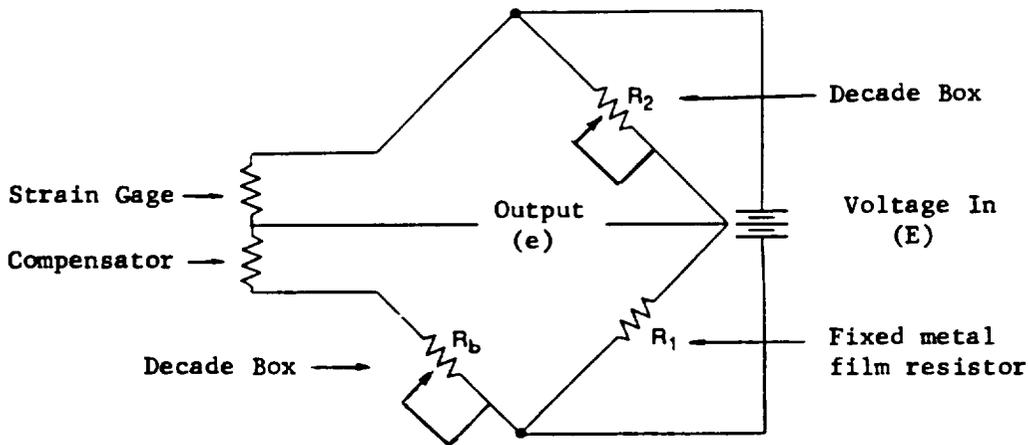


Figure 3: Pd-13Cr strain gage bridge completion network

This set-up is similar to that used by NASA in their laboratory work. The specimen, which had only one gage installed on it, was soaked at 1400°F for 16 hours. The gage calibration was then performed to determine the value for R_b (the ballast resistor). The R_b calibration procedure is outlined in Ref. 2. Thermal output data was then obtained for one thermal cycle.

The Pt bare wire was then removed from the gage and Pt conductor swagewire installed in its place. Swagewire style leadwire was chosen for use with the Pd-13Cr strain gage due to its durability and ease of handling. Simply sleeving bare wire conductors with a fiberglass braid would not be adequate to withstand the severe environments and routing paths in a gas turbine engine. The swagewire obtained for these tests were specially fabricated by Gordon Wire Co. and had the following properties:

- Outer sheathing material was Inconel 600
- Outer sheathing diameter was 0.092 inch
- Insulating media was compacted magnesium-oxide (minimum purity of 99.4%)
- Three Pt conductors, each 0.012 inch in diameter

The swagewire's Pt conductors were fusion welded to the strain gage leads using a Henes Corp water welding torch and stainless steel flux. Although a gold-nickle braze has been used in the past to make this splice, the fusion weld was found to be more consistent in quality and easier to prepare. Prior to fusion welding, the gage leads and swagewire conductors were thoroughly cleaned (scraped with sandpaper and wiped with alcohol) to remove any contaminants and/or oxides.

A thermal cycle was run to determine any affect the swagewire may have on strain gage performance. The value for R_p was not changed for this test.

The next task in this contract was to evaluate a commercial strain gage signal conditioning unit to replace the decade boxes used for the Wheatstone bridge completion network described earlier. Replacement of the decade boxes is necessary because of their impracticality in a field application or engine test stand environment.

An Encore unit, model #610 was chosen because of its frequent use at P&W for strain measurement. The Encore unit was tested for stability and drift over a 6 hour period. This was done by hooking up the Pd-13Cr strain gage (from the specimen used in the previous task) to the Encore unit, and powering the gage with one volt of excitation. The output of the gage through the Encore unit was then recorded over a 6 hour period.

The Encore unit was then modified to determine if an improvement in output stability could be gained. The manufacturer recommended replacing certain resistors in the input instrumentation amplifier section with equivalent value, high precision, low drift resistors. Another 6 hour output stability test was performed and directly compared to the previous results.

It should be pointed out that any commercially available signal conditioning unit (bridge completion network and amplifier) can be used if the unit has low drift characteristics of 10 ppm or less per 24 hour period. Drift tests should be performed to verify the manufacturer's specifications.

The decade box that was used for the ballast resistor (R_b) in the strain gage compensating circuit was also identified as a candidate for replacement. A miniature, variable resistance device with a low thermal drift coefficient was required. The small size was necessary for convenient attachment to the Encore signal conditioning unit.

A literature search revealed that the Spectrol series 534, 500 ohm, 10 turn potentiometer was the most likely candidate. This "pot" was chosen specifically for its low thermal drift coefficient of ± 20 ppm/degree C.

A new specimen with two Pd-13Cr strain gages was fabricated to test the effectiveness of the three system changes previously identified: the Pt conductor swagewire; the modified Encore signal conditioning unit; and the Spectrol " R_b pot".

A digital data acquisition system was assembled to accommodate recording of output data from several strain gages and to perform the gage calibration automatically. The components of this system are identified at the beginning of this section. A schematic of the system set-up is shown in Figure 4.

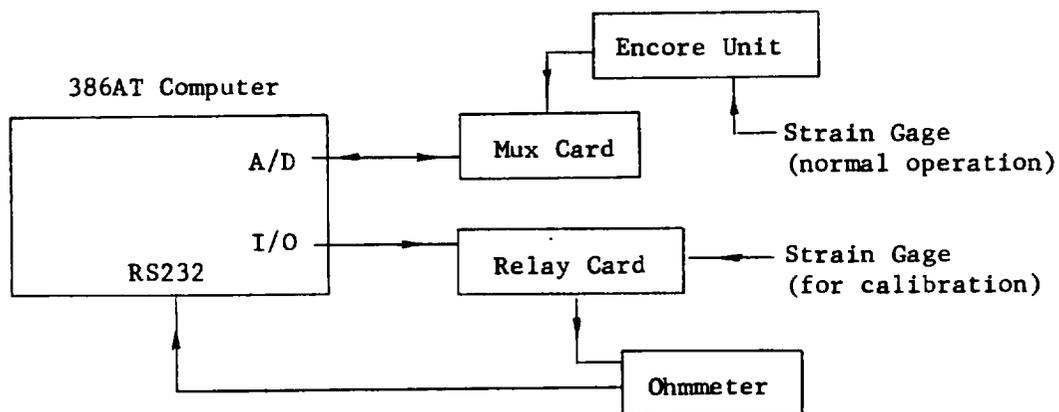


Figure 4: Schematic of the data acquisition system

The digital system was configured using Notebook XE, a general purpose data acquisition and control software by Labtech Corporation. This is a flexible, yet powerful menu based program that was used for switching in the relay card during the strain gage calibration and thermal output data acquisition during normal gage operation.

The final task of the contract involved evaluating the fatigue life characteristics of the Pd-13Cr strain gage. Pratt & Whitney routinely fatigue tests conventional strain gages on an electro-magnetic shaker system. A standard has been established to either certify a technician's strain gage installation skills, or qualify a new gage concept. The test system and certification test is fully described in a paper by E. Roesch (Ref. 3).

Four Pd-13Cr strain gages were installed in the constant strain area of the fatigue specimen. Each gage was hooked up in a two wire configuration to allow for dynamic strain measurement only. The specimen was subjected to the following conditions at room temperature:

- ± 500 microstrain (1×10^6 inch/inch) for 100,000 cycles
- ± 1000 microstrain for 100,000 cycles
- ± 1500 microstrain for 1,000,000 cycles

The gage outputs were monitored on a PC based data acquisition system and a digital oscilloscope. If a gage open circuit was detected, the number of cycles at failure was recorded. The standard requirement is that 2 out of 4 strain gages survive the entire test.

Results and Discussions

The first set of tests was intended to compare bare Pt wire (baseline) against Pt conductor swagewire for use as an extension lead on the Pd-13Cr strain gage. The data is presented as gage output versus temperature for a complete thermal cycle (heating and cooling). The gage output is in the form of e/E in parts per million (ppm), where "e" is the millivolt output and "E" is the bridge excitation of 1 volt. The results are plotted in Figure 5.

An R_b calibration was performed on the strain gage in the initial, bare wire form, but a re-calibration was not performed after changing to swagewire. This would explain the curve, or output data shift between the two tests. A new R_b value would be required to compensate for the change in leadwire resistance. The swagewire output data curve could be shifted upward if an appropriate value of R_b was obtained.

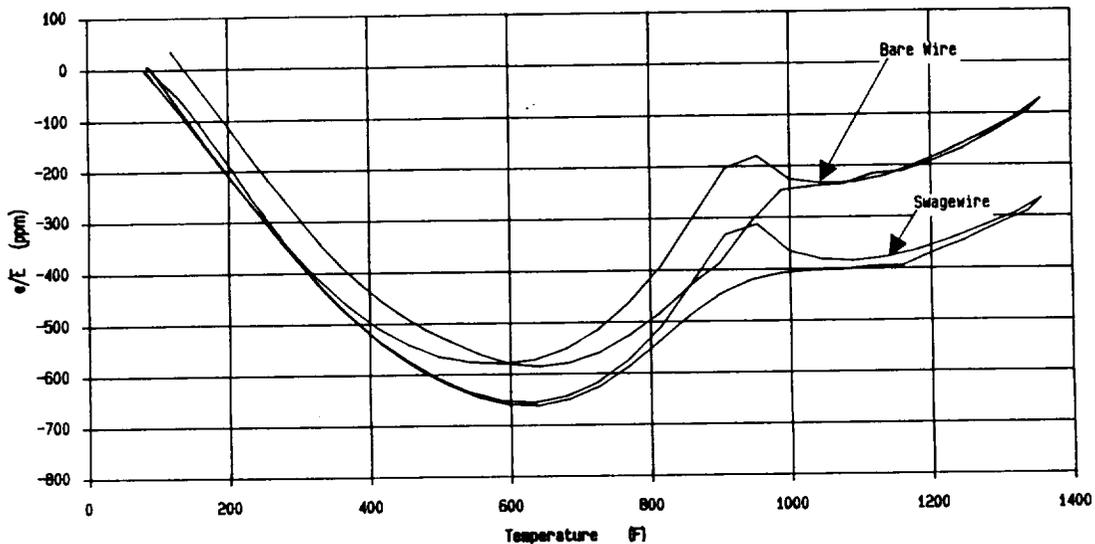


Figure 5: Comparison of bare wire and swagewire output

The output data from the swagewire specimen exhibits very little hysteresis. There is also a negligible shift in data upon return to zero (room temperature). Table 1 presents the data from key points in the output curve of the swagewire specimen.

Start (RT)	End (RT)	Heat 1100F	Cool 1100F	Heat 650F	Cool 650F	Max Temp 1350F
0	6	-386	-396	-656	-659	-266

Note: RT = room temperature
Values in parts per million

Table 1: Output data for Pd-13Cr strain gage with swagewire

The next test involved demonstrating the stability of the Encore strain gage signal conditioning unit in its unmodified and modified form. The outputs from both tests are plotted against each other in Figure 6.

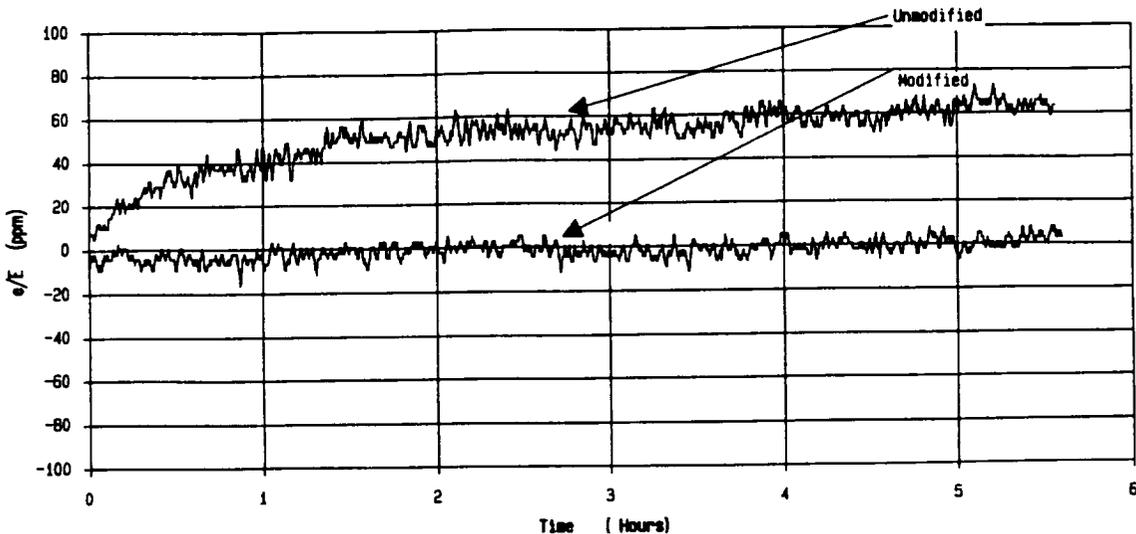


Figure 6: Unmodified versus modified Encore unit.

The drift test was only performed for 5½ hours but a significant change of 10 ppm/hour could be seen in the output of the unmodified unit. A drastic improvement however, was seen in the modified unit. There was no measurable net change in the unit's output over the 5½ hour period.

The next series of tests involved combining all three system improvements (swagewire, modified signal conditioning unit, and the miniature R_p pot) for evaluation on a specimen with two Pd-13Cr strain gages. During the strain gage calibration, one of two gages behaved erratically and was rejected from further testing. It was suspected that some form of contamination was affecting the gage's performance. Three thermal cycles up to 1350°F from the remaining gage are presented in Figure 7.

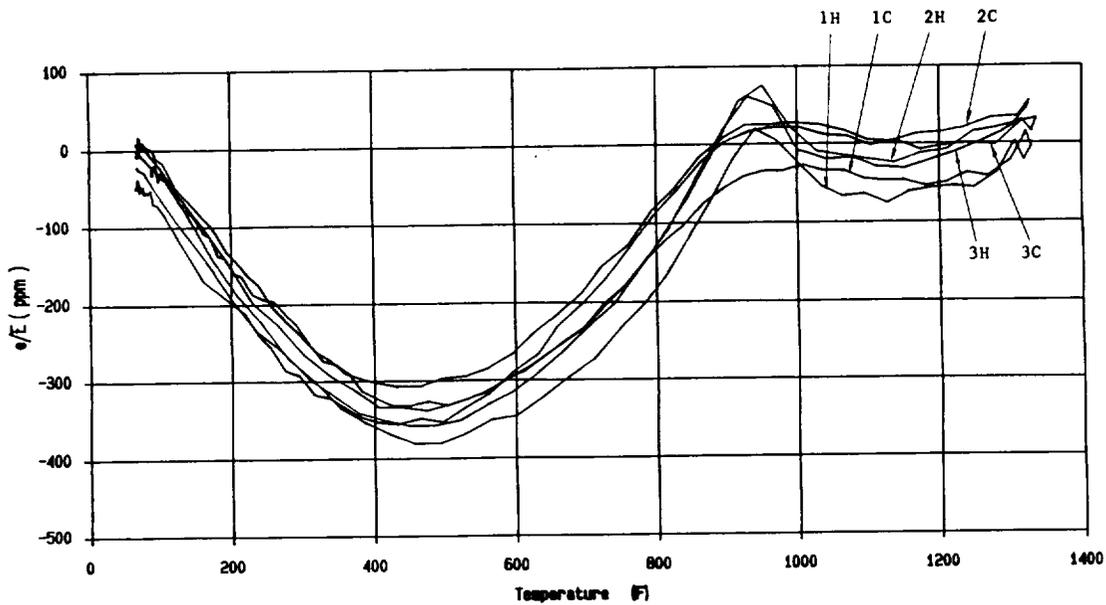


Figure 7: Thermal cycle data for all three system changes

The three cycles presented in this plot are relatively close to each other. Cyclic repeatability at 1350°F is within 15 ppm. Hysteresis between the heating and cooling cycles are within 50 ppm for all three cycles. Zero return (at room temperature) is within 25 ppm.

These values represent the potential performance for the Pd-13Cr strain gage and should not be interpreted towards any accuracy statement. To arrive at a conclusion on sensor and system accuracy, a larger number of strain gages and thermal cycles should be tested.

An interesting aspect of these thermal output curves are the relatively low absolute values in the temperature region between 950°F and 1350°F. Values are within ± 75 ppm. This can be attributed to a well run strain gage calibration that resulted in an optimum value for R_b . Experimentation with each of these resistance values can potentially rotate the thermal output curve to minimize output values for any temperature region desired. Values for these tests are summarized in Table 2.

Cycle #	Start (RT)	End (RT)	Heat 1100F	Cool 1100F	Heat 500F	Cool 500F	Max Temp 1350F
1	-12	-24	-61	-37	-391	-342	37
2	0	12	-24	12	-342	-317	24
3	-24	-49	-37	12	-378	-366	36

Note: RT = room temperature
Values in parts per million

Table 2: Output data for Pd-13Cr strain gage with system changes

The final task involved fatigue testing four Pd-13Cr strain gages. Three out of four gages survived the entire test. The fourth gage failed at just under 220,000 cycles in the last portion of the test (± 1500 microstrain). A post test failure analysis was performed on this gage. The failure mechanism was not in the gage grid area (which is typical of conventional gages) but in the splice area between the gage leads and extension wire. This is important to note, because in an actual application, this splice would be made in a low strain area. These results are promising and further tests should be conducted to determine the fatigue characteristics under heated conditions.

Conclusions

Various components of the Pd-13Cr strain gage measuring system were addressed to make the sensor more robust for a gas turbine engine environment and more compatible with field or test cell applications. Use of a Pt conductor swagewire, miniature potentiometer (for the ballast resistor), and a modified strain gage signal conditioning unit proved to all be successfully compatible with the Pd-13Cr strain gage.

The Pt conductor swagewire is an effective extension lead for use in high temperature regions. Its cost however, could be prohibitive where long leadwire routing lengths exist. Follow-on tests should be conducted to determine at what temperature the Pt leads could be transitioned to copper conductor leads without a noticeable affect on strain gage performance.

A commercially available strain gage signal conditioning unit was modified to increase its output stability with the Pd-13Cr strain gage. Also, a 10 turn potentiometer with a very low thermal drift characteristic (± 20 ppm/degree C) was identified and used as the ballast resistor in the strain gage compensating circuit.

All three improvements were tested together with the Pd-13Cr strain gage and thermal output characteristics were evaluated. The gage behaved extremely well at all temperature levels tested. The cyclic repeatability (over three cycles) at 1350°F was within 15 ppm. The hysteresis between the heating and cooling cycles was within 50 ppm. Zero return (at room temperature) was within 25 ppm.

It should be recognized however, that the performance of the Pd-13Cr strain gage is directly related to the installation technique and materials that are used. Any contamination within the gage or lead area could result in extremely poor thermal output characteristics. A specific installation technique was outlined in this report. Any deviation from this technique should be evaluated prior to use.

The fatigue characteristics of the Pd-13Cr strain gage appear to be very promising, indicating a potential use in dynamic strain measuring applications. Four Pd-13Cr strain gages were subjected to a standard P&W fatigue qualification test at room temperature. Three out of four gages successfully completed all portions of this test. Further tests should be conducted to determine the fatigue characteristics under heated conditions. This would lead to a potential application to measure dynamic strain on the High Pressure Turbine and Low Pressure Turbine blades of a gas turbine engine.

Acknowledgment

The authors would like to thank Mr. Steve Wnuk of Hitec Products for his assistance and direction during the critical strain gage installation technique portion of this contract.

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13. ABSTRACT (Maximum 200 words) This report summarizes the results of a six month study that addressed specific issues to transfer the Pd-13Cr static strain sensor to a gas turbine engine environment. The application issues that were addressed include: (1) evaluation of a miniature, variable potentiometer for use as the ballast resistor, in conjunction with a conventional strain gage signal conditioning unit; (2) evaluation of a metal sheathed, platinum conductor leadwire assembly for use with the 3-wire sensor; and (3) subjecting the sensor to dynamic strain cyclic testing to determine fatigue characteristics. Results indicate a useful static strain gage system at all temperature levels up to 1350°F. The fatigue characteristics also appear to be very promising, indicating a potential use in dynamic strain measurement applications. The procedure, set-up and data for all tests are presented in this report. This report also discusses the specific strain gage installation technique for the Pd-13Cr gage because of its potential impact on the quality of the output data.			
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