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HIGH TEMPERATURE STRAIN GAGES
FOR USE IN SODIUM ENVIRONMENTS
ORDER NO. 2161-70 and ORDER NO. 4037-01
RESEARCH REPORT NO. 5138

H.C. \$ 3.00; MN. 65

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DECEMBER 20, 1966

RELEASED FOR ANNOUNCEMENT
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HIGH TEMPERATURE STRAIN GAGES
FOR USE IN SODIUM ENVIRONMENTS

By: V. Rastogi

ABSTRACT

PURPOSE

The purpose of this project was to select and develop techniques for using a high-temperature (600F - 1000F) strain gage for use in equipment like the B&W Prototype Sodium-Heated Steam Generator (AEC Contract No. AT(11-1)-1280) where some of the gages would be used in sodium environments.

BRIEF OF TESTS

1. Gages available for high-temperature use were evaluated with regard to feasibility of installation, gage characteristics and inherent environmental protection.
2. Tests were run on the best available gage for this type of application to show large variability in characteristics from gage to gage.
3. A precalibration technique was evaluated for determining bonded gage characteristics of each gage before it is applied to the structure under test.
4. Nichrobrazing, nickel plating, and hut-type enclosures were evaluated for protection of the gages from atmospheres like sodium.

RESULTS AND CONCLUSIONS

1. The Microdot, Inc. SG-423-A weldable strain gage was selected as the best gage available for high-temperature use in fluid applications such as the steam generator.

Research Report No. 5138
Order No. 2161-70 and 4037-01
December 20, 1966
HIGH TEMPERATURE STRAIN GAGES
FOR USE IN SODIUM ENVIRONMENTS
BAW-1280-41

ABSTRACT (Cont'd.)

2. The precalibration technique was proven to be necessary and accurate.
3. Nichrobrazing and nickel plating were successful for protection of gages from sodium for short-time applications limited to one month.
4. Huts were found to be best suited for protection of gages from atmospheres like sodium.

RECOMMENDATIONS

1. It is recommended that the Microdot SG-423-A strain gage be used at high temperatures (600F - 1000F), and after enclosure in huts in sodium, for applications such as the steam generator. The gage should not be used where reinforcement due to the strain gage will be significant.
2. It is recommended that bonded gage characteristics of each gage be obtained prior to using it on the structure under test.
3. It is recommended that further investigation be carried out to develop economical techniques, other than huts, to protect this type of strain gage from sodium.
4. Further investigation into the long-term stability of these strain gages is recommended.
5. It is recommended that the program be extended to evaluate gages for use at higher temperatures.

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1.0 INTRODUCTION

This project was undertaken to develop means for measuring strains in air, argon, water, steam, and sodium at temperatures up to 1050F for use on B&W products like the prototype sodium heated steam generator (AEC Contract No. AT(11-1)-1280). This report describes the results of tests conducted to evaluate and adapt a high-temperature strain gage for such use.

As higher-temperature, higher-pressure equipment is being developed to meet increasing demands for greater equipment efficiency, design problems and material selection problems are increased. To determine the true behavior of the equipment and components, to evaluate the design, to improve upon it, and to be able to predict with adequate confidence and accuracy its capabilities and life, the strains and strain gradients (both time and position) of critical parts must be determined. In liquid metal systems the problems are further complicated making it difficult to use conventional strain gages^{(1)*} without some modification and redevelopment.

Transient thermal stresses are on many occasions a major contributor to the total stress in a component. In complex structures, present analytical procedures are not always capable of computing stresses at elevated temperatures and thus the stresses must be determined experimentally. Therefore, a definite need for a satisfactory high-temperature strain gage exists, for use not only in air but also in other environments such as water, steam, sodium etc. This project was therefore undertaken to select, analyze, and develop techniques for using a high temperature gage for long-term application in such environments.

Of particular concern is the need to obtain accurate information for components subjected to thermal gradients and superimposed mechanical loads. Gage characteristics as received from the manufacturer are known to vary with respect to temperature compensation, drift, and gage factor characteristics. The problem is to calibrate the gage adequately prior to actual application so that these various factors are known and can be considered in properly interpreting the data. In cases where adequate calibration is not performed prior to gage installation, the resulting data can lead to completely

*Superscripts refer to references at the end of the report.

erroneous conclusions regarding the values of strain. The successful accomplishment of the above requires:

1. selection of a suitable gage
2. calibration technique for obtaining bonded gage characteristics
3. verification of calibration technique
4. sealing techniques for use in sodium environment ,

These are described in detail later.

2.0 RESULTS AND CONCLUSIONS

- 2.1 The Microdot, Inc. SG-423-A weldable half-bridge strain gage was selected as the best gage available for high-temperature use in field applications such as the steam generator.
- 2.2 The precalibration technique was proven to be necessary and accurate.
- 2.3 Nichrobrazing and nickel plating were partially successful for protecting the gages from sodium. They could be used for short-time applications limited to one month.
- 2.4 Huts were found to be best suited for the protection of gages from atmospheres like sodium.

3.0 RECOMMENDATIONS

- 3.1 It is recommended that the Microdot SG-423-A strain gage be used at high temperatures (600F to 1000F) and, after enclosure in huts in sodium, for applications such as the steam generator where reinforcement due to the strain gage or the hut will not be a problem.
- 3.2 It is recommended that bonded gage characteristics of each gage be obtained prior to using it on the structure under test.
- 3.3 It is recommended that further investigation be carried out to develop economical techniques, other than huts, to protect this gage from sodium.
- 3.4 Further investigation into the long-term stability of these strain gages is recommended.
- 3.5 It is recommended that the program be extended to evaluate gages for use at higher temperatures.

4.0 SELECTION OF A SUITABLE GAGE

In selecting the proper type of strain gage for use on a large structure to be tested in the field, i.e., non-laboratory conditions, the following factors were considered.

1. feasibility of installation
2. temperature compensation
3. drift characteristics
4. gage factor shifts
5. reliable calibration techniques
6. gage reinforcement on the component
7. gage length of strain gage
8. environmental protection

To select the proper gage, several basic types of gages were evaluated using gage alloys of Nichrome and platinum-tungsten. Various bonding techniques were also tried; for example, ceramics, plasma spray using alumina particles, and the weldable bonding technique. Different types of gages were used since the various bonding techniques vary with the type of gage. Prebonded weldable shim type of gage utilizing gages bonded with ceramic cement and the encased etched wire type of gages were also used. These various gage materials, bonding techniques, and configurations were chosen because of their manufacturer's specified application to temperatures between 900 and 1000F.

4.1 Feasibility of Installation:

In evaluating the various types of gages, it was felt that the installation requirement of the gage would be most important. It was apparent that the ceramic cement application was not suitable because it took too long to cure and the proper curing environment could not be obtained at a field test site to permit its use. On the other hand, the plasma-spray and the welding techniques were both found to be quite suitable. The plasma-spray technique would be difficult to use in close quarters. The welding technique was given preference because of the possibility of obtaining these gages with integral leads, thereby avoiding the necessity of handling the frail lead connections that cause many gage failures in the field. The weldable gages also lend themselves best to prior calibration since they are rigid and can be removed

from the calibration specimen and rewelded to the structure under test.

4.2 Temperature Compensation and Drift Characteristics:

The temperature compensations and drift in the bonded condition are best evaluated when the weldable gages were bonded to a reasonably large mass of material similar to that which would be used in the component to be evaluated. When a large mass of material was used, the temperature could be accurately controlled when proper thermal shielding techniques were used.

4.3 Gage-Factor Shifts:

Gage-factor shifts can be best evaluated by comparing the output of the strain gages with known applied strains. This could be done by bonding the gages to a tension bar along with room temperature gages of known characteristics. A strain measuring system such as discussed later can be developed to measure applied strains accurately at temperature and the output of the high-temperature strain-gages be compared with this system to evaluate the effect of temperature on gage-factor shifts.

4.4 Reliable Calibration Techniques:

The calibration technique generally used is to evaluate a single characteristic on all gages and all the characteristics on a few of the individual gages completely. For instance, it is quite feasible to obtain an unbonded temperature coefficient characteristic for a great many weldable gages supposedly of the same type and from the same lot of basic material. A statistical sample could then be selected and would serve as a means of statistically bracketing the exact bonded characteristics where drift, temperature compensation, and gage factor evaluations would be completely analyzed. With this information, a tolerance could then be placed on the readings obtained from the remaining gages of this particular type. It was felt, however, that it would be preferable to find a way to individually calibrate each of the gages for the bonded condition before it is finally bonded to the actual product or component in the field. This was the approach taken to develop a gage for use in sodium environment at high temperatures and is described in this report.

4.5 Gage Reinforcement on the Component and Gage Length:

Of secondary importance is the effect of reinforcement of the gage on

the component since the component being evaluated was a large vessel and the size of the gage was insignificant compared to the mass of the material involved. However, in other applications where the reinforcement effect is significant, this characteristic can be most important, even to the extent of disqualifying all commercially available weldable gages manufactured at this time. The length of the gage also requires consideration. A long gage length averages the actual strain over the long length and has obvious disadvantages in high strain concentration regions.

4.6 Environmental Protection:

With the above factors taken into consideration, the Microdot SG-423-A type of gage was chosen. This gage has a gold plated active element made from platinum-tungsten alloy material⁽²⁾ and is temperature compensated with another element fabricated from the same material wound around the active element. The total configuration is encased in magnesium oxide that is shielded from environmental effects by a stainless steel tube. The output leads from the gage are sealed into a 3-wire sheath lead so that the gage wire and lead wire are sealed for environmental protection.

BASIC GAGE CONFIGURATION OF THE MICRODOT SG-423-A

5.0 CALIBRATION TECHNIQUE FOR OBTAINING BONDED GAGE CHARACTERISTICS

Perhaps the most important step in the use of the high-temperature strain gage for obtaining accurate valid strain data is gage calibration. Although manufacturers supply specification and calibration curves, no two gages are alike and actual gage characteristics can differ considerably from those specified. For accurate, meaningful, and reproducible results, therefore, each gage must be calibrated over the temperature range at which it will finally be used.

The technique developed here converts each gage into an effective strain transducer by mounting it on a shim. The basic gage, as shown in the center of Figure 5.1, has an area (integral shim) provided for welding the gage to the component to be analyzed. With the addition of the second shim (Figure 5.1 top), sufficient rigidity is added to this area so that the element can be applied to a testing bar for laboratory evaluation of the various bonded characteristics. At the same time it has sufficient structural rigidity to be picked up or unbonded from the calibration sample and used again on the actual component in the field. For the half-bridge elements used in this investigation, an eight-thousandth inch thick shim was used to mount each of the gages. A Weldamatic Type 1016 spot welder was used to bond all gages to the specimens.

Figure 5.2 shows the strain transducers and thermocouples mounted on a tension bar fabricated from the same material used in the component that is to be evaluated in the field. Various tests can now be performed on this laboratory test specimen very economically and quickly so that the bonded characteristics for each strain gage can be determined on the identical material that it will finally be applied to. These characteristics then provide a means of mathematically correcting strain data to determine the actual effective strain on the test component.

Apparent strain versus temperature curves, which are the changes in gage output with change in temperature at no load, were determined by heating the tension bars at a controlled heating rate of 150 degrees per hour and recording the strain readings and the temperature readings of each individual gage. Temperature and strain readings for each gage were taken

TENSION BAR FOR CALIBRATION OF GAGES

FIGURE 5.3

APPARENT STRAIN VS. TEMPERATURE CURVES

simultaneously, using automatic data-taking equipment. The results were punched out on computer tape so that the data could be rapidly analyzed. The final data was taken after the gages were subjected to three temperature cycles and the zero returns were within 20 microstrain of their initial values. This zero return was judged to be within the tolerable limits for gage accuracy considering the fact that part of the loss in return was due to drift that had occurred at elevated temperature. Each of the gages was cycled and calibrated to 50F above its expected operating temperature. The initial stabilizing temperature, however, was 100F above maximum operating temperature for the particular gage. Temperatures for this investigation were as high as 1050F for calibration and 1150F for stabilization. Figure 5.3 shows the apparent strain versus temperature characteristic of five strain gages. It is evident from these curves and it will be further evident from the results of the drift and gage factor tests, that the gages can be markedly different so that the use of a single calibration curve or just the curve specified by the manufacturer can be quite inaccurate.

It should be pointed out at this time that subsequent discussions with the manufacturer revealed that the differences from gage to gage in apparent strain and also the total maximum apparent strain can be drastically reduced with the use of a temperature compensating trim resistor. This resistor is added to the active leg of the strain gage at the read-out equipment. However, the value of this resistor was found to vary from 11Ω to 15Ω for different gages and had to be determined experimentally. This addition also led to trouble in reading the highly unbalanced bridge. Also, the addition of the trim resistor did not affect the variation of characteristics in drift or gage-factor, and, therefore, calibration was still necessary. In Figure 5.3 is shown also the change in the apparent strain curve of gage no. 5 when a temperature compensating trim resistor of 11Ω was used.

The bonded drift characteristics were determined on the same general setup as that for the apparent thermal strain test. In this case, however, the temperature was held constant and the strain readings were recorded at one-hour intervals for 24 hours. Tests were run at three different temperatures to cover the operating range for the particular gage being evaluated.

DRIFT AT TEMPERATURE WITH TIME

SPECIMEN LOADED IN UNIVERSAL TESTING MACHINE

APM 63E

FIGURE 5.5

Figure 5.4 shows the results for four of the gages used in the apparent strain test. Here again, the differences among them are dramatic.

For determining the bonded gage-factor characteristic, the tension bars were loaded by means of a universal testing machine, as shown in Figure 5.5. The bearings and special grips at the top and bottom of the tensile specimen reduced the bending to less than 2 per cent. A direct-current differential transformer arrangement, as shown in Figures 5.2 and 5.5, was used on opposite sides of the bar at room temperature and at elevated temperature to determine the actual strain applied to the gages being evaluated.

At room temperature, a further check using room-temperature strain gages was also made. Gage output and actual strains at various temperatures were recorded for an average gage factor of 3.75. The actual gage-factors, as specified by the manufacturer, for each of the gages used were 3.78, 3.77, 3.78, and 3.76. The gage factor of 3.75 was arbitrarily chosen to evaluate all the gages since automatic data-taking equipment designed for a single gage factor will be used for the final field test. Figure 5.6 shows the results of the gage factor tests for the same gages used earlier. The results illustrate not only the change in gage factor with temperature for each gage, but also the differences from gage to gage and the differences in the way they change.

The final step in calibrating the gages is to remove them from the tension bar, using razor blades as precise chisels. By carefully sliding the edge of a single-edge blade under the edge of the shim and tapping the spot weld that holds the shim to the base metal, the weld can be sheared and the gage left intact for remounting on the component. It will be noted that there are perforations through the shim material at those places where the spot welds had been located which indicated a good integral bond. However, by carefully locating the welds in accordance with the manufacturer's specifications of 30 welds to the inch, the strain transducer is in good condition for remounting on the structure. This can be readily done and proper corrections can be made to the readings since all the bonded characteristics are now known.

RESULTS OF GAGE FACTOR TESTS

6.0 VERIFICATION OF CALIBRATION TECHNIQUE

To verify the adequacy of this technique for evaluating the individual gage characteristics, a set of strain gages was first calibrated as previously described and then applied to a cantilever beam, as shown in Figure 6.1. This cantilever beam was then inserted into the test apparatus shown in Figure 6.2, and a constant-displacement test was performed. The gage characteristics obtained by the calibration method for one of the gages are shown in Figure 6.3 together with the results of the same gage when removed from the calibration specimen and remounted on a cantilever beam as shown in Figure 6.1. It will be seen that the strain can be very accurately evaluated for apparent strain and gage factor shifts. The largest deviation in the gage-factor results is at 1050F at which temperature the gage is being pushed to its limit. The differences in the drift characteristics are due largely to the very small strains being measured especially at 700F.

The only difference that exists between this application and that in the field is that, for the cantilever beam used, the weldable type strain gages do have an appreciable reinforcing effect on the beam. It is suggested that a more heavy member be used in the future.

STRAIN GAGE MOUNTED ON CONSTANT STRAIN CANTILEVER BEAM

TESTING APPARATUS FOR CANTILEVER BEAM

COMPARISON OF GAGE CHARACTERISTICS AS
OBTAINED BY CALIBRATION AND ON CANTILEVER BEAM

7.0 SEALING TECHNIQUES FOR USE IN SODIUM

Although this type of gage is fully encased in Inconel-X, the brazed joints make it vulnerable to the sodium environment. The gage, however, is quite suitable for direct immersion in water, steam, and other environments in which the silver-gold junction will not be attacked. For the particular case of sodium protection, however, three different techniques were investigated to overcome the sealing handicap. Each one was at least partially successful.

The first technique tried was that of substituting a nichrobraz⁽³⁾ weld junction for the silver-gold braze used by the manufacturer. Several partially assembled gages in which the joints were left unbrazed were obtained from the manufacturer. A torch nichrobrazing technique was developed for sealing the junctions on the gage and a nichrobraz alloy was chosen with the lowest melting point available. Nichrobrazing was selected because of the resistance of this particular alloy to sodium. A high mortality rate of sealing the gage was experienced in that there was a loss in resistance to ground which was highly dependent on the time that the joints or junctions were kept hot (1800F). However, if extreme care is taken, the junctions can be made. As a result of this technique the life of these gages in sodium could be increased to over one month in comparison to a two-day life for the gages that were brazed using standard gold-silver alloys.

The second technique used was that of electroplating the commercially available silver-brazed gage with nickel. The gage was first degreased with acetone and nickel-plated in a Watt's-type bath. The gage was electrolyzed for a total of 50 minutes to obtain a plating thickness of approximately 2 mils. The results of this technique showed similar lifetimes to the nichrobrazed gage when immersed in sodium and was found to be much more economical, especially considering the loss during the nichrobrazing sealing. A lifetime of one month, however, was not considered satisfactory.

The third technique employed was that of building small huts around the gage. Figure 7.1 shows a hut configuration for a biaxial gage installation along with the thermocouple for measuring the base metal temperature near the gage. It was found that the hut is the most reliable method of protecting

"HUT" FOR BIAXIAL GAGE CONFIGURATION

the gage since the gage never sees the undesirable environment. The gage leads are first fed through the outlet tubes and the gage is spot-welded to the structure under test. The outlet tubes are then sealed to the gage and the thermocouple leads using nichrobraz, and finally the roof for the top of the hut is welded into place. The extra tube shown in Figure 7.1 is used for leak checking the hut after sealing. This tube is finally sealed following verification of a leak-tight hut.

One problem involved in using a hut is the effect of thermal transients on the gage. It is felt that at this time the exact relation between rapid thermal transients imposed directly on the gage and the base material cannot be accurately evaluated. However, the hut has the advantage of protecting the gage from sodium and still permits the recording of slowly changing transients and steady state thermal strains and the calibration curves are still valid. For the data to be accurate, the hut was kept to a minimum size. Previous test work at the Research Center⁽⁴⁾ has shown that for the type of structure that was being evaluated, the hut had virtually no effect on the reinforcement of the component under test.

8.0 ACKNOWLEDGMENTS

This work was performed partially under Atomic Energy Commission Contract No. AT(11-1)-1280 entitled "Sodium Heated Steam Generator Development." The author wishes to acknowledge the helpful discussions with the manufacturers of the strain-gage used. The manufacturers are willing to calibrate their strain-gages for their customers and also they will mismatch the active and compensating legs of the gages such that the addition of a trim resistor will make the bridge a balanced 120 Ω bridge. The trim-resistor would then be supplied as part of the gage.

The author wishes to acknowledge also the advice and help of Messrs. K. D. Ives, W. A. Crawford, and C. E. Davis.

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