UNCLASSIFIED

AD NUMBER

ADB000924

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; Jul 1974. Other requests shall be referred to AF Flight Dynamics Laboratory [FYA], Wright-Patterson AFB, OH 45433.

AUTHORITY

AFFDL ltr, 10 May 1976

THIS PAGE IS UNCLASSIFIED

AFFDL-TR-74-95

AD B000924

DEVELOPMENT OF STRAIN AND TEMPERATURE MEASUREMENT TECHNIQUES FOR USE IN COMBINED THERMAL ACOUSTIC ENVIRONMENT

TECHNICAL REPORT AFFDL-TR-74-95

OCTOBER 1974

Distribution limited to U.S.Government agencies only; test and evaluation; statement applied July 1974. Other requests for this document must be referred to Air Force Flight Dynamics Laboratory (FYA), Wright-Patterson Air Force Base, Ohio 45433.

AIR FORCE FLIGHT DYNAMICS LABORATORY
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

AIR FORCE/56780/16 December 1974 — 150

AFFDL-TR-74-95

DEVELOPMENT OF STRAIN AND TEMPERATURE MEASUREMENT TECHNIQUES FOR USE IN COMBINED THERMAL ACOUSTIC ENVIRONMENT

S. P. Wnuk, M. E. Low, J. G. MacLean
HITEC Corporation

Distribution limited to U.S. Government agencies only; test and evaluation; statement applied July 1974. Other requests for this document must be referred to AF Flight Dynamics Laboratory (FYA), Wright-Patterson AFB, OH 45433.

FOREWORD

The research described in this report was performed by HITEC Corporation, Westford, Massachusetts, for the Aero-Acoustics Branch, Vehicle Dynamics Division, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, under Contract F33615-73-C-3052. This work was performed under Project 1471, "Aero-Acoustic Problems in Flight Vehicles", Task 147104, "Aero-Acoustic Instrumentation and Data Analysis".

Stephen P. Wnuk, Jr. of the HITEC Corporation was the Project Engineer. Other members of the investigative team were Malcolm E. Low and John G. MacLean. The work was administered by Mr. Richard C. Taylor, Project Engineer, of the Vehicle Dynamics Division.

This report covers work conducted from March 1973 to March 1974. It was submitted by the authors in August 1974 for publication as an AFFDL Technical Report.

This technical report has been reviewed and is approved.

WALTER J. MYKYTOW
Asst. for Research & Technology
Vehicle Dynamics Division

ABSTRACT

This report covers the Development of Instrumentation Techniques for Strain and Temperature Measurements on aerospace test structures in a combined high temperature and acoustic noise environment. Techniques for attaching instrumentation to test panels for vibratory testing up to 1400°F were developed and evaluated at the Air Force Flight Dynamics Laboratory (AFFDL) Sonic Fatigue Facility. Methods for measuring static strains for short periods (up to one hour) at 1200°F were also developed. Strain gages, temperature sensors, lead wire selections and installation techniques are covered in the report.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Cont'd)

TABLE OF CONTENTS
(Cont'd)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS
(Cont'd)

LIST OF ILLUSTRATIONS
(Cont'd)

LIST OF TABLES

I. INTRODUCTION

Aircraft structural components which are located in the vicinity of the jet engine or which are passed by the jet efflux experience heating combined with random dynamic excitation which results from the acoustic or pseudoacoustic noise emitted by the jet efflux. This combined loading causes frequent fatigue failure of the structural components. The development of such fatigue resistant structures requires the measurement of static and dynamic strains and structural temperatures under laboratory conditions where a test structure is exposed to a combined thermal-acoustic noise environment. The strain response during such tests results from sound pressures which may attain levels of 174 dB in a range of frequencies from near 0 Hz to 10 k Hz. Simultaneously, structural surface temperatures up to 1400^{0}F have to be measured. At this time, an extension of the techniques developed for resistance type strain gages into the realm of high temperature dynamic testing appears as the only feasible approach.

In addition to accurate dynamic strain data resulting during combined environment sonic fatigue tests, it is important to know the static pre-stresses and strains resulting from structural heating which will alter the fatigue life of the material. During the complete test duration the surface temperature distribution has to be monitored and controlled. This requires reliable and accurate temperature measuring techniques which can be applied in the combined environment. It is, therefore, required that attachment techniques be applicable for both strain gages and thermocouples.

The objective of this project was the development of strain and temperature measuring techniques for use under combined elevated temperature and acoustic conditions. Test demonstrations of the static and dynamic strain and temperature measuring techniques are part of the requirement.

It was not the intent of the program to develop new sensors but to extend the application of current devices for strain measurement on thin aerospace structures in a combined thermal and acoustic environment.

II. SUMMARY

Analytical and experimental investigations were carried out on promising techniques. The flame spray and ceramic cement bonding techniques used for vibratory strain measurements for aircraft engines were found most suitable for this application for both vibratory strain and temperature measurements.

Circuit compensation techniques were found useful for short-term static strain measurement. Both thermocouple and resistance thermometer compensation techniques were fully explored. The resistance thermometer method was more successful for static testing to 1200°F. A unique and new circuit was devised using this technique. In-service demonstration tests run at the AFFDL Sonic Fatigue Facility indicated the developed methods would substantially fulfill the test requirements. However, a very careful study of lead wire exiting methods must be made part of every test program. Detailed precautions are included in the Analysis of Results and Recommendation sections of this report.

III. STATEMENT OF WORK

A. Statement of Problem

The development of fatigue resistant aircraft structures requires the capability for measurement of static and dynamic strains and structural temperatures under laboratory conditions where a test structure is exposed to a combined thermal and acoustic noise environment. In addition to accurate dynamic strain data, it is important to know the static stresses resulting from structural heating which will alter the fatigue life of the structure. During the complete test duration, the surface temperature and temperature distribution of the structure must also be monitored and controlled. This requires the use of reliable and accurate temperature measuring instrumentation which will withstand the combined environment.

The objective of this program was to develop strain and temperature measuring instrumentation and installation techniques for use on thin aerospace structures under the combined conditions. The temperature ranges of interest can be roughly divided into three ranges: 200°F to 500°F, 500°F to 800°F, and 800°F to 1400°F. Structural materials frequently employed are: titanium alloys, stainless steels, nickel base alloys, and refractory metals. Structural configurations are typical of thin walled reinforced aircraft shell or panel sections.

B. General Strain Gage and Temperature Sensor System Specifications

Temperature Ranges:	300°F to 500°F
	500°F to 800°F
	800°F to 1400°F

Strain: 2000μ" Static
1000μ" R.M.S. Dynamic

Accuracy: ±5% Room Temperature to 1400°F

Durability: 50 Hrs. Testing to 800°F
1 Hr. Testing at 1400°F

Noise: From Quartz Lamp - Must be eliminated to achieve above accuracy

Calibration: Appropriate techniques must be devised

Frequency Range: Static to 10k Hz

Specimen Materials: Typical aerospace panel structures

IV. DEVELOPMENT PROGRAM

A. Strain Gage Development

A variety of strain measurement methods are available to the test engineer for measuring strain at elevated temperatures. A literature search was conducted to review the various methods of measurement that are available and to assess their applicability to the problem at hand. Primary consideration was given to the requirement that the instrumentation was to be attached to thin structures and that the attachment of the sensors should not affect the vibratory characteristics of the structure. Bonded resistance strain gages were determined to be the most suitable for this application. The use of bonded resistance strain gages to measure vibratory strain on aircraft engine components is routine and measurements up to 1800°F are often made. The requirement for measuring static strains at high temperature proved to be the most challenging. In order to determine whether a measurement can be made, it is essential to take into consideration the maximum test temperature, the rate of temperature rise, the amount of and the rate of temperature fluctuation, maximum time at temperature, the strain range anticipated, and the type of loading applied. The instrumentation must be considered as a system to include the sensor, lead work, method of signal transfer from part to stationary terminals, signal conditioning, and instrumentation system.

1. Alloy Data

Table 1 shows pertinent data on commercially available strain gage alloys. All alloys useful for temperatures above 800°F have a greater sensitivity to temperature than to strain. Figure 1 shows resistance vs. temperature for a platinum tungsten alloy

TABLE I Strain Gage Alloy Data

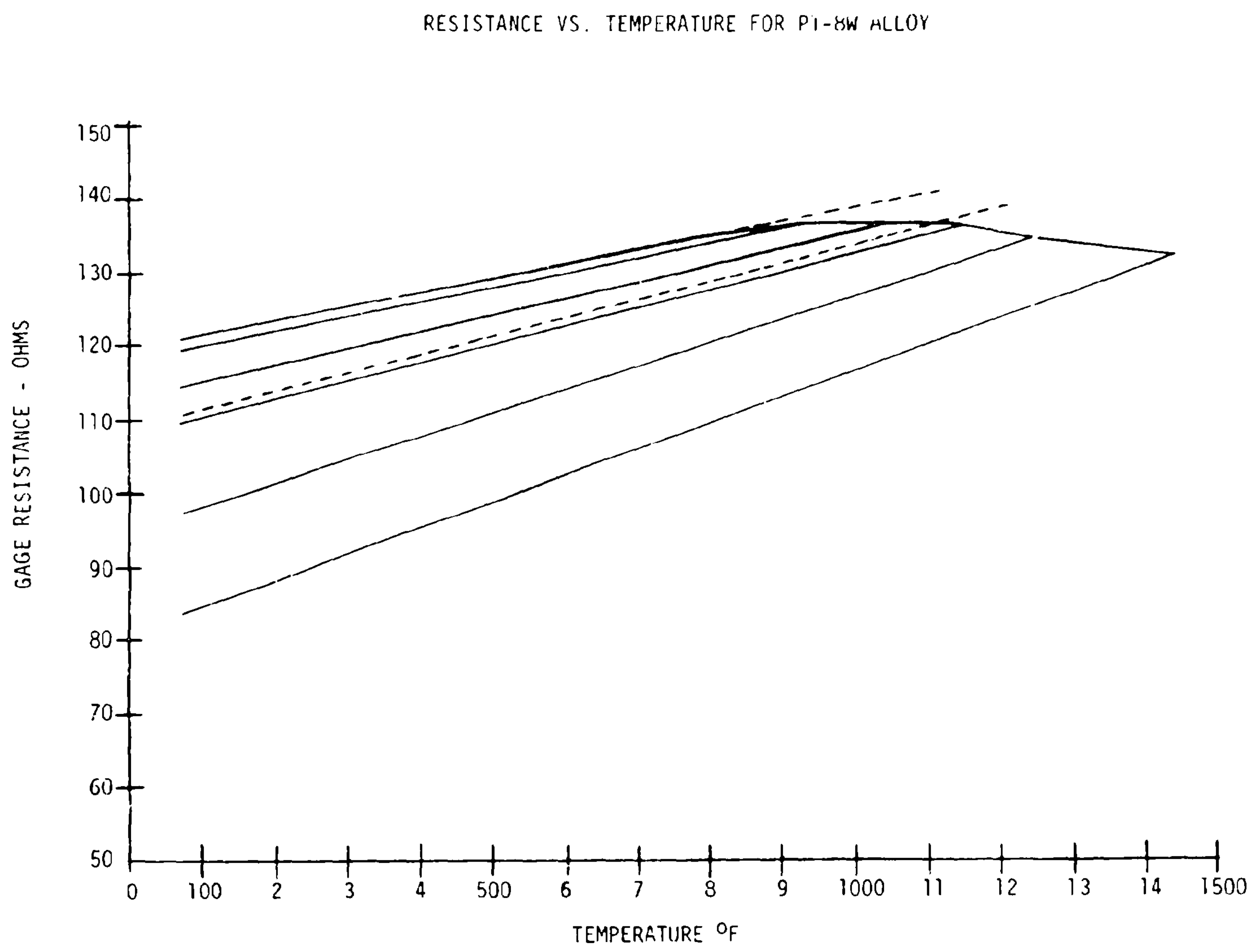
Alloy	Electr. Resistivity Micro..m	Electr. Resistivity Ω/cmf	T.C.R.	$\alpha_{\Delta T}$	σ_T Hard	σ_T Annealed	Young's Modulus E
Pt 10 Rh	19.2	108	.0017/°C (10-100°C)		90 KSI	45 KSI	
Pt 40 Rh	17.5	105	.0014/°C (10-100°C)		182 KSI	82 KSI	
Pt 15 Rh 5 Ru	31	186	.0007/°C (10-100°C)				
Pt 15 Rh 6 Ru	30	180	.0007/°C (0-100°C)	8.69×10^{-6} in/in/°C	250 KSI		25×10^{-6} psi
Pt 8W	62	372	.00024/°C (10-100°C)	7.99 x "	250 KSI		25×10^{-6} psi
Pt	9.85	63.8	.003927/°C (0-100°C)	9.1 x "	45 KSI	18 KSI	24.8×10^{6} psi
Cu	1.724	10.37	.00393/°C (20°C)	16.6 "	60 KSI	35 KSI	
80 Ni 20 Cr	108	650	.00011/°C (20-500°C)	17.0 " (10-1000°C)	200 KSI	100 KSI	
73Ni 20Cr+Al+Fe	133	800	.00002 /°C (20°C)	13.3 " (20-100°C)	180 KSI	130 KSI	
57 Cu 43 Ni	49	294	.00002 /°C (20°C)	14.9 " (20-100°C)	100 KSI	60 KSI	

Symbols: T.C.R. - Temperature Coefficient of Resistance

$\alpha_{\Delta T}$ - Thermal Expansion Coefficient

σ_T - Tensile Stress

TABLE I



RESISTANCE VS. TEMPERATURE FOR Pt-8W ALLOY
GAGE RESISTANCE - OHMS
150
140
130
120
110
100
90
80
70
60
50
0
100
2
3
4
500
6
7
8
9
1000
11
12
13
14
1500
TEMPERATURE °F

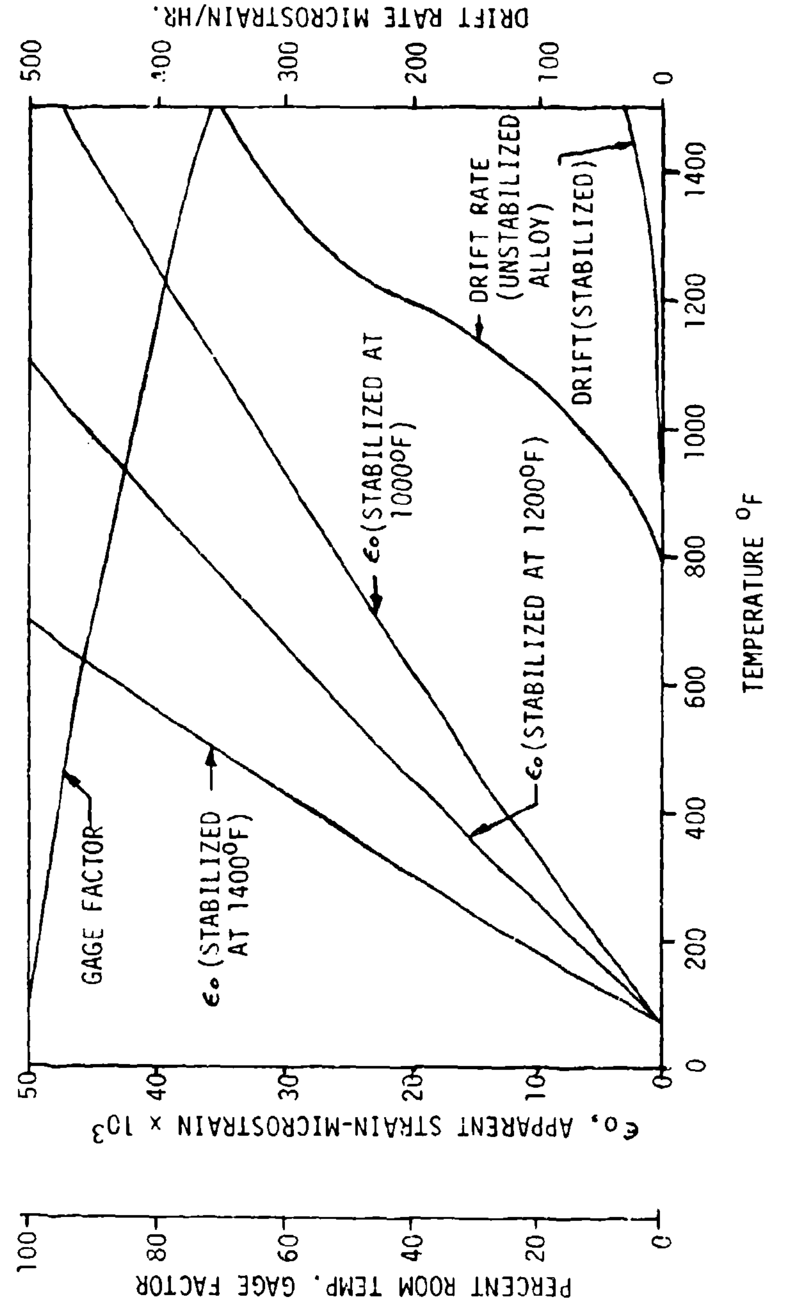
FIGURE 1

gage. The resistance characteristics of this alloy are dependent on the temperature at which it is stabilized. This alloy, stabilized at 1200°F, for example, will have a higher resistance-temperature curve than when stabilized at 1000°F. As the stabilization temperature increases, the slope of the resistance-temperature curve also increases. The stabilization process does not affect the elevated temperature gage resistance to any great extent. However, it manifests itself as a negative adjustment of room temperature resistance. Figure 2 shows the effect of stabilization on apparent strain for this alloy. Note that the slope of the apparent strain curve for material stabilized at 1400°F is approximately double that for material stabilized at 1000°F. When using this alloy for static strain measurements, the gage should not be stabilized at temperatures far greater than the test conditions without suffering unduly high apparent strain. The drift rate of stabilized material is also shown in Figure 2. This drift is sufficiently low to render the alloy useful for short-term testing in the 1000°F to 1400°F temperature range.

2. Strain Limit

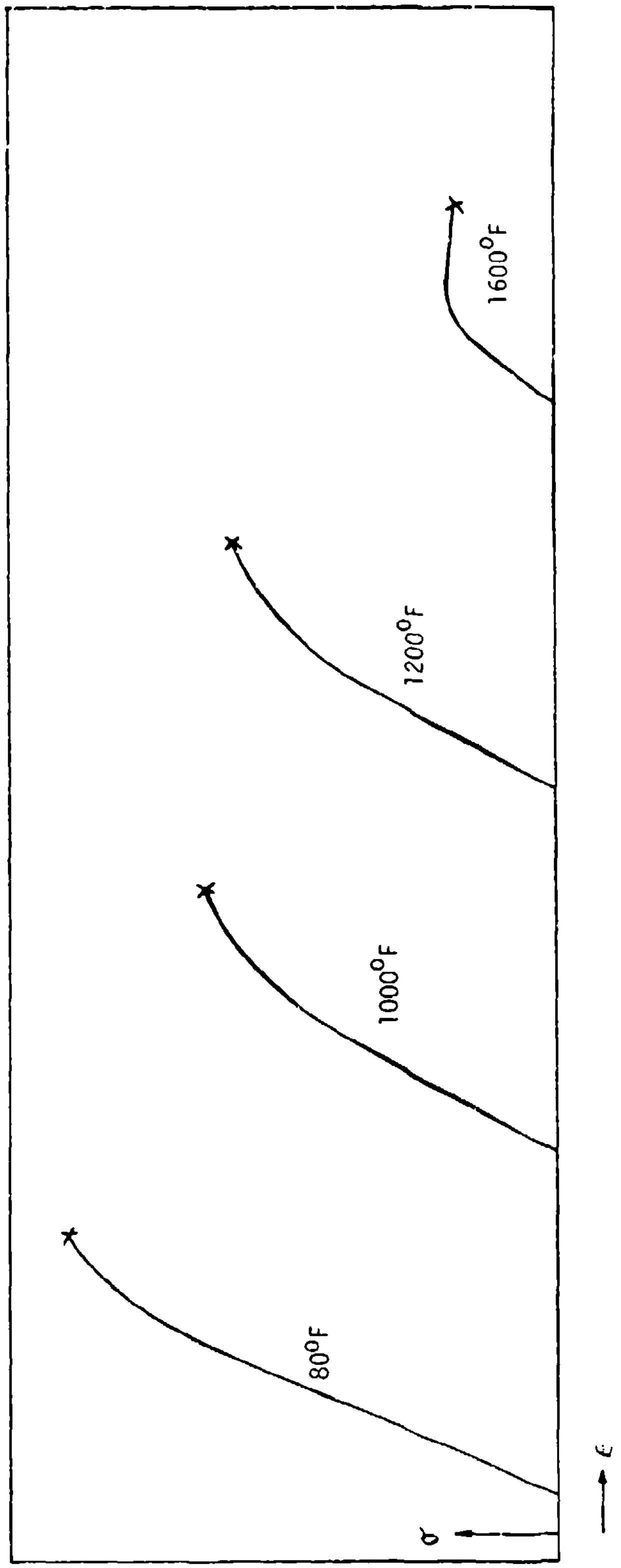
The gage factor normally published for strain gage materials applies to the alloy strained within its elastic limit. If the sensing alloy is strained beyond its elastic limit, a change in gage factor usually results; and this must be taken into account. The gage factor of platinum tungsten, for example, within its elastic range is about 4.0. When it is strained beyond its yield point, the gage factor becomes close to 2.0. The yield strength vs. temperature for platinum tungsten is shown in Figure 3.

The strain induced by the difference in thermal expansion coefficient ($\alpha \Delta T$)between the specimen and the gage is an important



GAGE FACTOR APPARENT STRAIN AND DRIFT RATE OF PT-8W ALLOY

FIGURE 2



σ-ε DATA FOR PT-8W VS. TEST TEMPERATURE

FIGURE 3

consideration for determining maximum strain limit; for example, a platinum tungsten gage having an $\alpha \Delta T$ of 4.9 ppm/^{o}F bonded to a 9 ppm/^{o}F material will have a temperature induced tensile strain equivalent to 4.1 microinches/^{o}F: Therefore, if the platinum tungsten gage is bonded to an austinetic stainless steel which is subjected to a temperature increase of 1000^{o}F, the induced strain caused by differences in thermal expansion between the specimen and the gage grid would be 4100 microinches. If the yield point of the strain gage alloy is 5000 microstrain at 1000^{o}F, then only a 900 microinch strain is needed to reach the yield point of the alloy, and hence, the point at which a gage factor change occurs.

3. <u>Compensation Techniques</u>

a. Self-Temperature Compensation

Self-temperature compensated strain gage alloys of the Karma* alloy type bonded with organic adhesives are generally used in the 200 to 500^{o}F range, and those bonded with ceramics are used in the 500 to 800^{o}F temperature range. Beyond 800^{o}F, self-temperature compensated resistance strain gages are not commercially available.

b. Gage Calibration

One approach, which has been used in England by Easterling[1] and Bertodo[2] is to stabilize a platinum tungsten gage above maximum test temperature and to calibrate the gage against a thermocouple over the entire temperature range. This calibration is done under isothermal conditions to eliminate thermally induced stress. During actual test, a departure from this calibration curve is interpreted as strain. This method is difficult to use because the instrument span must

* Trademark - Driver Harris Company, Harrison, New Jersey

be set at about 100,000 microinches and must be able to resolve strains on the order of 10 microinches. An early attempt to overcome this problem employed a dummy or compensating gage bonded to an unstrained specimen physically located in the vicinity of the active gage. Theoretically, if the active and compensating gage are exposed to the same temperature, the resistance change induced by temperature will be the same for both. The problem with this method is the extreme difficulty in maintaining the active and compensating gage at the same temperature.

c. Bridge Methods

If a compensating gage oriented in a transverse direction could be bonded adjacent to the active gage, good temperature compensation would result. An examination of this method reveals that it is useful for applications where the ratio of axial/transverse strains is known and is repeatable, (such as for axial tensile specimens, where the only thermal strains are those generated by the thermal expansion of the specimen). On complex structures, however, where thermal stress magnitudes and directions are unpredictable and the ratio of axial/transverse strain is unknown, this method cannot be used.

d. Thermocouple Compensation

This method utilizes a thermocouple output to compensate for the apparent strain output in a DC excited, modified wheatstone bridge circuit. Refined versions of this method were used by Adams[3] and also Kershisnik[4] to measure short-term strains at test temperatures to 1600°F. An amplified thermocouple output is used to provide a bucking voltage equal to the apparent strain output of the platinum tungsten gage. Two variables can readily be adjusted: (a) power to the strain gage bridge will adjust bridge output, and (b) thermocouple amplification can be adjusted to match bridge output.

Due to the linearity differences of the thermocouple EMF and the strain gage alloy apparent strain, it is very difficult to achieve perfect cancellation. Typically, at the temperatures under investigation, apparent strain of the strain gage alloy changes with time as well as temperature and circuit adjustment must be almost continuous. The thermocouple does have the advantage of requiring minimum space on the test specimen and does not require calibration at temperature.

e. Resistance Thermometer Compensation

This circuit employs a resistance thermometer element bonded adjacent to the active gage and wired into the compensating arm of the bridge. Since the thermometer is more sensitive to temperature than the strain gage, a thermometer resistance less than that of the gage is required to compensate for the temperature induced resistance change of the strain gage. A ballast resistor, therefore, is used in series with the thermometer element to provide bridge balance.

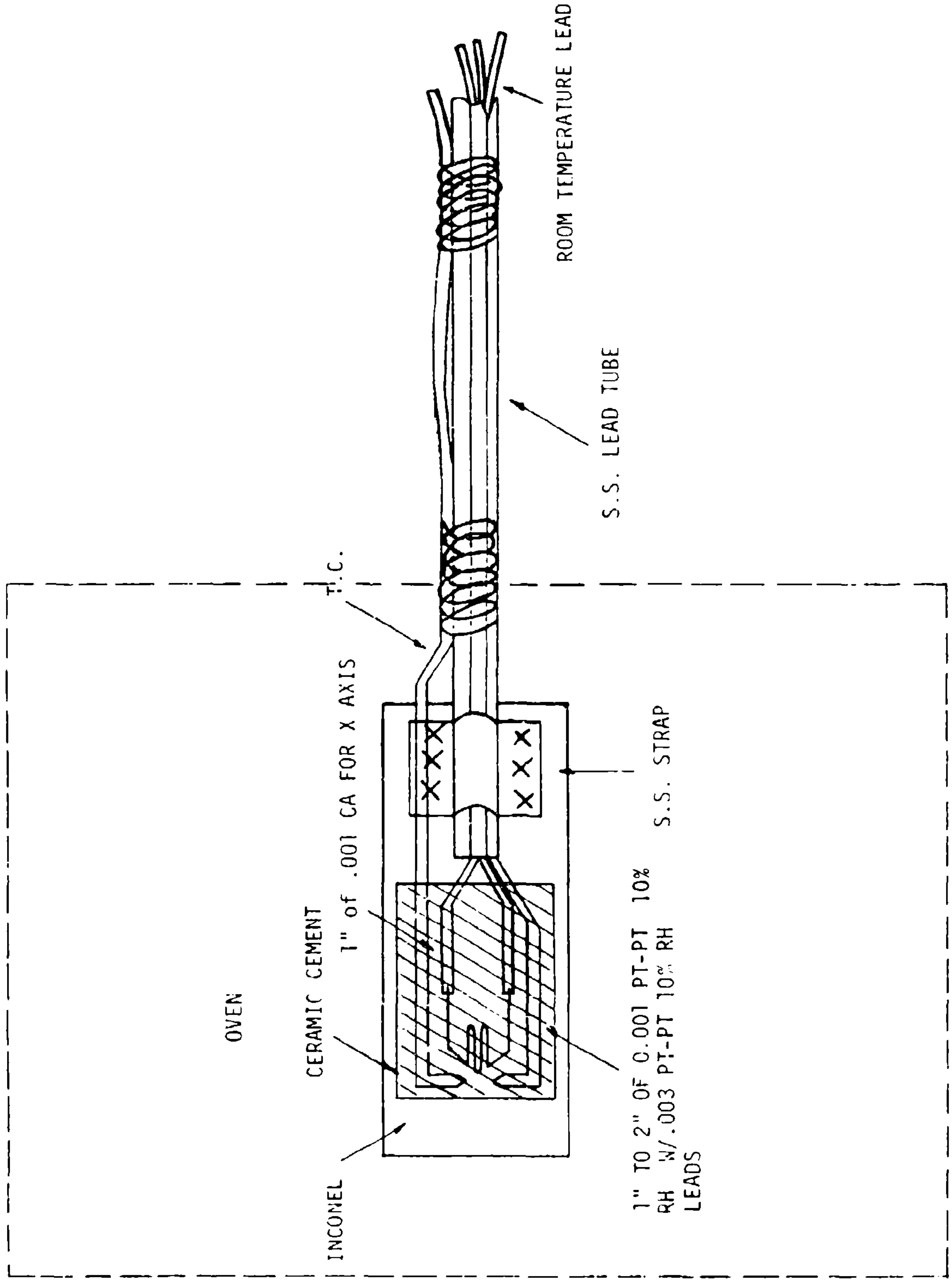
Again, the linearity differences of the thermometer output and the apparent strain of the strain gage make cancellation difficult; however, under specified temperature conditions, the output vs. temperature of thermometer grade alloys is very linear. If the specified temperature range is exceeded, gross non-linearities in apparent strain will result. In addition, the circuitry is more conventional and less expensive. The completed installation must be calibrated for shunt resistance values after installation of the sensors and the components under test must be raised to test temperature during calibration.

4. <u>Compensation Technique Development</u>

a. Thermocouple Compensation

A number of published and some unpublished thermocouple compensation systems were evaluated. In particular, Kershisnik's (Fig. 5) circuit utilizing two Fairchild 747 integrated circuit amplifiers to achieve self-compensation and gage factor compensation was evaluated. The same circuit using Ellis amplifiers was also tried. The constant current circuit used by Adams was also breadboarded and evaluated (Fig. 6, 7). In addition, other systems utilizing a voltage divider network at th amplifier output were evaluated (Fig. 8, 9, 10, 11, 12, 13). These systems employed both constant current and constant voltage power supplies.

The test specimen used is shown in Figure 4. Strain gages were installed on a 1 x 3 x 1/16" thick Inconel X test bar. Two thermocouples were also attached. A 1 mil chromel/alumel thermocouple was initially employed, but was later replaced by a 1 mil platinum platinum 10% rhodium thermocouple for increased stability at elevated temperatures. The platinum 8% tungsten test gage was stabilized at 1400^{0}F for 16 hours. Test specimens were plunged into a preheated oven and apparent strain vs. temperature was plotted on an X-Y plotter. Figures 7, 10, 11, and 13 show apparent strain results for various circuitry.



SKETCH OF STRAIN GAGE TEST SPECIMEN FOR THERMOCOUPLE COMPENSATION

FIGURE 4

LOCKHEED CONSTANT VOLTAGE
DUAL AMPLIFIER CIRCUIT

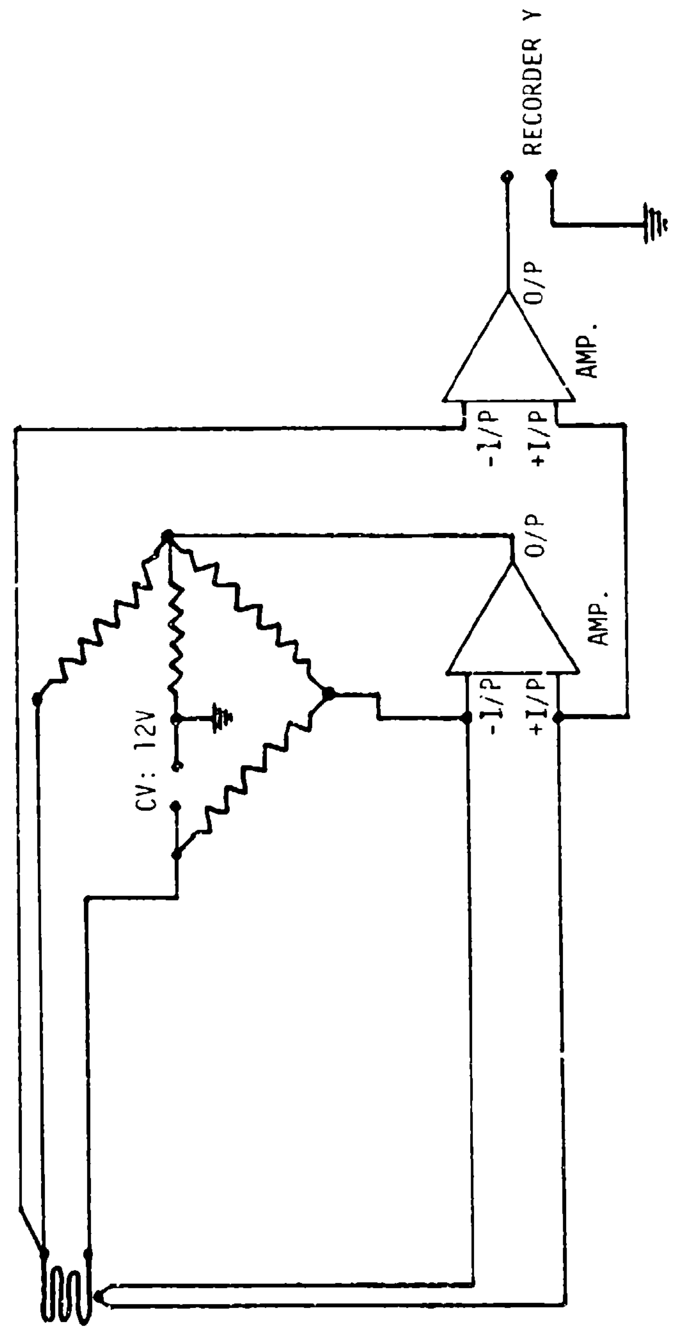


FIGURE 5

SANDIA - CONSTANT CURRENT CIRCUIT

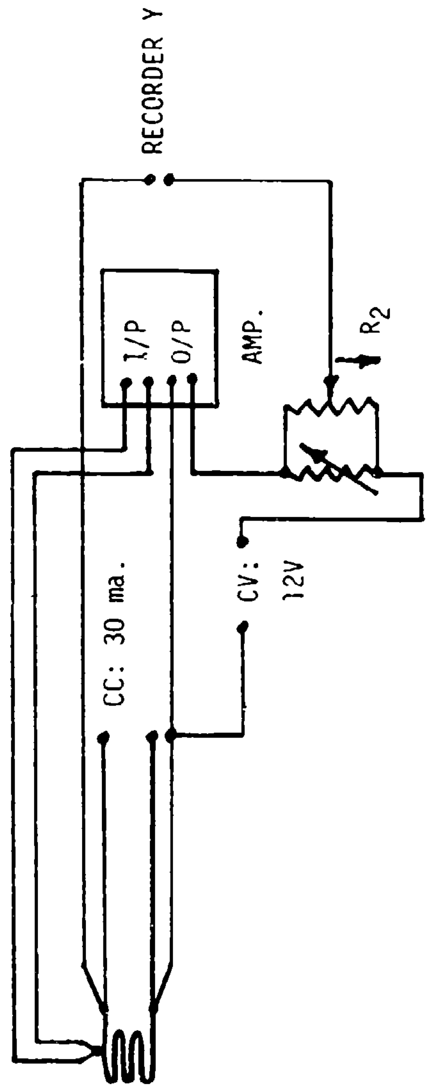


FIGURE 6

SANDIA
CONSTANT CURRENT CIRCUIT

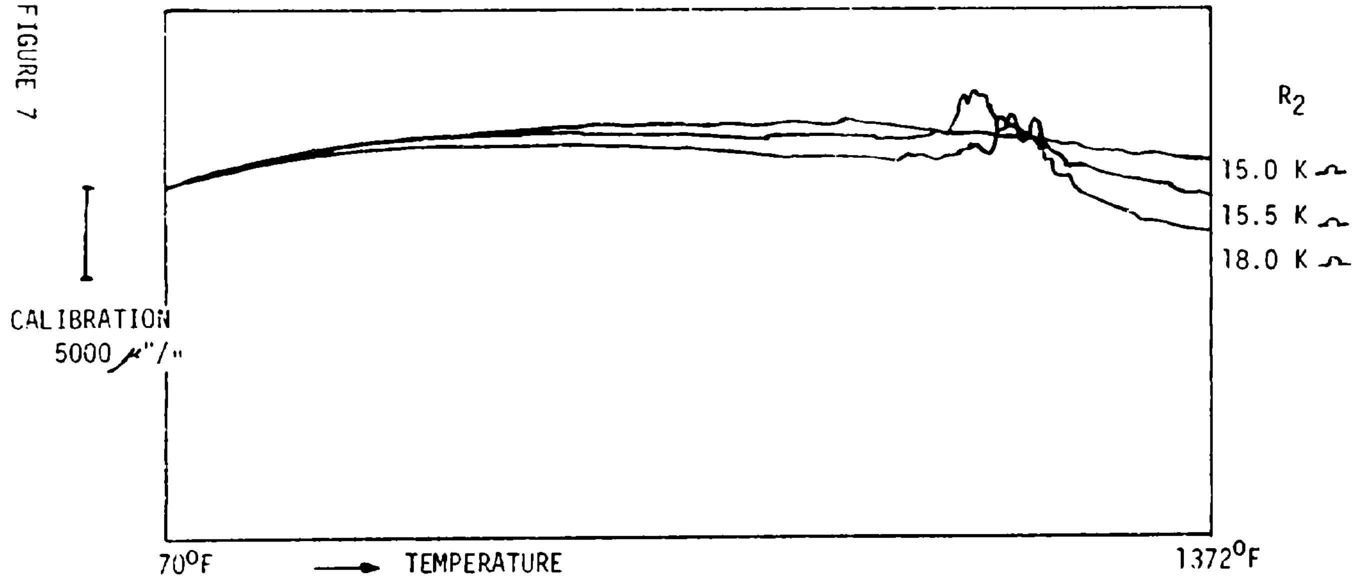


FIGURE 7

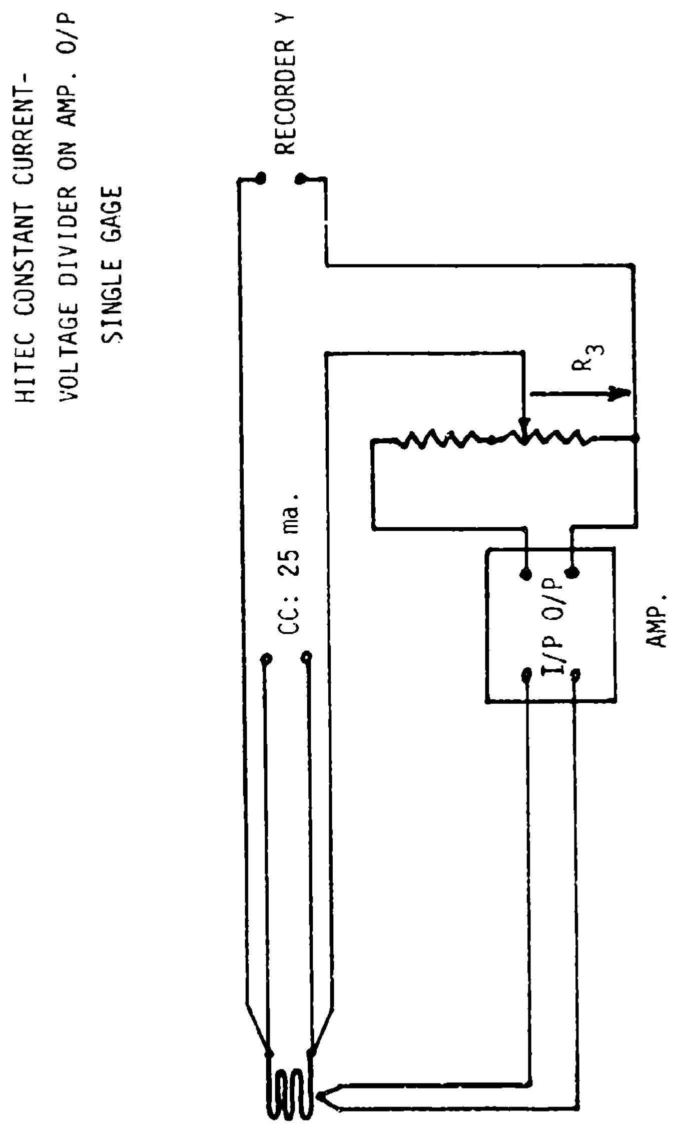

HITEC CONSTANT CURRENT-
VOLTAGE DIVIDER ON AMP. O/P
SINGLE GAGE
RECORDER Y
R_3
CC: 25 ma.
I/P O/P
AMP.

FIGURE 8

HITEC CONSTANT CURRENT-
VOLTAGE DIVIDER ON AMP. O/P

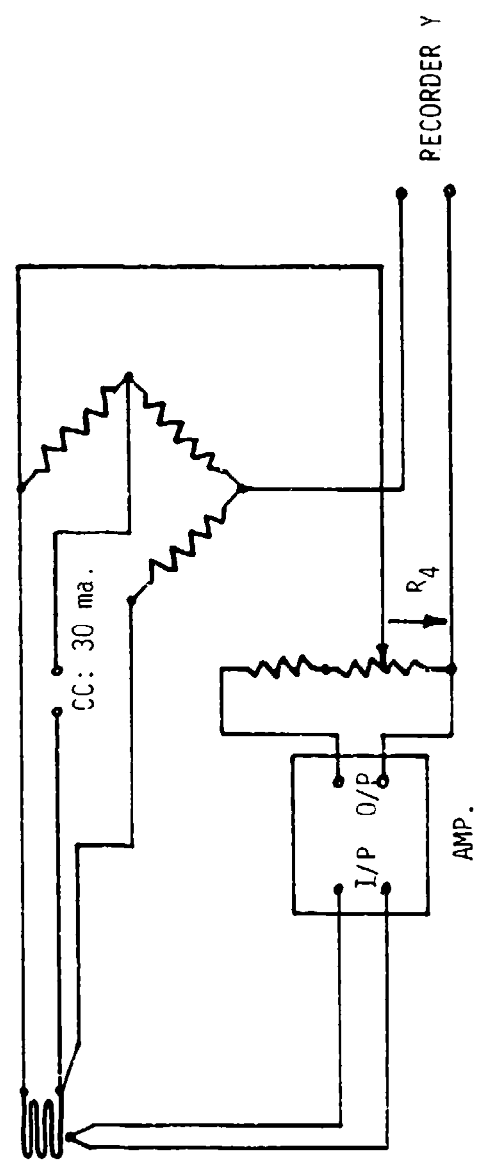
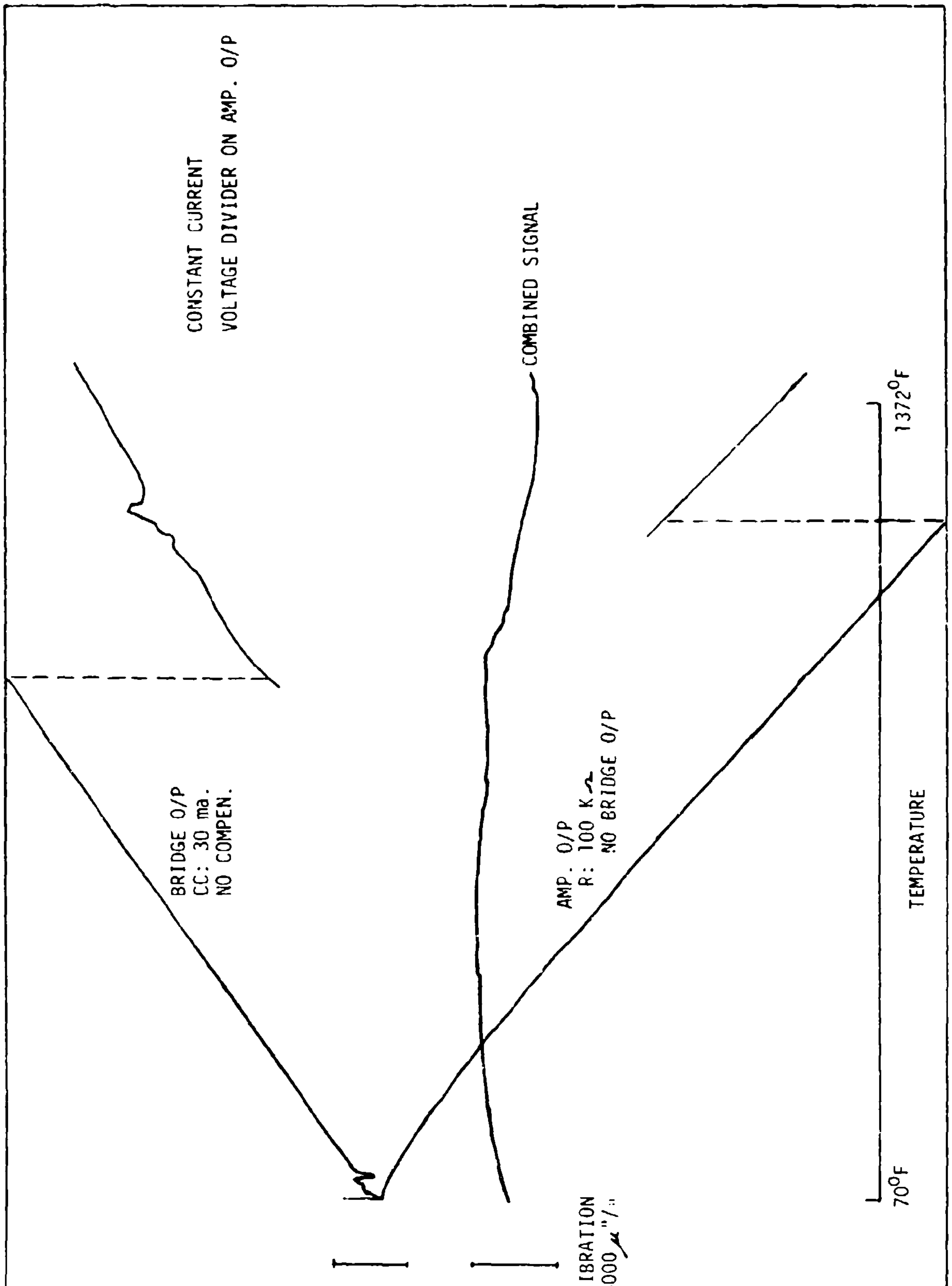


FIGURE 9



CONSTANT CURRENT
VOLTAGE DIVIDER ON AMP. O/P
COMBINED SIGNAL
1372°F
BRIDGE O/P
CC: 30 ma.
NO COMPEN.
AMP. O/P
R: 100 KΩ
NO BRIDGE O/P
TEMPERATURE
70°F
CALIBRATION
5000µ"/"

FIGURE 10

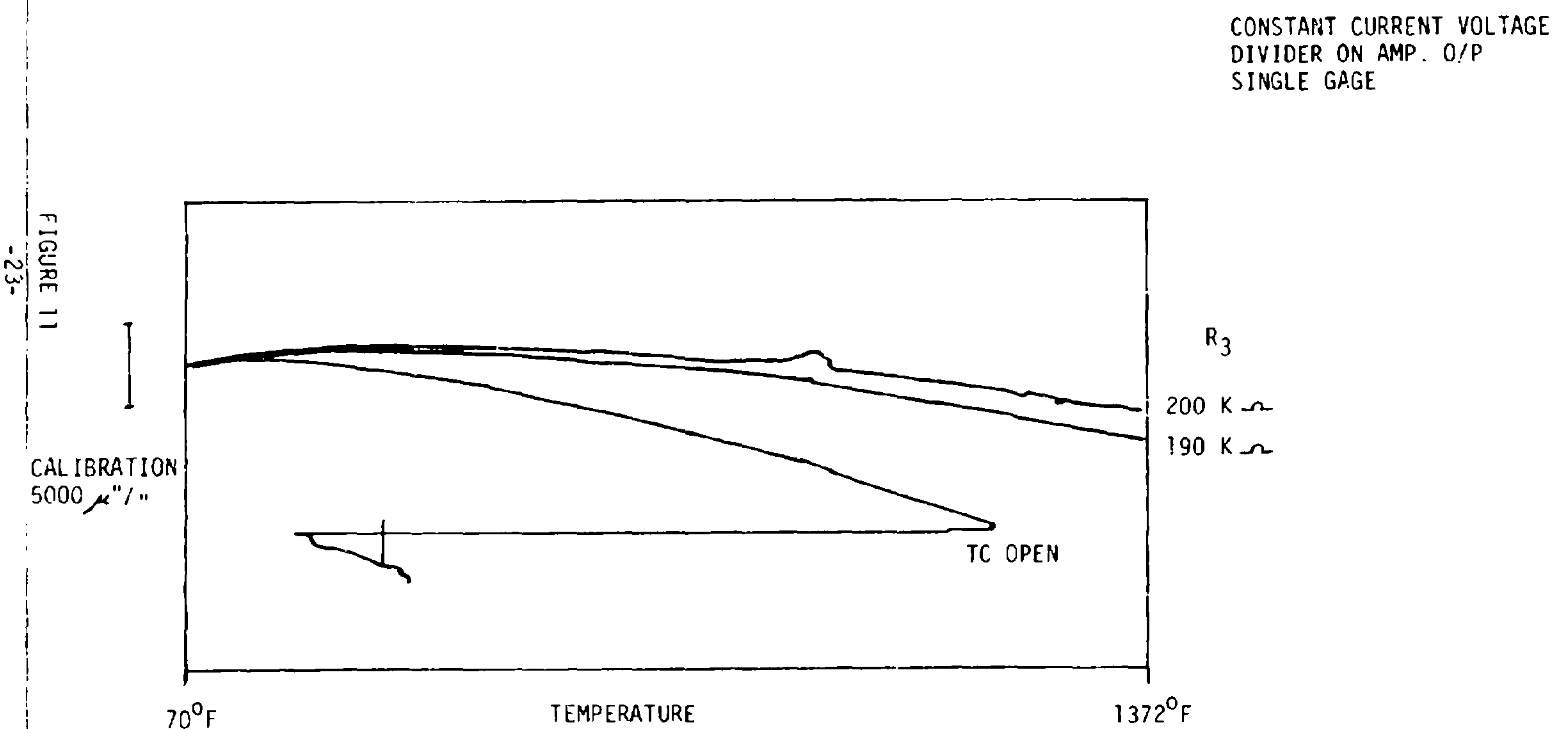

CONSTANT CURRENT VOLTAGE
DIVIDER ON AMP. O/P
SINGLE GAGE
R_3
200 K Ω
190 K Ω
TC OPEN
CALIBRATION
5000 μ"/"
70°F
TEMPERATURE
1372°F

FIGURE 11

HITEC CONSTANT VOLTAGE-
VOLTAGE DIVIDER ON AMP. O/P

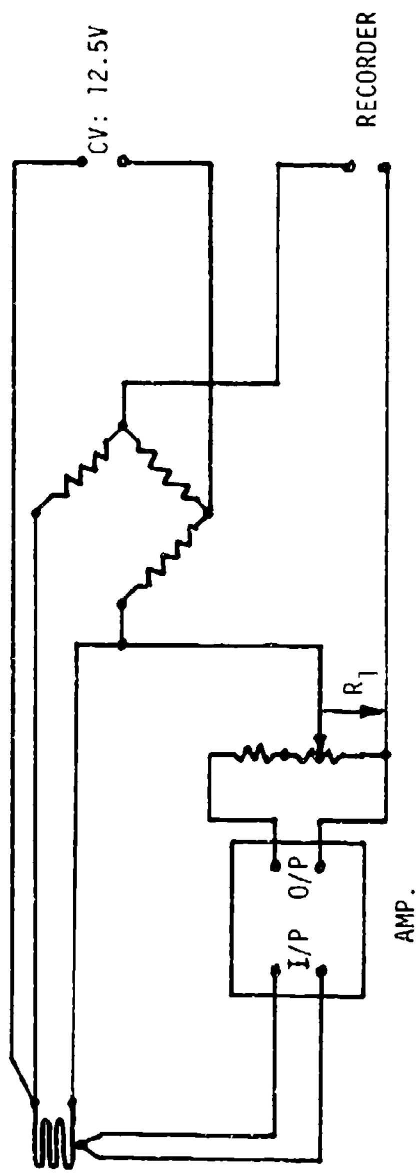


FIGURE 12

CV 12 VDC. VOLT. DIV. TC AMP O/P R_1 GIVEN

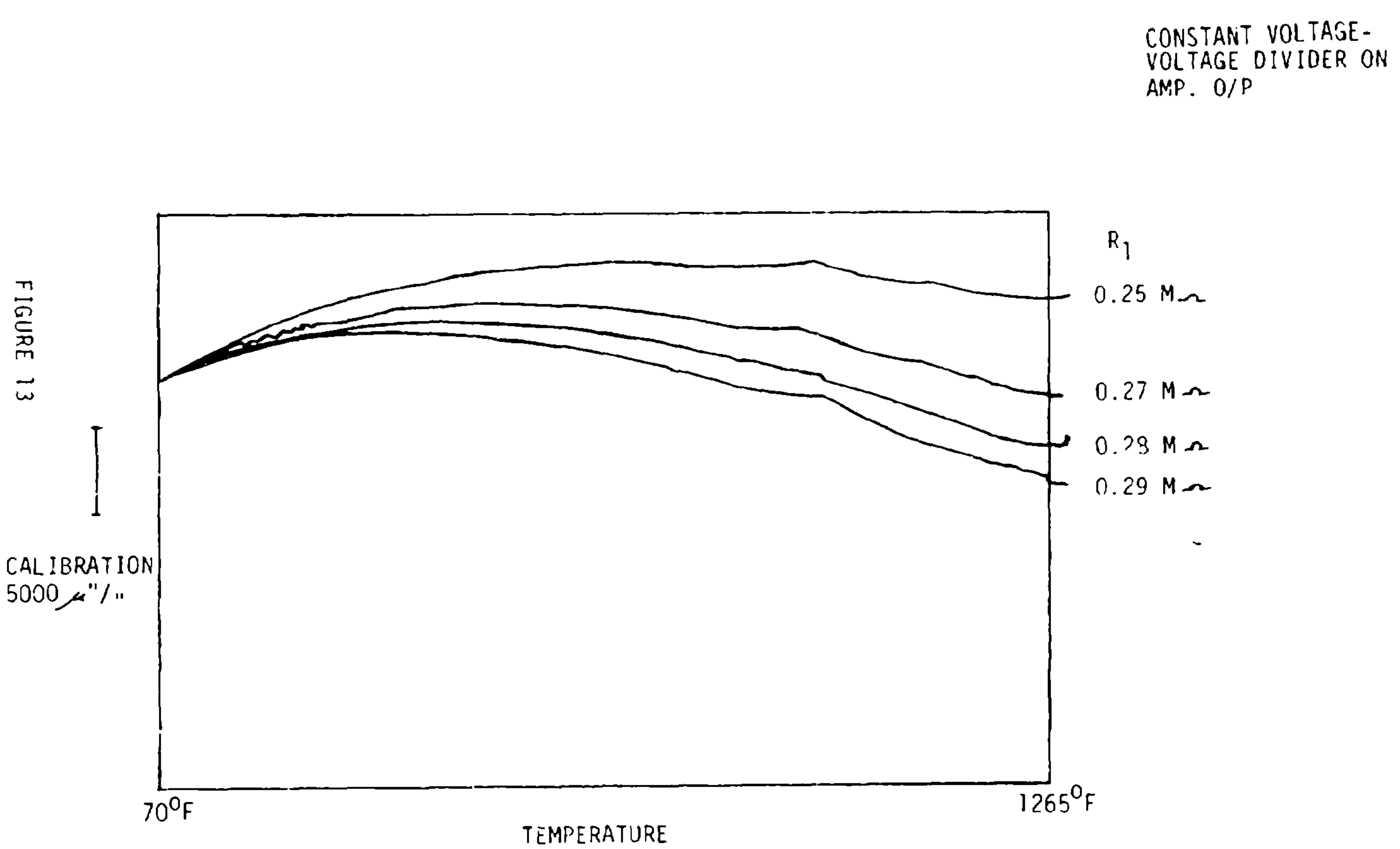


FIGURE 13

b. Resistance Thermometer Compensation

b.1 Alloys

Five thermometer alloys initially selected for evaluation are:

- Platinum 10% Nickel
- Platinum 15% Rhodium 6% Ruthenium
- Platinum 8% Nickel 2% Tungsten
- Platinum 10% Rhodium
- Platinum 40% Rhodium

Resistance thermometer compensating elements were fabricated and bonded with ceramic cement to Inconel X test specimens. Active elements of Platinum 8% Tungsten alloy were bonded alongside each compensating grid. The Pt 10 Ni alloy was dropped from consideration because it is not commercially available in suitable fine wire form. All test gages and compensating elements were stabilized for 16 hours at test temperature prior to each test. The results are shown in Figures 14, 15, 16, 17, and 18.

Platinum 40% Rhodium elements show good linearity up to 1200°F but a comparatively high drift rate. The Platinum 10% Rhodium shows equally good linearity to 1100°F and better drift characteristics. Both of these alloys show excessive non-linearity in the 1300° to 1400°F range and excessive drift in this region. The Platinum 15% Rhodium 6% Ruthenium alloy shows better stability than both Platinum Rhodium alloys but a much lower temperature coefficient. This requires a higher resistance compensating element which reduces the gage factor. The Platinum 8% Nickel 2% Tungsten alloy shows good drift characteristics; however, apparent strain non-linearity becomes excessive above 1300°F.

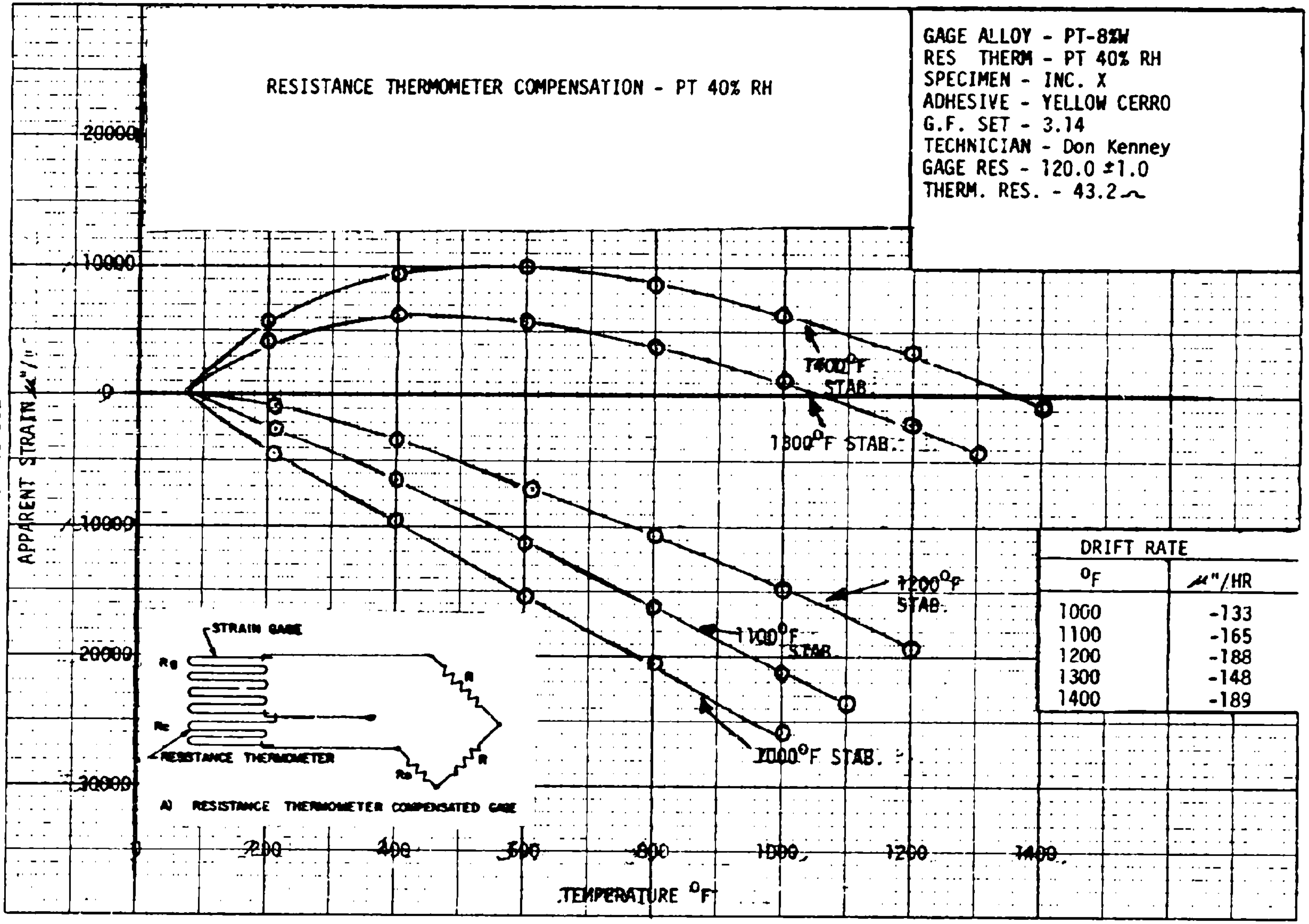

RESISTANCE THERMOMETER COMPENSATION - PT 40% RH
GAGE ALLOY - PT-8%W
RES THERM - PT 40% RH
SPECIMEN - INC. X
ADHESIVE - YELLOW CERRO
G.F. SET - 3.14
TECHNICIAN - Don Kenney
GAGE RES - 120.0 ±1.0
THERM. RES. - 43.2Ω
1400°F STAB.
1300°F STAB.
1200°F STAB.
1100°F STAB.
1000°F STAB.
DRIFT RATE
°F μ"/HR
1000 -133
1100 -165
1200 -188
1300 -148
1400 -189
STRAIN GAGE
Rg
Rc
R
R
Rb
RESISTANCE THERMOMETER
A) RESISTANCE THERMOMETER COMPENSATED GAGE
APPARENT STRAIN μ"/"
20000
10000
0
-10000
-20000
-30000
0
200
400
600
800
1000
1200
1400
TEMPERATURE °F

FIGURE 14

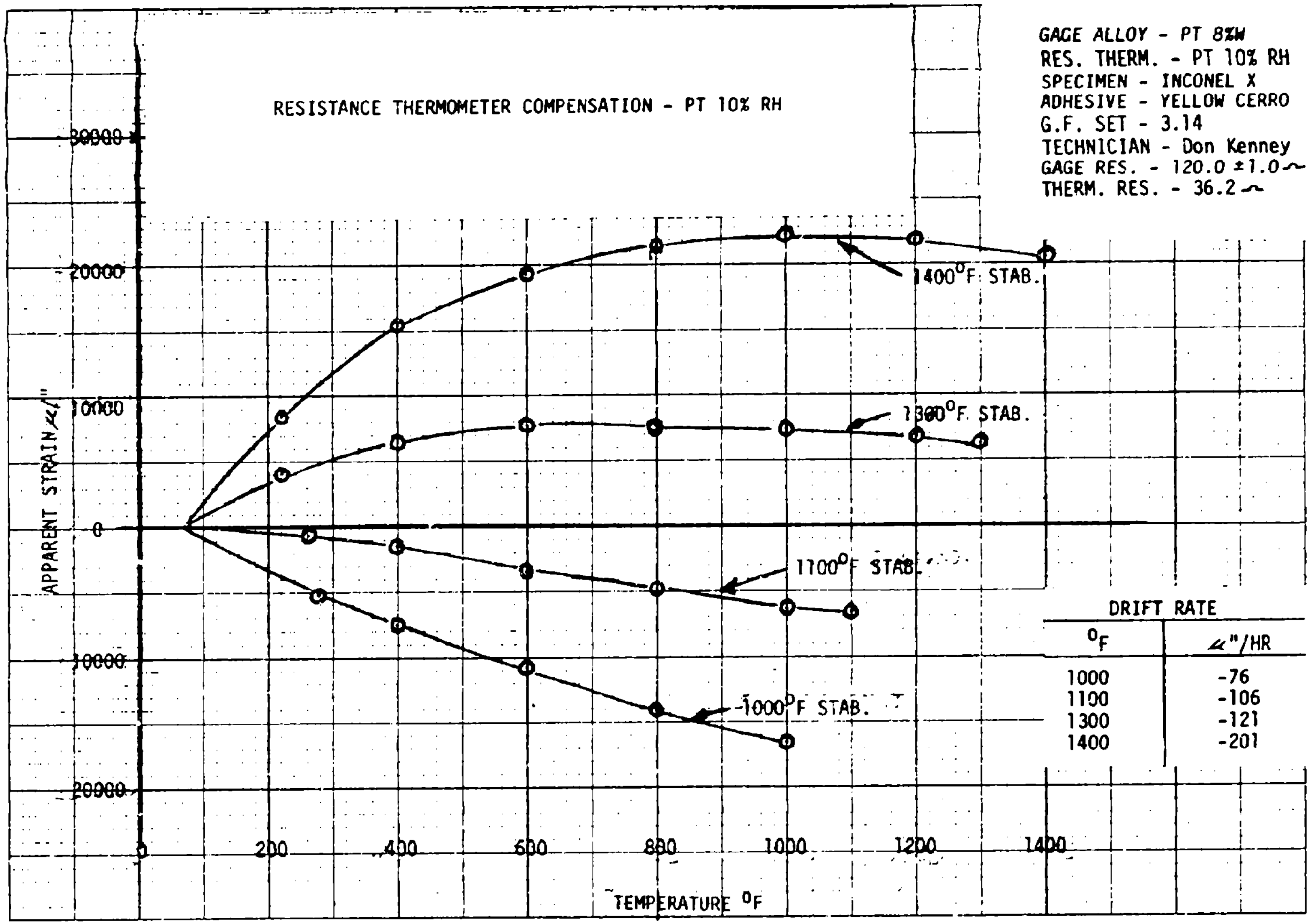
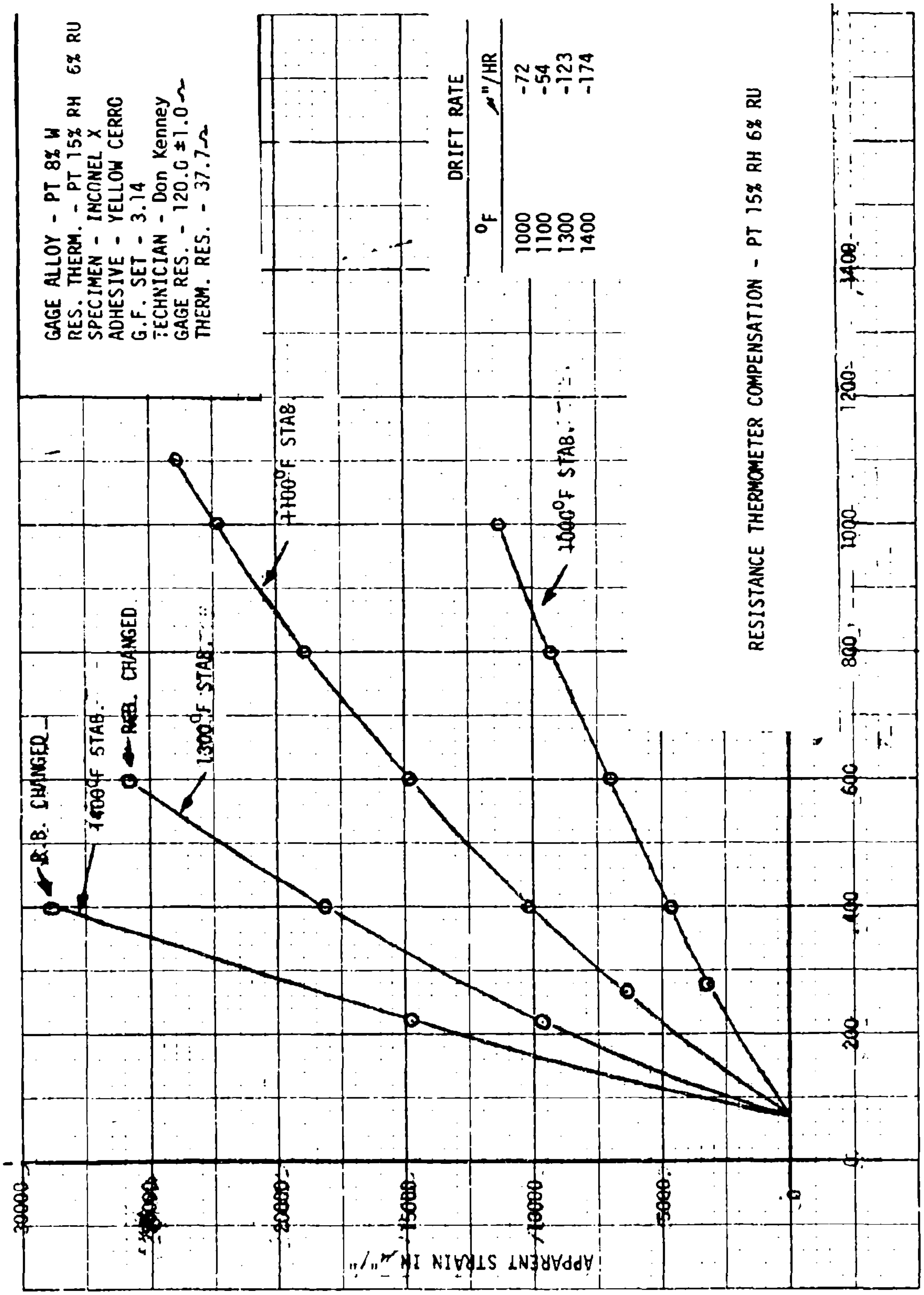

RESISTANCE THERMOMETER COMPENSATION - PT 10% RH
GAGE ALLOY - PT 8%W
RES. THERM. - PT 10% RH
SPECIMEN - INCONEL X
ADHESIVE - YELLOW CERRO
G.F. SET - 3.14
TECHNICIAN - Don Kenney
GAGE RES. - 120.0 ±1.0 Ω
THERM. RES. - 36.2 Ω
1400°F STAB.
1300°F STAB.
1100°F STAB.
1000°F STAB.
DRIFT RATE
°F | μ"/HR
1000 | -76
1100 | -106
1300 | -121
1400 | -201
APPARENT STRAIN μ"
30000
20000
10000
0
10000
20000
0
200
400
600
800
1000
1200
1400
TEMPERATURE °F

FIGURE 15



GAGE ALLOY - PT 8% W
RES. THERM. - PT 15% RH 6% RU
SPECIMEN - INCONEL X
ADHESIVE - YELLOW CERRO
G.F. SET - 3.14
TECHNICIAN - Don Kenney
GAGE RES. - 120.0 ±1.0Ω
THERM. RES. - 37.7Ω
DRIFT RATE
°F
µ"/HR
1000 -72
1100 -54
1300 -123
1400 -174
RESISTANCE THERMOMETER COMPENSATION - PT 15% RH 6% RU
R.B. CHANGED
1400°F STAB.
R.B. CHANGED
1300°F STAB.
1100°F STAB.
1000°F STAB.
APPARENT STRAIN IN µ"/"
30000
25000
20000
15000
10000
5000
0
0
200
400
600
800
1000
1200
1400

FIGURE 16

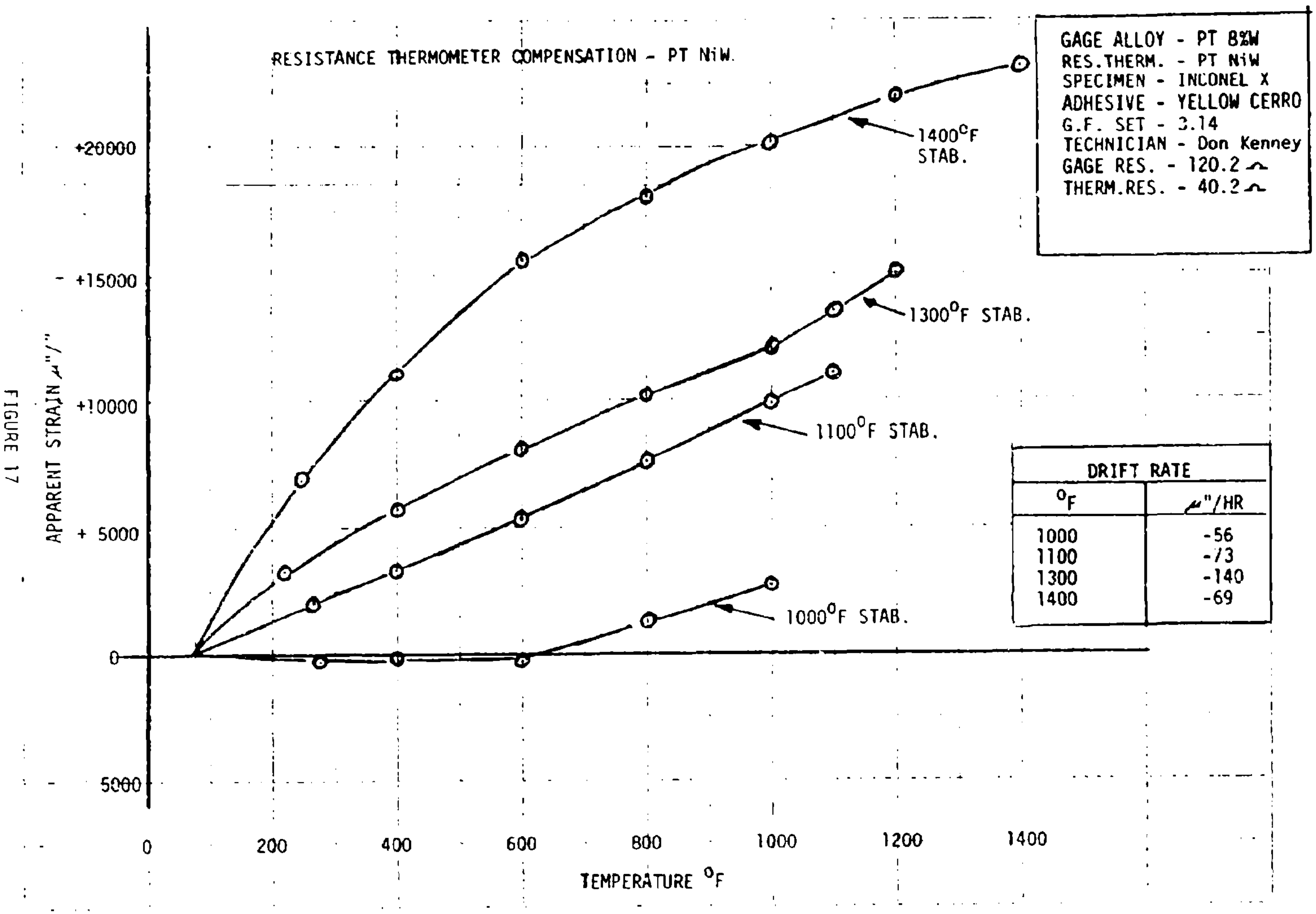
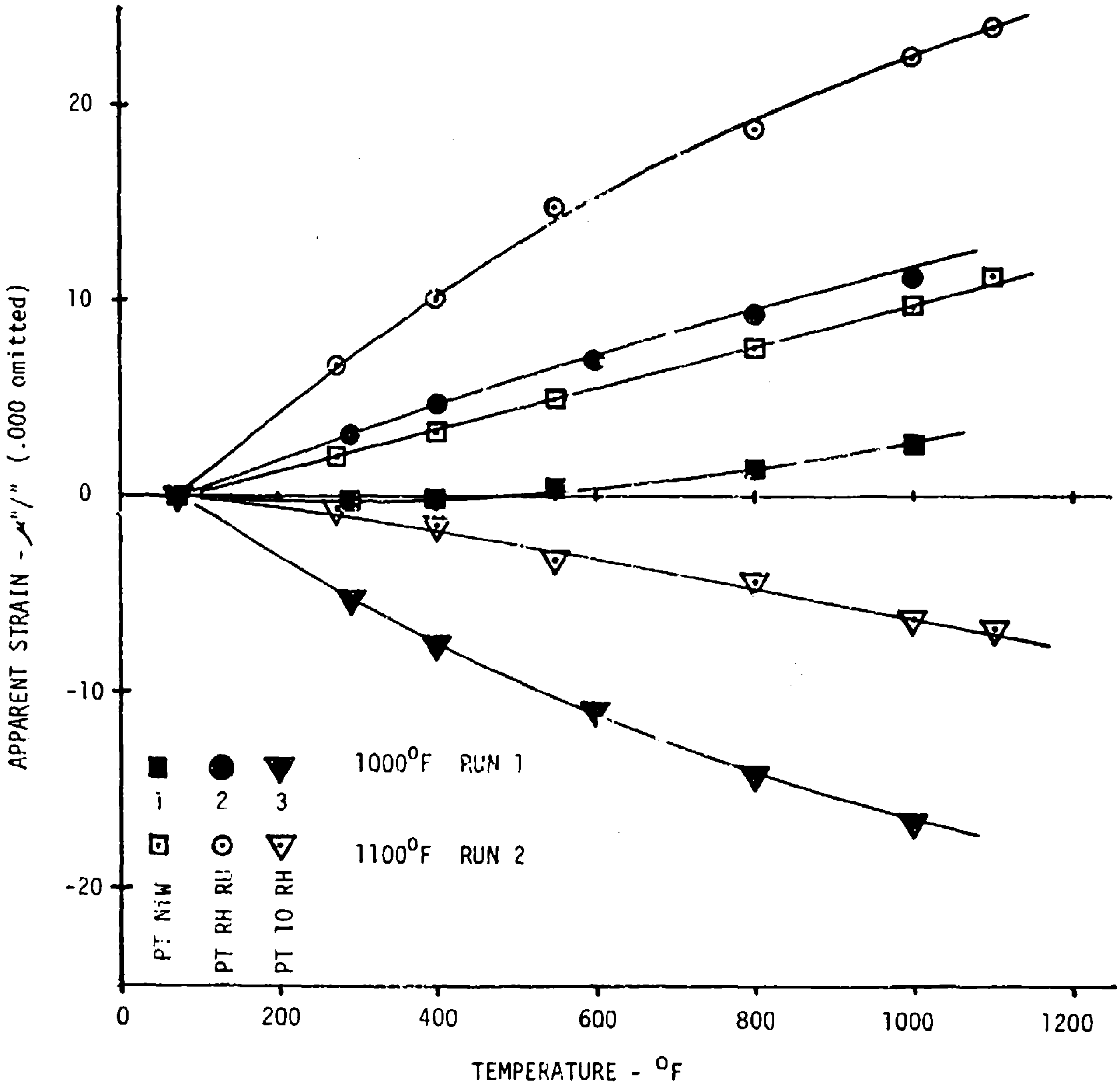

RESISTANCE THERMOMETER COMPENSATION - PT NiW.
GAGE ALLOY - PT 8%W
RES.THERM. - PT NiW
SPECIMEN - INCONEL X
ADHESIVE - YELLOW CERRO
G.F. SET - 3.14
TECHNICIAN - Don Kenney
GAGE RES. - 120.2 Ω
THERM.RES. - 40.2 Ω
1400°F STAB.
1300°F STAB.
1100°F STAB.
1000°F STAB.
DRIFT RATE
°F | μ"/HR
1000 | -56
1100 | -73
1300 | -140
1400 | -69
APPARENT STRAIN μ"/"
+20000
+15000
+10000
+ 5000
0
5000
0
200
400
600
800
1000
1200
1400
TEMPERATURE °F

FIGURE 17



RESISTANCE THERMOMETER
COMPENSATION
PT 10 RH, PT RH RU, PT NiW

FIGURE 18

A second group of gages was fabricated and bonded to Inconel X specimens. Compensating elements were made from Platinum 10% Rhodium and Platinum 15% Rhodium 6% Ruthenium. This time the thermometer elements were made to a higher resistance than required and adjusted to desired values by trimming with a shunt resistor. (See Figure 19). Using this technique, the gage can be made to compensate on virtually any material over any temperature range for which the gage and thermometer alloys are sufficiently stable.

b.2 Calibration

The procedure used initially was simple but time consuming. The gage was stabilized at 50°F above maximum test temperature for 16 to 20 hours. An apparent strain calibration curve was recorded during oven cooling to room temperature. If the thermometer element R_t is larger than necessary, the apparent strain curve will be negative. To reduce the affect of R_t, a shunt resistor R_s is applied across $R_t + R_b$. R_b is then adjusted to maintain bridge balance. The value for R_s is selected by trial and error. With experience, the correct value can be achieved on the second trial. Analytical methods to determine shunt resistances were derived and are included in the Appendix A. Calculated values compared with experimental values are shown in Table II.

It became evident from these studies that this simple shunt-ballast resistor method for adjusting apparent strain introduced an error. This error is caused by the shunting of one lead wire leg and not the other.

For very low resistance leads and high shunt values, this error may be insignificant; but for long high resistance leads or low shunt values, it cannot be ignored. The problem

TABLE II Shunt Resistance (Rs) Values

Δ ng	R_{T_8}	R_T	Calculated R_S	Experimental R_S	R_T Alloy
13.2	55.4	34.6	175.32		Pt-Rh
12.8	54.0	33.8	170.39	180	Pt-Rh
17.2	59.7	34.2	214.34	[illegible]	Pt-Rh
17.1	58.4	33.5	220.86	201	Pt-Rh
20.6	61.4	34.7	345.38	320	Pt-Rh
20.3	60.0	34.0	355.19	320	Pt-Rh
25.6	64.4	34.2	570.23	560	Pt-Rh
25.1	62.8	33.5	596.56	[illegible]	Pt-Rh
16.2	87.5	65.55	465.86	[illegible]	Pt-Rh-Ru
19.9	92.19	66.90	623.83	[illegible]	Pt-Rh-Ru
26.3	94.70	66.28	2035.32	[illegible]	Pt-Rh-Ru
16.3	87.50	65.55	476.25	475	Pt-Rh-Ru
19.7	91.3	65.9	540	[illegible]	Pt-Rh-Ru

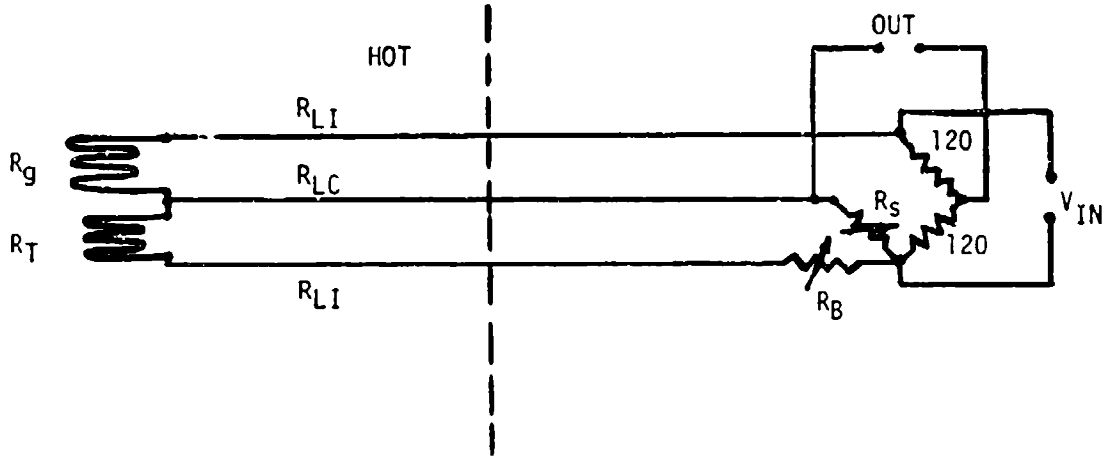
was solved by placing the shunt resistor directly across the thermometer only as shown in Figure 19. This eliminated shunting lead wires and the resultant error. This method was verified experimentally using long leads.

b.3 Instrumentation

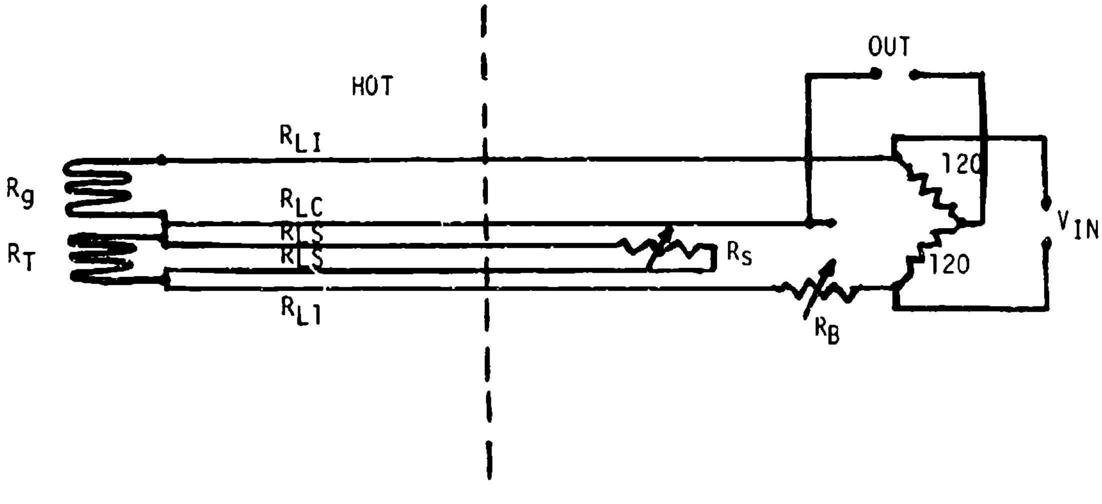
Custom signal conditioning instrumentation was built to interface between the strain gage and standard strain gage instrumentation. This signal conditioning unit included terminals for each of five strain gage lead wires, a variable shunt resistor, R_s and a variable ballast resistor R_b. This package also included a DC power supply. This system was used throughout the test program with static strain indicators such as the Vishay-Ellis P-350 and the BLH Model 120C. For readout instruments with integral power supplies, the signal conditioning power supply could be totally disconnected by turning the bridge power switch to "off". The internal power supply can be used when the signal conditioning is used in conjunction with a Moseley Model 135 X-Y plotter or other millivolt instrument.

b.4 Stabilization

Strain output was plotted on the vertical axis while specimen temperature was plotted on the horizontal axis. The apparent strain curve for Platinum Rhodium and Platinum Rhodium Ruthenium compensated gages are shown in Figures 20 and 21. Excellent temperature compensation can be achieved using the resistance thermometer compensation techniques. To achieve the results shown, however, requires that the alloys be stabilized at the temperatures shown. Specifically, the Platinum Rhodium compensated gage must be stabilized at 1250^{o}F and Platinum Rhodium Ruthenium compensating element must be stabilized between 1050^{o}F and 1075^{o}F. These alloys are therefore, limited to approximately

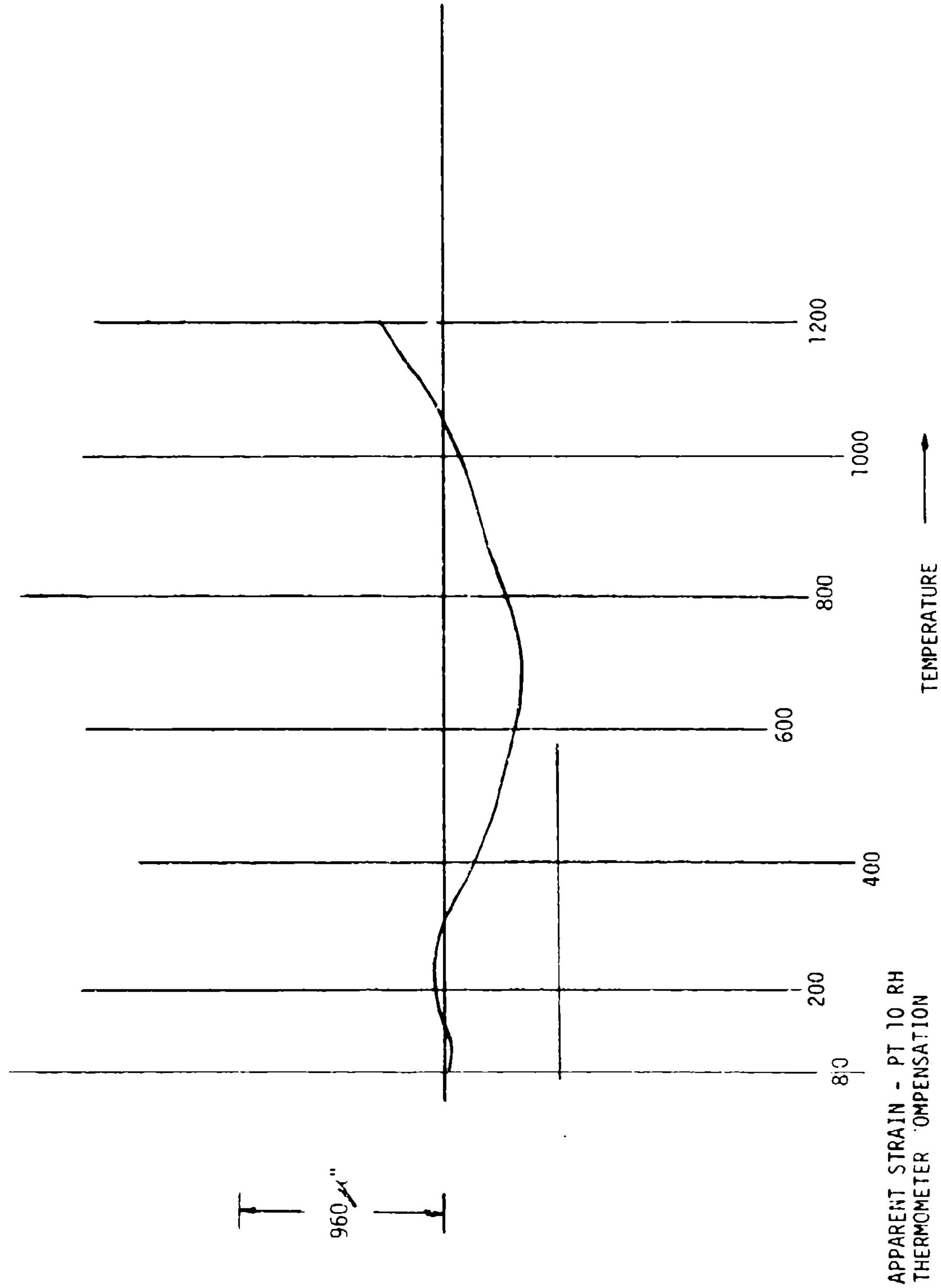


THREE WIRE SHUNT



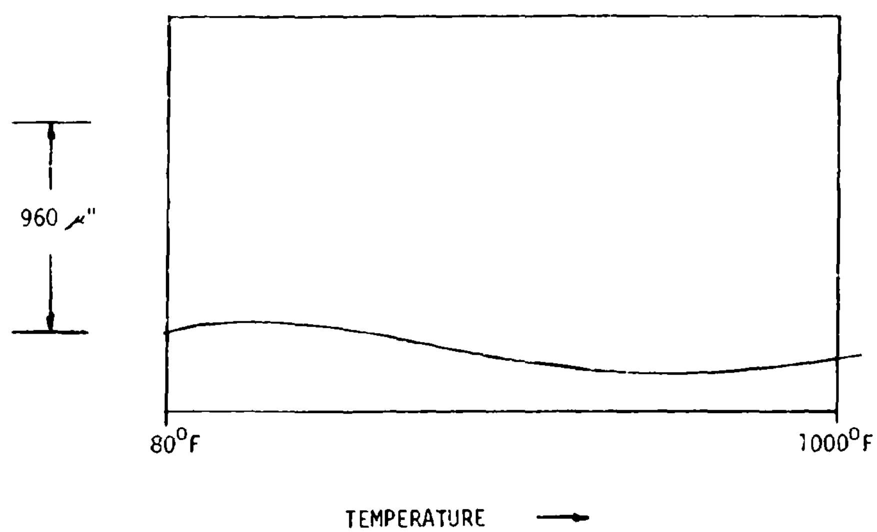
FIVE WIRE SHUNT

FIGURE 19



80
200
400
600
800
1000
1200
TEMPERATURE
960μ"
APPAREΝT STRAIN - PT 10 RH
THERMOMETER 'OMPENSATION

FIGURE 20



APPARENT STRAIN PT RH RU THERMOMETER COMPENSATION

FIGURE 21

1200°F for Pt Rho and 1050°F for the Pt Rh Ru. The stabilization temperatures given also produce optimum linearity; and stabilization temperatures lower or higher than those given will increase non-linearity. The gross non-linearity of Platinum Tungsten alloy above 1250°F was totally unexpected at the beginning of the experimental program. As an example, a Platinum Rhodium-Platinum Tungsten gage stabilized at 1400°F is shown in Figures 22 and 23.

c. Lead Wire Material - Selection of

It is important to define the largest lead that can be used for a given test program and, therefore, a lead evaluation program was made part of the AFFDL tests; and a number of lead systems, increasing in size, were used on the strain gages under test.

Factors to be considered for a lead wire selection are:

(a) Temperature coefficient and resistivity
(b) Stability at test temperature
(c) Lead length in the hot zone
(d) Wire diameter or ribbon cross sectional area.

Lead materials evaluated are: (a) Nichrome V*wire (b) Nichrome V ribbon (c) Constantan wire (d) Nickel clad copper wire (e) stainless clad copper wire. The results of these tests are covered under Analysis of Results.

B. Temperature Sensor Development

1. General

The maximum heat-up rates used at the AFFDL Sonic Fatigue Facility

* Trademark - Driver-Harris Company, Harrison, New Jersey

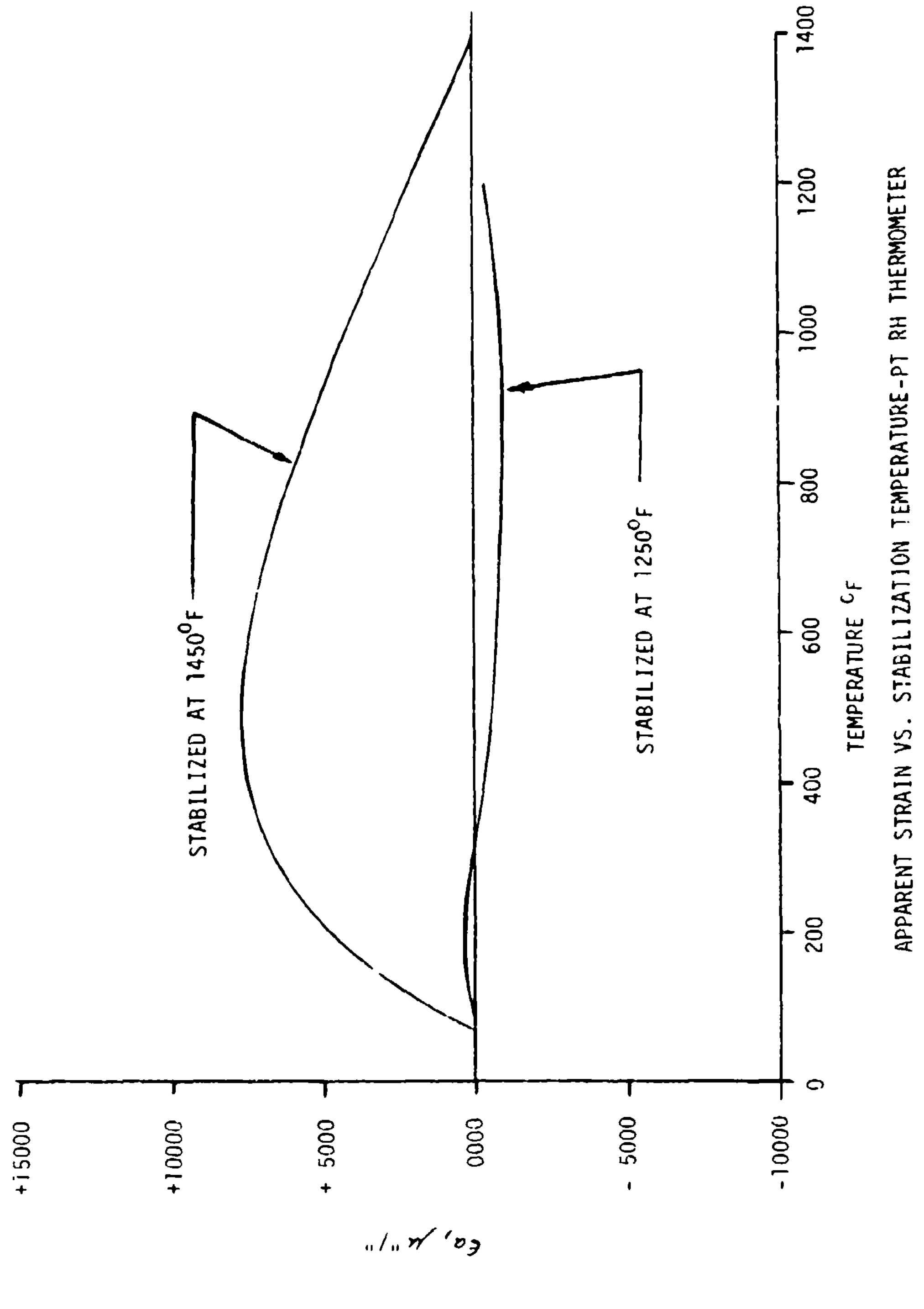
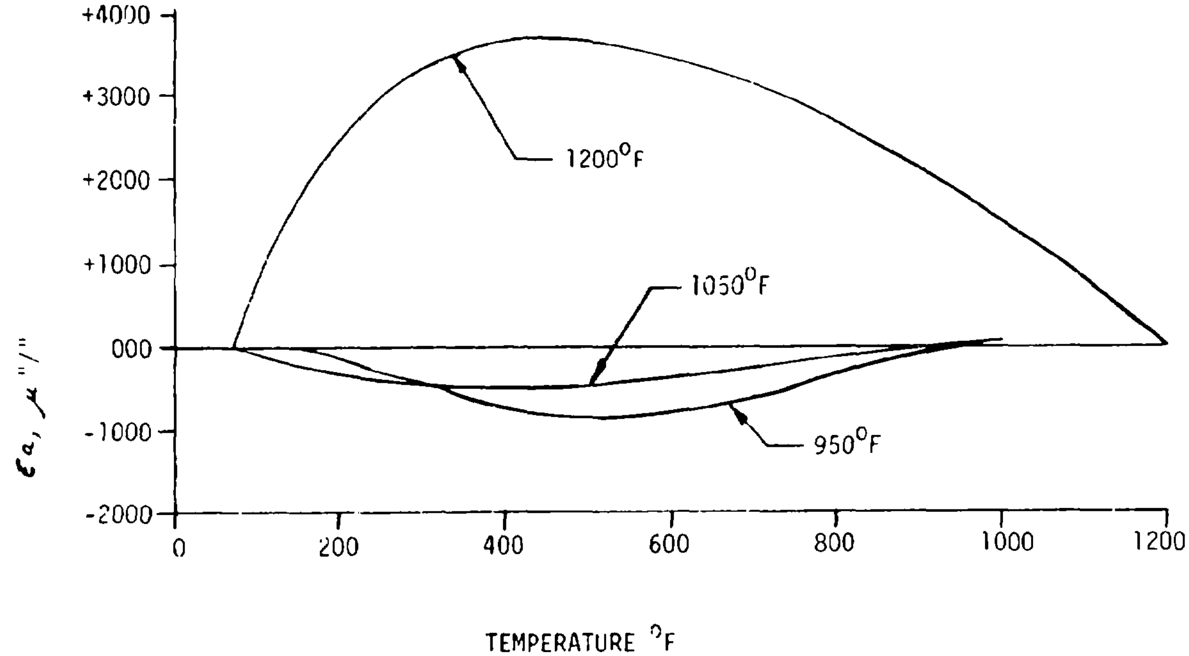

STABILIZED AT 1450°F
STABILIZED AT 1250°F
+15000
+10000
+5000
0000
-5000
-10000
0
200
400
600
800
1000
1200
1400
TEMPERATURE °F
APPARENT STRAIN VS. STABILIZATION TEMPERATURE-PT RH THERMOMETER

FIGURE 22



APPARENT STRAIN VS. STABILIZATION TEMPERATURE-PT RH RU THERMOMETER

FIGURE 23

are:	RT to 800°F	4 minutes
	RT to 1200°F	10 minutes
	RT to 1400°F	12 minutes

Laboratory evaluations indicated that a properly installed AWG #30 wire will respond accurately to the given heat rates. Therefore, AWG #30 or smaller chromel/alumel thermocouples will be employed.

Thermocouple junctions may be attached to the specimen by: (a) ceramic cement bonding (b) spot welding (c) metal flame spray bonding or (d) special bonding methods such as NASA FRC-Bond 668C. Flame spray bonding with nickel aluminide powder is a new technique which provides a self-adhering, conductive coating with excellent bond strength to the base metal skin. Spot welding is the easiest and most convenient method; however, in many cases, the spot welds can cause premature fatigue failure[5]. Thermocouple junctions bonded to Inconel X test specimens with flame spray nickel aluminide (with lead wires bonded with a thin insulating coating of flame sprayed aluminum oxide) were evaluated by repeatedly plunging into a preheated 1450°F furnace. The system was found to work well over the temperature range. The method also works well on thin skin materials. The installation of .001" diameter thermocouples to .005" thick stainless steel strip was accomplished by using the nickel aluminide flame spray technique.

NASA Type FRC-668C[6] cement was prepared according to instructions received from NASA Edwards AFB, and extensive evaluations of this technique were performed. Although the bond holds at temperatures up to 1000°F, a great deal of strength is lost between 800° and 1000°F. Sauereisen No. 8, Yellow Cerro, and Allen PBX cements were also evaluated. The Sauereisen No. 8 was difficult to use, requiring particle screening, and had low bond strength. The Yellow Cerro and Allen PBX were easy to use and worked well up to 1400°F. The Yellow Cerro was selected for a further testing because of its lower cure temperature (350°F) compared to 650°F for the Allen cement.

C. Test Phase - Strain Gages

1. Gage Factor and Apparent Strain Vs. Temperature Calibration Tests Prior to Acoustic Tests

a. Test Equipment

Test gages were mounted on 1" x 18" long Rene' 41 alloy test bars. The gages were located in the center of the oven hot zone. A CERL[7] capacitance strain gage was mounted on the bottom side of the beam exactly opposite the test gage. The capacitance gage was read out on an Automatic Systems Laboratories Model 1055.1 manual capacitance indicator. The test bar was mounted in a Budd VSP 150 fatigue testing machine. Load was applied using dead weights.

b. Test Procedure

The maximum strain limit of the test bar, with good zero return, was 1050 microinches and was the strain level employed during this test series. The capacitance gage was employed as a strain standard. The capacitance gages characteristically maintain virtually constant gage factor over the temperature range of RT to 1200°F. Because part of the test bar protruded out of the oven and a temperature gradient existed along the length of the bar, deflection at the end of the bar could not be used as a measure of strain because of the variation in Young's modulus along the length of the bar. The dead weight loading was used as one measure of strain; however, it was necessary to rely on published data for Young's modulus of the test bar. This method served as an independent check on the capacitance gage data.

Three load cycles were applied at each test temperature increment to record gage factor vs. temperature. Apparent strain was plotted between load points. Results for Platinum Rhodium and Platinum Rhodium Ruthenium compensated gages are shown in Figure 24 and 25. Note the excellent zero returns after loading for both alloys. A zero adjustment was not made during the entire duration of the test.

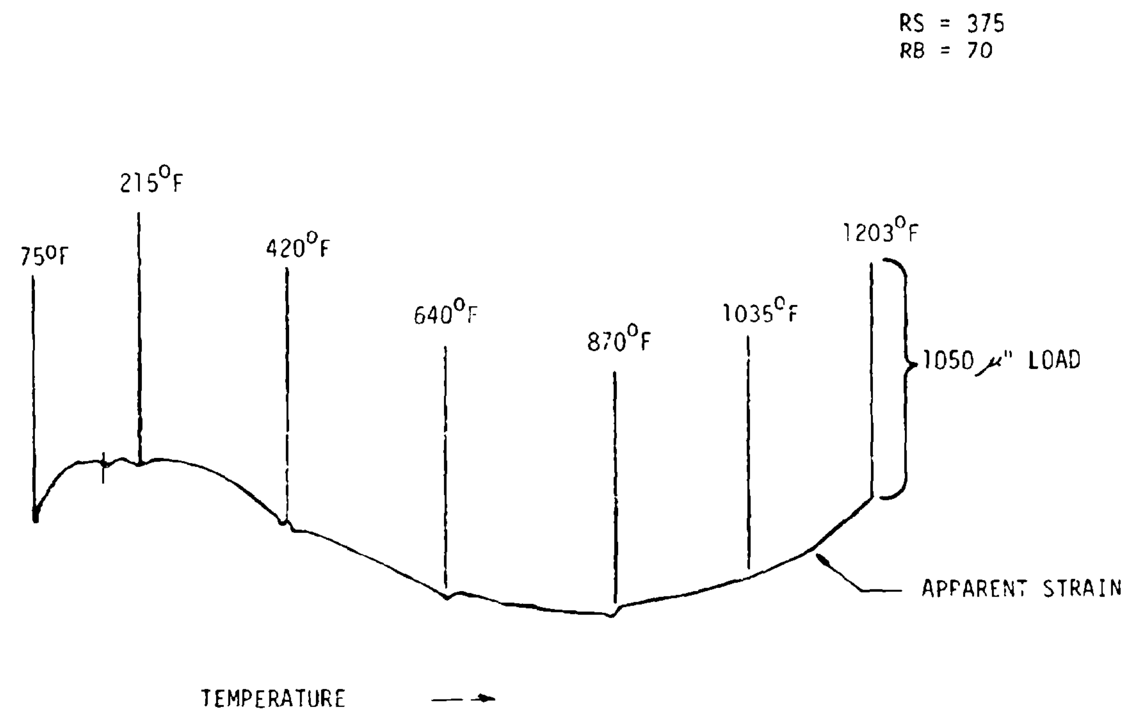
c. Vibratory Gages

Similar calibration can be performed for vibratory strain gages but can usually be eliminated since most strain gage manufacturers supply calibration data.

2. Acoustic and High Temperature Test

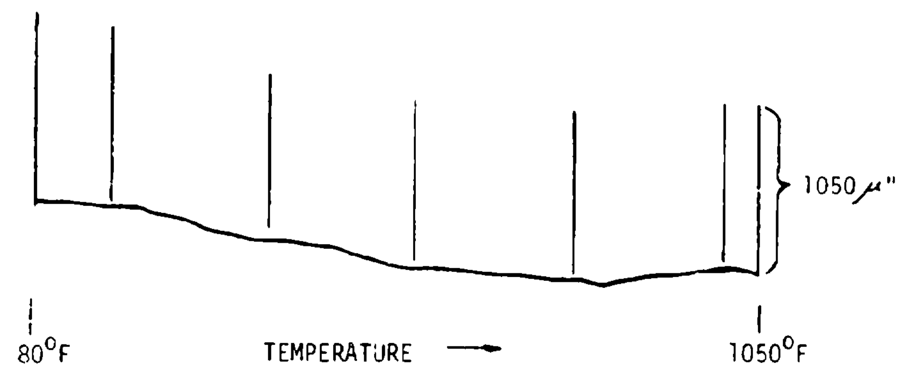
a. Facility Description

The Small Sonic Fatigue Facility at the Aero Acoustics Branch of the Air Force Flight Dynamics Lab, Wright-Patterson AFB, Ohio, was utilized for this test series. This facility will accommodate but is not limited to specimens approximately 14" x 20" in cross section and .020" to .030" thick. The air siren will produce a maximum sound pressure level of 174 decibels. Quartz tube heaters are used to produce



APPARENT STRAIN AND GAGE FACTOR VS. TEMPERATURE - PT RH ALLOY THERMOMETER

FIGURE 24



APPARENT STRAIN AND GAGE FACTOR VS. TEMPERATURE - PT RH RU THERMOMETER

FIGURE 25

temperatures up to $1400^{0}F$. Thermocouples surface mounted to the test panel are used for temperature control. Up to 12 temperature recording channels are available as part of the temperature and control instrumentation. Strain gages are conditioned on 48 channels of B&F Model 210A signal conditioning modules. These modules may be direct coupled for reading static data or capacitance coupled for dynamic measurements. The test panels are flange mounted over a 7.8" x 14" horizontal opening in the test chamber duct. Two microphones are located directly behind the test panel to measure sound levels. The panel is clamped in place utilizing a gasketed flange 1/8" thick, bolted to the test duct with six 1/2" bolts.

b. Test Panels

b.1 200^{0} to $500^{0}F$ Test Panel

This panel was a 14" x 20" austinetic stainless steel panel .020" thick. Test strain gages and thermocouples were bonded to the 7.8" x 14" test area exposed to acoustic noise. Vendor designations for the strain gages installed on this panel are given in Table III. Organic backed gages were installed using M-Bond 610 adhesive and cured according to the manufacturer's instructions. Lead wires were attached to each gage using $580^{0}F$ solder and routed over the panel surface to the edge of the clamped area where they were spliced to external lead wires. The leads were routed over a cured 1 mil thick GA-60 cement insulating precoat. The lead wires were taped in place at approximately 1/4" intervals and bonded to the structure with GA-60 cement. The panel was warmed using a heat lamp to enhance flow and insure a thin application of cement.

AFFDL Test Gages Table III

Panel	Gage #	Gage Type	Lead Adhesive	Lead Wire	Time to Failure (Minutes)	Analysis of Failure
302 Stainless Steel (500°F)	1	WK-06-125AD-350	GA-60	.005" Dia Copper, Polyimide insulation	No failure	Recorder Level to Low
	2	DLB-PT12-2A	GA-60	"	No failure	Gage Functional at End of Test
"	3	WD-DY-125AD-350	GA-60	"	No data	Solder Joint Open
	4	HFK-12-250-SCW	Ceramic Cement	.005" Dia NCC(Nickel Clad Copper)	No data	Ceramic failure at Clamp Point
"	5	HFP-12-125-SPW	"	.005" Dia NCC	No data	"
"	6	HFK-12-250-SCW	"	.005 Dia Nic V	No data	"
"	7	HFN-12-125-SCW	"	"	No data	"
"	8	WK-06-125AD-350	GA-60	.005 Dia Copper, polyimide insulation	No data	Solder joint at Splice area open, gage Functional
"	9	WK-06-125AD-350	GA-60	"	No failure	# Pre amp. gain to high-signal chopped
"	10	DLM-PT-35-4A	GA-60	"	No failure	Solder joint at Splice open, gage functional
"	11	WD-DY-125AD-350	GA-60	"	No failure	Gage functional at End of Test
"	12	WK-06-125AD-350	GA-60	.005" Dia NCC	No failure	Solder joint at Splice open, gage functional

TABLE III

Table III

Panel	Gage #	Gage Type	Lead Adhesive	Lead Wire	Time to Failure (Minutes)	Analysis of Failure
302 Stainless Steel (500^{o}F)	13	DLB-PT12-2A	GA-60	.005" Dia. NCC	No failure	Gage Functional at End of Test
	14	FSM-25-35-4A	GA-60	.005"Dia.NCC	No failure	"
	15	HFN-120125-SCW	Rokide	.005 x 1/32 Nic V	Immediate	Lead failure-Rokide failure-gage open
"	16	HFP-12-125-SPW	Rokide	.005 x 1/32 Pt-8W	"	"
"	17	HFN-12-125-SCW	Rokide	.005 x 1/32 Nic V	"	"
"	18	CLB-PT12-2A	GA-60	.005 Dia NCC	No failure	Gage Functional at End of Test
"	19	WK-06-125AD-350	GA-60	"	"	"
"	20	WK-06-125AD-350	GA-60	"	"	"
"	21	WD-DY-125AD-350	GA-60	"	No Data	Solder Joint at Gage Open
"	22	WD-DY-125AD-350	GA-60	"	No Data	"
	Thermocouple	C/A	Rokide	.003 Dia C/A Wire	No failure	Thermocouple functional at End of Test
	Thermocouple	C/A	Ceramic Cement	.003 Dia C/A Wire	3	Ceramic Failure at Clamp Joint
	"	C/A	GA-60	.003 "	8	Splice Joint at Clamp Open
	"	C/A	GA-60	.010 "	20	Splice Joint at Clamp Open

TABLE III

Panel	Gage #	Gage Type	Lead Adhesive	Lead Wire	Time of Failure (Minutes)	Analysis of Failure
(Inconel X) (1200°F)	1	HFP-12-125 SPW	Yellow Cerro Ceramic Cement	.003 Dia Pt.-8w	No Data	Gage Functional at End of Test
"	2	PtRhRu	"	.005x.031 Nic. V	No Data	Gage Functional at End of Test, leads shorted to ground at clamps after 2 minutes
"	3	Pt-W-PtRh	"	.005x.031 Nic. V	26	Thermometer open circuit
"	4	Pt-W-PtRh	"	"	26	Gage Functional at End of Test
"	5	HFN-12-125-SCW	"	.005 Dia Nic. V	22	One lead shorted to Ground, one lead Broken, Gage Open
"	6	Lead Wire	"	.005 Dia Constantan	27	
"	7	Lead Wire	"	.003 Pt 10 Rho.	33	
"	8	Pt-W-PtRh	"	.005x.031 Nic. V	Sig. Overloaded Recorder	Gage Functional at End of Test, Thermometer Element open, lead Broken at Shin Cap
"	9	Pt-W-PtRh	"	.005x.031 Nic. V	"	Gage Open, Thermom. open
"	10	PtRh Ru	"	.005x.031 Nic. V	No Failure	Gage Functional at End of Test
"	11	HFN-12-125-SCW	"	.005 Dia Nic. V	22	Gage Functional at End of Test

TABLE III (Cont'd)

TABLE III

Panel	Gage #	Gage Type	Lead Adhesive	Lead Wire	Time of Failure (Minutes)	Analysis of Failure
(1200°F)	Thermocouple	.003 Dia. C/A wire	Yellow Cerro Ceramic Cement	.003 Dia. C/A	29	Lead splice open at flange
	"	.002 x .012" C/A ribbon	"	.002 x .012 C/A ribbon	25	Lead splice open at flange
	"	.002 x .012 C/A ribbon	"	.002 x .012 C/A ribbon	25	Lead splice open at flange
	"	.003 Dia. C/A wire	"	.003 Dia. C/A wire	No Failure	----
	"	.002 x .012" C/A ribbon	"	.002 x .012 C/A ribbon	22	Lead splice open at flange
	"	.003 Dia C/A wire	"	.003 Dia. C/A wire	No Failure	----

TABLE III (Cont'd)

Table III

Panel	Gage#	Gage Type	Lead Adhesive	Lead Wire	Time to Failure (Minutes)	Analysis of Failure
Rene'41 1400^{o}F	1	HFP-12-125-SPW	Rokide	.005 PT.8W	41	Lead Splice with joint failed at Clamp, Gage Functional
	2	HFN-12-125-SCW	Rokide	.005 Nic. V	No Data	"
	3	HFK-12-250-SCW	"	1/64 x .003 Nic. V	No Failure	Gage Functional at End of Test
	4	HFP-12-125-SPW	"	.005 Pt. 8W	"	"
	5	HFK-12-250-SCW	"	1/64 x .003 Nic. V	No Data	Zero shift overloaded recorder, Gage open at End of Test
	6	HFN-12-125-SCW	"	.005 Nic. V	No Data	Channel may not have been D.C. coupled, Gage Functional at End
	7	HFN-12-125-SCW	"	.005 Nic. V	"	D.C. Shift overloaded recorder, lead weld at clamp broken, gage Functional at End of Test
	8	HFK-12-250-SCW	"	1/64 x .003 Nic.V	"	"
	9	HFP-12-125-SPW	"	.005 Pt. 8W	54	Lead weld at clamp Open, gage functional at End of Test
						Summary: At End of Test 8 Gages Functional 1 Gage Open

TABLE III (Cont'd)

TABLE III

Panel	Gage #	Gage Type	Lead Adhesive	Lead Wire	Time of Failure (Minutes)	Analysis of Failure
1400^0F	Thermocouple	.003" Dia. C/A wire	Nickel Aluminide over junction, Rokide over leads	.003 Dia. C/A	No Failure	----
	"	.002 x .012 C/A ribbon	Rokide	.002 X .012 C/A	1	Lead splice open at flange
	"	.002 x .012 C/A ribbon	Rokide	.002 x .012 C/A	26	Lead splice open at flange

TABLE III (Cont'd)

TABLE III

Panel	Gage #	Gage Type	Lead Adhesive	Lead Wire	Time of Failure (Minutes)	Analysis of Failure
Thermo-couple 302 Stainless Steel	Thermocouple	.003 Dia C/A wire	GA-60	.003 Dia C/A	No Failure	----
	"	.003 Dia C/A wire	GA-60	.003 Dia C/A	No Failure	----
	"	.010 Dia C/A wire	FRC-688	.010 Dia C/A	No Failure	----
	"	.010 Dia C/A wire	FRC-688	.010 Dia C/A	No Failure	----
	"	.003 Dia C/A wire	Yellow Cerro	.003 Dia C/A	No Failure	----
	"	.003 Dia C/A wire	" "	.003 Dia C/A	No Failure	----
	"	.003 Dia C/A wire	Nickel Aluminide over jct., Rokide over leads	.003 Dia C/A	No Failure	----
	"	.003 Dia C/A wire	" "	.003 Dia C/A	No Failure	----

TABLE III (Cont'd)

A number of different lead systems was evaluated. Specifically, bare nickel clad copper wire, constantan alloy wire, and polyimide insulated copper wire were evaluated. Gage lead wires were spliced to external leads which were sleeved with a glass fiber sleeving. A sheet of 1 mil thick mica tape was placed under the spliced junction to prevent shorting. The spliced junction was covered with a 3 mil thick Nichrome V alloy shim stock spot welded to the specimen. The lead wires were routed off of the test duct to a terminal strip which was wired into the B&F Model 210A signal conditioning equipment.

The 500°F gage installations were covered with an aluminum filled silicone coating to provide a coating with a reflectivity similar to the bare test panel. Previous tests on GA-60 cement installations heated by quartz tubes indicated that the dark color of the cement absorbed heat and caused the gage temperature to rise well above that of the test panel. The aluminum filled silicone reflective shield provided a measurable reduction in the gage temperature.

Unbacked flame sprayed gages were also installed on this panel in order to run a life comparison between unbacked and organic backed gages. The gages were installed with Yellow Cerro ceramic cement. These gages had lead splicing and wiring similar to the organic backed gages previously described.

b.2 <u>1200°F Test Panel</u>

The 1200°F panel is made from Inconel X alloy 14" x 20" x .023" thick. This panel was instrumented with four resistance thermometer compensated static strain gages which were stabilized at 1250°F and calibrated for use over the room temperature to 1200°F range. These resistance thermometer compensated gages consisted of a 120 ohm Platinum 8% Tungsten alloy active gage compensated with a Platinum 10% Rhodium compensating element. Since the test temperature for these gages is above the stable operating temperature of the Platinum Rhodium Ruthenium thermometer element, it was not feasible to test both of these alloy types on the same panel. But since it was desirable to evaluate the Platinum Rhodium Ruthenium alloy in an acoustic fatigue environment, three of these elements were installed on this test panel and monitored dynamically over the test period. Vibratory strain gages were also installed. These consisted of Nichrome V and Platinum 8% Tungsten alloy gages.

Single wires consisting of 5 mil diameter constantan and 3 mil diameter Platinum 10% Rhodium alloy were also bonded to the test panel to evaluate their fatigue characteristics in a high temperature acoustic environment.

Leads on the Platinum Rhodium Ruthenium alloy gages and the Platinum Tungsten Platinum Rhodium compensated gages were .005" x .031" Nichrome V alloy. These relatively heavy leads were used to minimize lead resistance in the hot zone. Their inclusion also served to provide test data on the maximum size lead wires that can be bonded on the panel and survive the test conditions.

The four static strain gages were wired into custom signal conditioning equipment built for these gages. The power supplies were set at 10 volts and the output from the signal conditioners (approximately 10 millivolts per 1000 microinch of calibration) was introduced into an Intech amplifier. The output of the amplifier was recorded on tape.

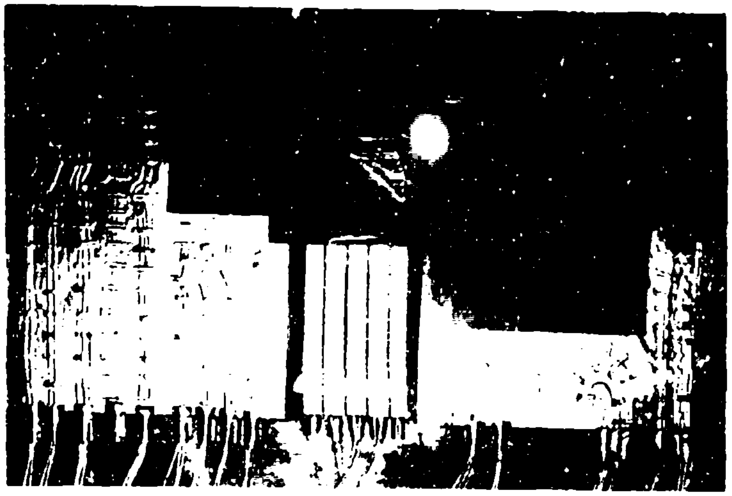
The four static strain gages were stabilized for 20 hours at 1250^{0}F and were precalibrated to provide an apparent strain equal to ±500 microstrain over the entire temperature range (room temperature to 1200^{0}F) on test panel (see Figure 20). The correct values for R_b and R_s were then recorded for each signal conditioning channel, and these settings were re-established during setup at the AFFDL facility.

b.3 <u>1400^{0}F Test Panel</u>

The 1400^{0}F test panel consisted of a 14" x 20" Rene' 41 alloy sheet .025" thick. All gages and thermocouples on this panel were installed using the Rokide* flame spray technique. Since it was discovered during the analytical phase of this program that static strain gage alloys could not be operated above 1250^0 with an acceptable linearity, it was decided that only vibratory gages would be evaluated at the 1400^{0}F maximum temperature.

Vibratory strain gages of Platinum 8% Tungsten alloy and Nichrome V alloy were installed for this test series. Several self-temperature compensated Karma type alloy gages were also installed on this test for operation to 800^{0}F. It was decided to evaluate these gages at 800^{0}F briefly prior to embarking on the 1400^{0}F run. The lead hookup to external wires was similar to that used for previous panels except that external leads were welded to the test gage leads at the edge of the clamp area. Because of shorting problems existing in the initial panel, fiberglass reinforced electrical tape was placed under the glass fiber sleeved lead out wires. Tape was also placed between the test wires in order to build up this area and reduce the clamp pressure on the lead wires. Photographs of all three panels are shown in Figures 26A, 26B, and 26C.

* Trademark - Norton Company, Worcester, MA.



500°F PANEL

FIGURE 26A

1200°F PANEL

FIGURE 26B

1400°F PANEL

FIGURE 26C

c. Test Description

The sound generator was activated and the quartz tube heaters were energized to bring the specimen to the desired test temperature. The test temperatures achieved are shown in Figures 27, 28, and 29. The detail of events, such as the frequency sweeps, time of day, and sound levels are shown in Table IV. The 1200°F panel was brought directly up to 1200°F and held at this temperature for the duration of the test. The 1400°F panel was first brought up to 800°F , held for a brief period and returned to room temperature. This was done to provide for an initial 800°F temperature calibration. Subsequently, the temperature was quickly brought up to 800°F. This temperature was held for a short period of time and then increased to 1400°F and held until termination of test.

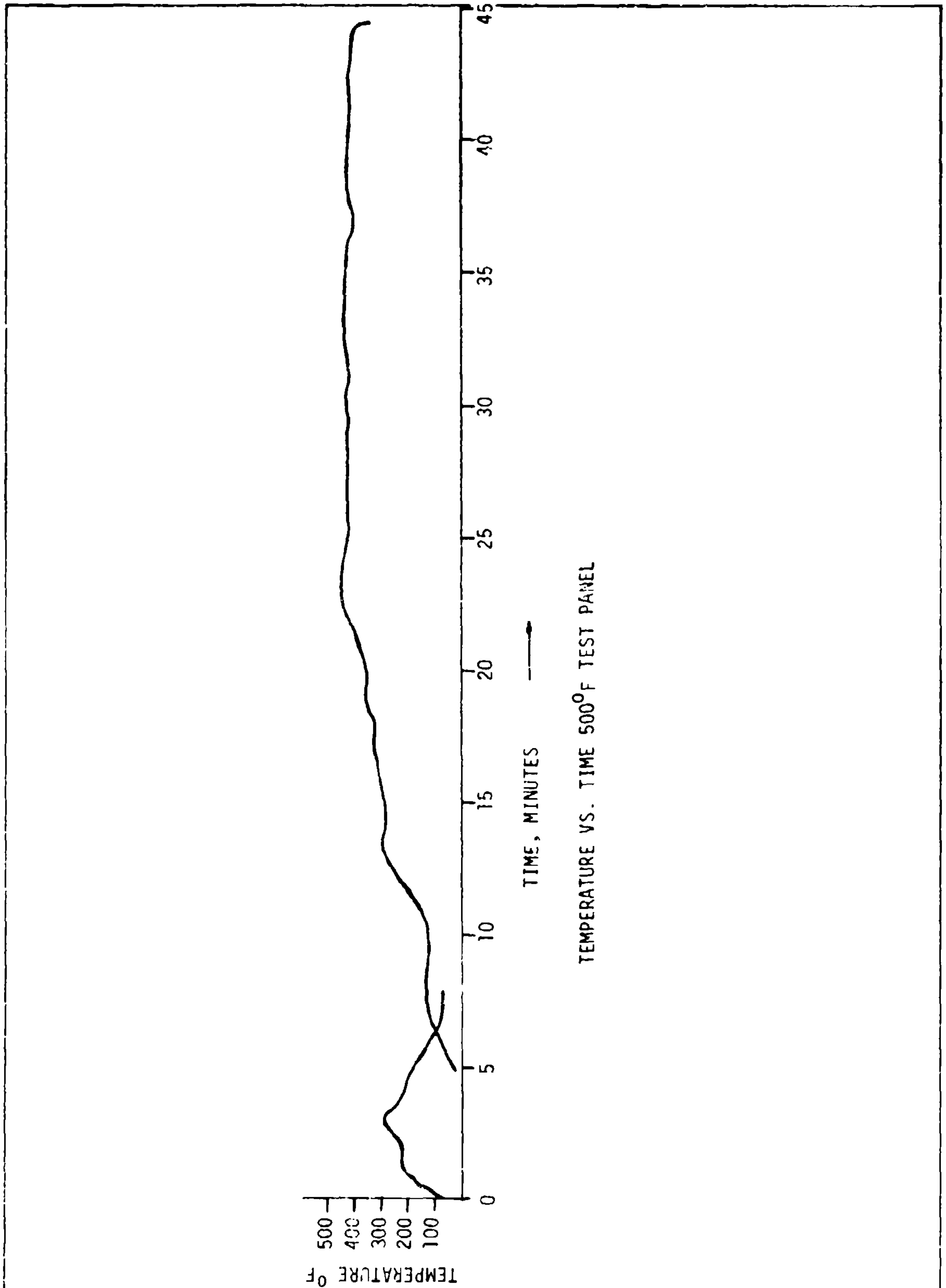
d. Results

d.1 Platinum-Tungsten, Platinum Rhodium Ruthenium Compensated Gages (Max Temp 1050°F)

The apparent strain and load data for this alloy is shown in Figure 25. The load was applied using dead weights which provided a strain of 1050 microinches at the gage location. This curve shows that excellent apparent strain compensation is achieved with this alloy and that the strain gages are also closely compensated for modulus.

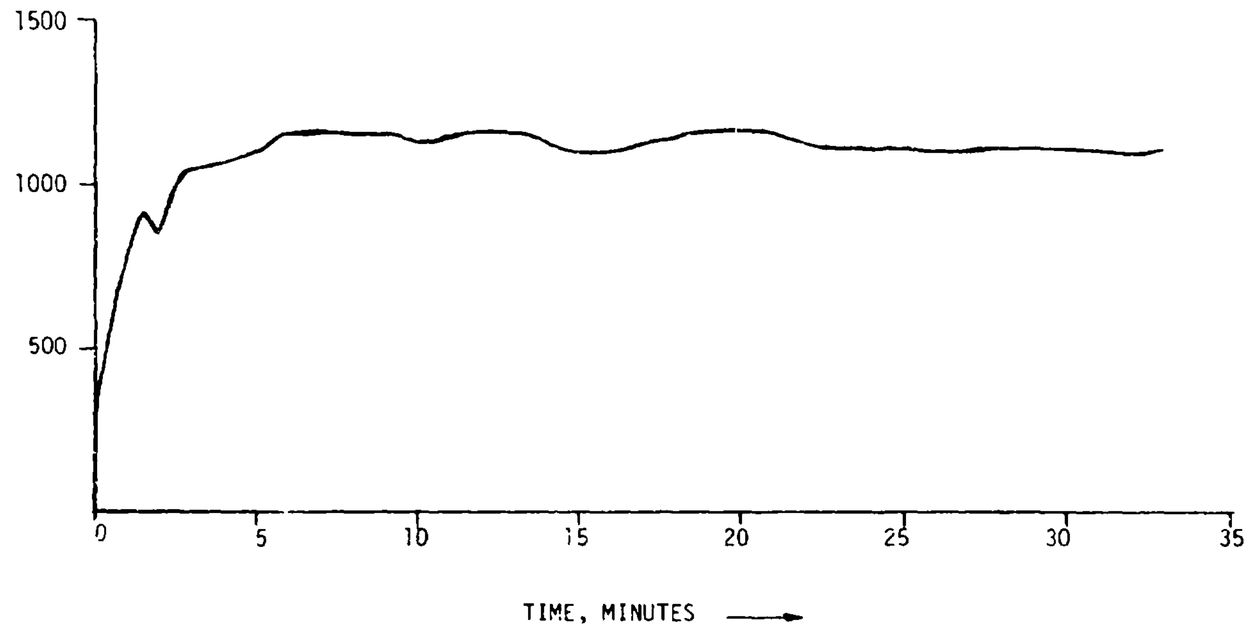
d.2 Platinum Tungsten Platinum Rhodium Alloy Compensated Gages

The apparent strain and load data from room temperature to 1200°F for this alloy are recorded on an X-Y plotter and shown in Figure 24. The applied strain was 1050 microinches. As the apparent strain curve indicates, this alloy combination provides excellent compensation over the temperature range, but is not as linear as the Platinum Tungsten Platinum



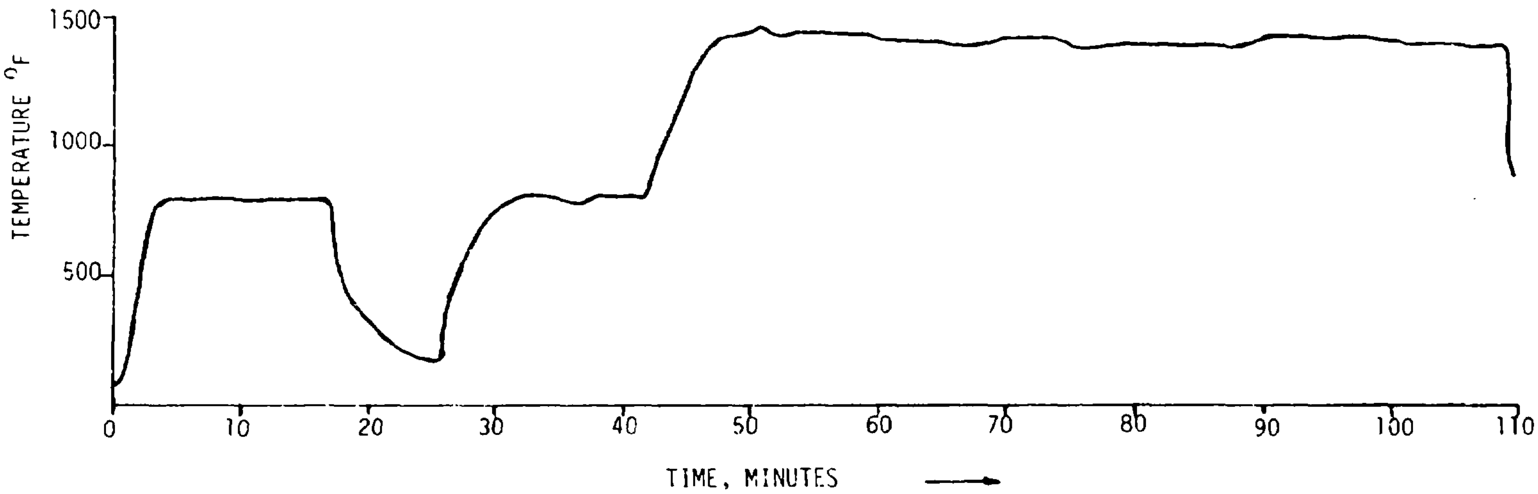
TEMPERATURE VS. TIME 500°F TEST PANEL

FIGURE 27



TEMPERATURE VS. TIME - 1200°F TEST PANEL

FIGURE 28



TEMPERATURE VS. TIME - 1400°F TEST PANEL

FIGURE 29

Table IV Log of Events

AFFDL Acoustic & Temperature Test

I. 500°F Panel

Time of Day	Event
14 03 52	Start of fatigue test
14 09 20	Shut down, panel loose in frame, installed new gasket, repaired thermocouples
15 21	New start
15 25	Panel at 200°F
15 34	Panel at 400°F
15 39	Panel at 500°F
16 00	End of Test

II. 1200°F Panel

10 26	Frequency Sweep, 70 to 500 Hz, 120 dB SPL
10 41	Frequency Sweep, 70 to 130 Hz, 130 dB SPL
13 46	Start of fatigue test, sound & heat applied to panel, siren modulated 60-150 Hz
13 53	Panel at 1200°F
13 57	Increased center frequency
14 03	Increased center frequency again, modulated 125-225 Hz
14 20	End of Test

III. 1400°F Panel

13 22	Start of fatigue test
13 26 50	Recording started
13 29	Panel at 800°F
13 33 50	Recording stopped
13 39	Started cooling
13 43 30	Recording started
13 48	Started heating
13 54	Panel at 800°F
14 04	Started to raise temperature
14 11 20	Panel at 1400°F
15 11 20	End of Test

Rhodium Ruthenium alloy gage. The output data also indicates that the gage is modulus compensated on the Rene' 41 test bar over the entire temperature range. The load and unload points show excellent repeatability for each load cycle.

d.3 AFFDL Test Results

The gage types, the lead wires and lead wire adhesives used are tabulated in Table III. The time to failure and analysis of failure is also tabulated. The test temperatures recorded are plotted in Figures 27-29, and the sequence of events is shown in Table IV. Similar data for the 1200°F and the 1400°F panel are shown in Tables III and IV. The test temperature profiles are shown in Figures 27, 28, and 29.

D. Test Phase - Temperature Sensors

1. Test Equipment

An Air Force supplied stainless steel test panel was instrumented with thermocouples to evaluate bonding techniques and to evaluate their durability in a combined high temperature and acoustic environment.

2. Bonding Methods

Temperature Range	Method (See Appendix C for detailed instructions)
300°F to 500°F	Prepare surface using 120 grit light sandblasting. Precoat 1 mil thick GA-60 cement, oven cure. Tape .003" diameter chromel alumel thermocouples in place and bond with GA-60. Cure one hour at 350°F.

Temperature Range	Method
$500^{o}F$ to $800^{o}F$	NASA Edwards Method. Spot weld #30 chromel alumel thermocouples to 4 mil, 1/4" square stainless steel shim. Bond to specimen using FRC-663 adhesive. Cure with hot iron. Strap lead wires using stainless steel shim and same adhesive. Cover installation with aluminum filled silicone moisture-proofing material.
$800^{o}F$ to $1400^{o}F$	Ceramic Cement Method. Application method identical to GA-60 procedure above except Yellow Cerro cement is used.
	Flame Spray Method. Apply 1 to 3 mil precoat of Nickel Aluminide over light sandblasting surface. Apply 2 mil pre-coat of Aluminum Oxide in lead area. Tape thermocouples in place. Bond junction using Nickel Aluminide. Bond lead wires using high purity Aluminum Oxide.

3. Test Description

The above installations were evaluated at the AFFDL Sonic Fatigue Facility. At 150 DB sound pressure, the test panel was held for 1/2 hour at $500^{o}F$, for 1/2 hour at $800^{o}F$, and for 1/2 hour at $1450^{o}F$.

4. Test Results

The thermocouple types, lead wires, and bonding adhesives are tabulated in Table III.

E. Analysis of Results

1. Gage Factor and Apparent Strain Vs. Temperature Test

The apparent strain and gage factor tests on both resistance thermometer compensated gage types show that both gage systems can be used for short-term testing (for up to 1 hour) up to their respective maximum temperature. The linearity of the Platinum Rhodium Ruthenium compensated gage is superior to that of the Platinum Rhodium compensated gage and should be selected when the maximum test temperature does not exceed 1050°F. The Platinum Rhodium compensated gage, however, has acceptable linearity over the temperature range and should be selected if the test temperature falls between 1050 and 1200°F. The zero return of these alloys is dependent on the time at test temperature. Although the gage resistance at constant temperature changes very little, the slope of the apparent strain curve changes. A zero return deviation of as much as 1000 microinches can take place after an excursion to maximum temperature for approximately 1 hour.

The curves in Figures 24 and 25 also indicate that the gages are very closely modulus compensated and that for most tests, room temperature gage factor can be used over the entire temperature range. This eliminates the need for correcting for the loss in gage factor or in Young's modulus when reducing the strain data.

2. Acoustic Fatigue Test Data

a. 200 to 500°F Test Panel

The time to failure and a brief analysis of each failure is tabulated for each gage type tested in Table III.

The flame spray and ceramic cement installed gages failed early in the test. Post-test examination indicated that the ceramic cement failures occurred close to the clamping point. Due to panel yielding, the brittle ceramic cement did not withstand the imposed strain. Ceramic cements are limited to 4000 to 5000 microinch strains and, for most high strength materials, they will not perform satisfactorily in the yield region. Severe yielding and buckling of the test panel was evident. The flame spray installed gages, although generally capable of withstanding tensile strains up to 1.5%,also failed. These failures were partially attributed to the large size lead wires used (5 mil x 1/32" ribbons). These ribbons were installed adjacent to .003" wires, which did not fail. Similarly during the 1400^{O}F test, flame spray installed 3 mil diameter thermocouples did not fail. This indicates that flame spray installations with small diameter wires will withstand the combined temperature and acoustic environment.

A post-test analysis of the organic bonded gages indicated that all of the failures occurred either due to lead problems or instrumentation wiring, and that all of the test gages were functional. Therefore, every type of organic backed gage and lead wire tested is adequate for acoustic and high temperature testing under the conditions evaluated.

b. 1200^{O}F Test Panel

The results for the 1200^{O}F test panel are tabulated in Table III. The problems associated with lead splicing and shorting of the leads under the flange caused failures during this test. The post-test examination indicated that all but two gages survived the combined 1200^{O}F and acoustic exposure. The test, however, was terminated after 33 minutes of operation because of lead wire failures at the clamp joint area. These failures were caused primarily by the brittleness of the ceramic cement and the inability of the lead wires to withstand high strains in the yield region. Buckling of the panel did occur. The static loading due to temperature caused the panel to buckle outwardly, providing a high compressive stress on the gage leads at the edge of the flange clamp area. This put the ceramic cement in compression (which is more severe on ceramic cement than strains in tension). This high compressive strain contributed to failure of the leads in this area. The gages and lead wires located near the center of the panel (where thermal stresses were somewhat lower) survived the test environment.

Static data was not recorded because the severity of the induced thermal strains was much greater than anticipated. The static strain output exceeded the range of the recording equipment. Strains anticipated were not to exceed ±2000μ"; the actual static strains were above ±5000μ".

c. 1400°F Test Panel

The time to failure and analysis of the 1400°F test are shown in Table III. Again, the lead splice area under the clamp was the principle cause of failures for this test series. Post-test examination indicated 8 gages were functional at the end of the test while one gage was open. The results of the 1400°F thermocouple test panel and the survival of the 3 mil flame spray bonded thermocouples in the 500°F test indicated that the flame spray system is suitable for mounting vibratory gages and fine diameter thermocouples for testing over the entire temperature range. However, splices to external lead wire must be made in low stress areas.

A review of Table III indicates that most of the gages survived the duration of the test and that the difficulty in measuring strain throughout the test resulted from lead wire failures at the splice area. It is evident that a panel heated in the center and rigidly clamped in place at the edges, has the maximum stresses at the flange joint. It became evident from the test that severe working or movement of the specimen occurred under the clamping flange. This working, in many cases, sheared the protective Nichrome shim over the splice joint and in some cases, the lead wires in the gasketed area became abraded and shorted to the test specimen. Fiberglass reinforced electrical tape was placed under the lead wires in this area to prevent shorting on subsequent tests; however, the working of the specimen under the flange resulted in shorting or breaking of the splice joint again.

This problem was overcome on the thermocouple test panel by extending the bond coating to within 1 inch of the test panel outer edge. This flame sprayed ceramic adequately protected the lead wires from abrasion in the flange area.

d. Thermocouple Test Panel

All instrumentation remained intact and performed correctly within its design temperature range. The bonding methods described are considered adequate for their respective temperatures.

V. RECOMMENDATIONS

A. It is recommended that the splice from the bonded lead wires on the panel to external wiring be made in a stress free area such as at the periphery of the specimen to eliminate abrasion due to working between the panel and the clamp. The lead wire system used on the thermocouple test panel was 100 percent successful and should be employed on future tests employing similar type panels.

B. It was found that the 5 mil x 1/32" Nichrome ribbon leads installed by Rokide or ceramic cement were too heavy for testing in an acoustic environment.

C. Ceramic cements are brittle, have a low strain theshold, and should not be used on applications where the strains may approach the yield point of the materials or 4000μ". Ceramic cements are suitable for bonding static strain gages over the design strain and temperature range specified for this program (±2000 microstrain).

D. Signal Conditioning - The signal conditioning for high temperature tests should provide for a large balance range in order to accommodate large lead wire resistances normally associated with high temperature strain gages. The narrow balance range of the instrumentation employed is typical of that employed for standard resistance strain gages and is not suitable for high temperature measurements. Since the basic instrumentation concept for the resistance thermometer compensated strain gage provides for a wide balance range, it could be utilized as the basis for signal conditioning of high temperature strain gages.

E. Temperature Measurement Capability - The data acquisition system should include temperature recording capability so that strain and temperature can be recorded on tape simultaneously.

F. Strain Gage Application Procedures

1. 200 to 500^{0}F Tests

The strain gages, both static and dynamic chosen for this test series are suitable, and commercially available, for the temperature and vibration environment imposed upon them by the AFFDL Sonic Fatigue Facility. The GA-60 cement used for lead bonding proved highly successful and withstood the test environment. The coating of the entire installation with an aluminum filled silicone provided sufficient reflectivity and a temperature at the gage area equivalent to that of the specimen surface. This procedure is recommended for tests employing quartz tube heaters.

2. 1200^{0}F and 1400^{0}F Tests

The ceramic cement application procedure on the 1200^{0}F and 1400^{0}F type tests should be limited to strains in the region of $\pm$2000 microstrain. Lead work extending from the gages should be bonded using Rokide flame sprayed ceramic. Flame spray installed vibratory strain gages and small diameter temperature sensors were extremely successful over the entire temperature range from room temperature to 1400^{0}F and should be used for dynamic tests and when strains may exceed the yield point of the material.

REFERENCES

1. Easterling, K.E.; High Temperature Resistance Strain Gages; British Journal of Applied Physics, 41, 79, 1973.

2. Bertodo, R.; Platinum Metal Alloys for Measurement of Strains at High Temperature; Institute of Physics and the Physical Society, Cambridge, England, March, 1968.

3. Adams, P.H.; Strain Measurements on Carbon-Carbon Cylinders; ISA Paper 71-620, 1971.

4. Kershisnik, D.P.; High Temperature Strain Gage Techniques on Graphite; Spring Meeting, Society for Experimental Stress Analysis; Los Angeles, California, May 1973.

5. Imig, L.A.; Effect of Strain Gage Attachment by Spot Welding and Bonding on Fatigue Behavior of Ti-6Al-4V, Rene' 41, and Inconel X; NASA TN D-5973, October, 1970.

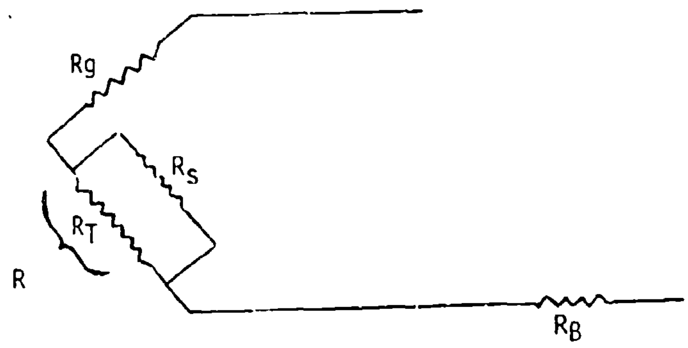
6. Wilson, E.J.; Strain Gage and Thermocouple Installation on a Research Airplane, Proceedings; Western Regional Strain Gage Committee, September, 1971.

7. Noltingk, B.E., et al; High-Stability Capacitance Strain Gage for Use at Extreme Temperatures; Proc. IEE, Volume 119, No. 7, July 1972.

8. Wnuk, S.P.; Progress in High Temperature and Radiation Resistant Strain Gage Development; Experimental Mechanics, March, 1965.

APPENDIX A

DERIVATION OF SHUNT RESISTOR EQUATION



In order to compensate, ΔR must equal ΔRg

(1) $\Delta Rg = Rg_{800} - Rg_{80}$

(2) $\Delta R = R_{800} - R_{80} = \Delta Rg$

From theory of parallel resistors,

(3) $R_{800} = \dfrac{R_{T_8} R_s}{R_{T_8} + R_s}$ R_{T_8} = Resistance Thermometer at Elevated Temperature

(4) $R_{80} = \dfrac{R_T R_s}{R_T + R_s}$ R_T = Resistance Thermometer at Room Temperature

(5) $\Delta R = \Delta Rg = R_{800} - R_{80}$

(6) $$\Delta R_g = \frac{R_{T_8} R_s}{R_{T_8} + R_s} - \frac{R_T R_s}{R_T + R_s}$$

Multiply $\left(R_{T_8} + R_s\right)\left(R_T + R_s\right)$

$$R_{T_8} R_s\left(R_T + R_s\right) - R_T R_s\left(R_{T_8} + R_s\right) = \Delta R_g\left(R_{T_8} + R_s\right)\left(R_T + R_s\right)$$

$$\cancel{R_T R_{T_8} R_s} + R_{T_8} R_s^2 - \cancel{R_T R_{T_8} R_s} - R_T R_s^2 = \Delta R_g\left(R_s^2 + R_s R_{T_8} + R_T R_s + R_{T_8} R_T\right)$$

$$R_s^2\left(R_{T_8} - R_T - \Delta R_g\right) = \Delta R_g R_s\left(R_{T_8} + R_T\right) + \Delta R_g R_{T_8} R_T$$

(7) $$R_s^2\left(R_{T_8} - R_T - \Delta R_g\right) - R_s\left(R_{T_8} + R_T\right)\Delta R_g - R_{T_8} R_T \Delta R_g = 0$$

$\Delta R_g = R_{g_{800}} - R_{g_{80}} = 135.2 - 121.2 = 14.0$

$R_{T_8} = 54.86$

$R_T = 34.46$

(8) $-6.4 R_s^2 - 1250 R_s - 26460 = 0$

$a = 6.4$
$b = -1250$
$c = -26,460$

General Solution of Quadratic Equation

(9) $$R = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$R_g = \frac{+1250 \pm \sqrt{(-1250)^2 + 4 \times 6.4 \times 26,460}}{2 \times 6.4}$$

$R_s = 214.5$

APPENDIX B

INSTALLATION INSTRUCTIONS - STRAIN GAGES

A. Ceramic Cement

Cement Preparation: Using a steel spatula or glass stir rod, mix powder and liquid thoroughly.

Surface Preparation:

(1) Remove grease and oil by vapor degrease or solvent cleaning with MEK or Trichloroethylene.

(2) Gage area must be free of pits, tool marks, and deep scratches. Grit blast the area with 120 grit Al_2O_3.

(3) Clean an area larger than the gage with a chemically clean solvent such as MEK.

Precoat:

(1) Using a 1/4" No. 62 artist's brush, apply a .001" coating of the cement to the gage area and any uninsulated lead area.

(2) Air dry for 15 minutes at room temperature, then raise to $350^{o}F$ for 1 hour.

Gage Installation:

(1) Remove free filament gage from protective backing, (not carrier!) and position on precoat. Press with Teflon film under finger. Do not rub.

(2) Place a piece of tape, Kapton or Scotch, about halfway down the leads for support.

(3) Using an 00 artist's brush, apply cement to exposed grid end loops and as much of the leads as desired. Air dry at room temperature for 15 minutes.

(4) With heat lamp, oven, or heat gun, cure for 10-15 minutes at 150-175°F. While still warm, peel tape carrier, with tweezers, at a 45° angle to grid strands.

(5) After cooling to room temperature, apply thin coat of cement to the entire gage and desired lead wires.

(6) Cure at 150-175°F for 10-15 minutes, cool to room temperature and repeat steps 5 and 6 until grid is well covered. Total thickness should not exceed .008".

(7) Remove tape on leads and Final Cure 1 hour at 350°F. Although this cure is adequate to transmit strain, a cure at max temperature is advisable for best stability.

B. <u>Flame Spray Instructions</u>

Surface Preparation:

(1) Remove grease and heavy oils by vapor degreasing or washing with a suitable solvent like Toluol, Acetone, or Trichlorethylene.

(2) The area to be gaged must be uniform, free of pits, deep tool marks or scratches.

(3) Sand blast the gage area at a 45° angle with a very clean No. 30 to 46 aluminum oxide grit.

NOTES: (1) Use pressure blast generator with 20 to 40 psi line.

(2) Fine grit sand cannot be used because poor adhesion will result.

(3) Precoats should be applied as soon as possible after surface preparation to avoid oxidation or further specimen contamination.

Specimen Precoat:

(1) Mask off area to be precoated using glass fiber reinforced Teflon pressure sensitive tape.

(2) Place specimen in exhaust hood.

(3) Apply a .002 to .004 inch thick Rokide coating by moving the gun in either a vertical or horizontal direction across the specimen surface. Hold the gun approximately 6-8 inches from the specimen surface.

Gage Preparation:

(1) Remove the free filament gage or thermocouple from its protective shipping and storage holder.

(2) Lay the gage face down on a clean surface with the white protective paper up.

(3) Keeping the gage flat, remove the white protective paper, using tweezers, by peeling it back on itself at 90^0 angles to the gage grid.

Gage Installation:

(1) Locate the gage on the specimen surface with the grid wires in contact with the precoat.

(2) Cover the tape carrier with a thin clear plastic and press gently to insure intimate contact between the gage and precoated surface.

(3) Place a piece of pressure sensitive Teflon tape over the lower exposed lead ribbons. Only the narrow shank portion of the lead should be exposed.

(4) Flame spray sufficient Rokide to tack the grid end loops and lead ribbons to the specimen surface. Hold the gun approximately 8 inches from the surface and move in the direction of the gage grid.

(5) Remove the tape grid carrier. Grasp the carrier with tweezers at the lower corner and peel back on itself at a 45^{0} to the gage grid

(6) Flame spray installation until all exposed grid and lead areas are covered. Hold the gun approximately 8 inches from the specimen surface and move in the direction of the gage grid.

(7) Remove Teflon tape over lead ribbons.

APPENDIX C

INSTALLATION INSTRUCTIONS - THERMOCOUPLES

GA-60 Application

(1) Clean surface as per Appendix B.

(2) Mask bond area and lightly grit blast with #120 AL_2O_3.

(3) Clean blasted area with gauze pads and mask as per S.O.P.

(4) Precoat bond area with GA-60 using 1/4" artist's brush. Specimen and adhesive should be heated to 125^{O}F for good results. Leave uncoated spot for T.C. junction.

(5) Cure precoated specimen 1 hour at 400^{O}F.

(6) Follow Yellow Cerro procedure with the exception of using cure times of 1 hour at 400^{O}F.

Yellow Cerro Application

(1) Prepare and clean surface per Appendix B.

(2) Mask bond area and lightly grit blast with #120 grit AL_2O_3.

(3) Precoat blast area as per described in Appendix B. Do not precoat T.C. junction area.

(4) Cure precoat as described in Appendix B.

(5) Prepare .003 T.C. chromel/alumel wire by spot welding two ends to form junction.

(6) Tape junction in place on unprecoated area provided with a piece of 1132 tape, 1/8" x 1/2".

(7) Place similar pieces of tape every 1/2" along entire bond area.

(8) Fill in between tape bars with Yellow Cerro using standard techniques described in Appendix B.

(9) Cure and finish application using techniques described in Appendix B.

<u>FRC-Bond 668-C</u>

(1) Clean specimen per Appendix B.

(2) Grit blast bond area with 120 AL_2O_3.

(3) Precoat bond area except for T.C. junction area with S.L. aluminum and air dry.

(4) Weld #30 chromel/alumel T.C. to 1/4" square x .006 S.S. shim stock.

(5) Mix eccobond 58-C with M Bond 610.

(6) Using iron with 1" square block tip at 600^{O}F apply paste every 1" or so in 1/2" widths and cure with hot iron with a .002 Teflon sheet between iron and paste. Hold iron on paste for approximately 1 minute. Bond junction on shim in like manner.

(7) Paint silicone aluminum over entire installation and air dry.

(8) Installation ready to use.

T.C. Junction Ni Aluminide and Rokide

(1) Prepare .003 chromel/alumel T.C. by spot welding junction.

(2) Prepare bonding surface using standard preparation for Rokide gaging described in Appendix B.

(3) Mask off area where T.C. junction contacts surface and apply Rokide precoat.

(4) Hold T.C. junction in place with a piece of X1132 tape 1/8" x 1/4".

(5) Spray tack coat of Nickel Aluminide using powder gun.

(6) Remove X1132 tape.

(7) Cover entire junction area with Nickel Aluminide.

(8) Using strips of X1132 tape every 1/2" (tape size 1/2" x 1/8") secure bare T.C. wire on Rokide precoat.

(9) Using standard Rokide gaging techniques, proceed to attach bare wires.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFFDL-TR-74-95
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): DEVELOPMENT OF STRAIN AND TEMPERATURE MEASUREMENT TECHNIQUES FOR USE IN COMBINED THERMAL ACOUSTIC ENVIRONMENT
5. TYPE OF REPORT & PERIOD COVERED: FINAL REPORT 19 Mar 73 to 19 Mar 74
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): Stephen P. Wnuk, Jr; Malcolm E. Low; John G. MacLean
8. CONTRACT OR GRANT NUMBER(s): F33615-73-C-3052
9. PERFORMING ORGANIZATION NAME AND ADDRESS: HITEC Corporation, Snake Road, Westford MA 01886
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 1471; 147104; 14710403
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Flight Dynamics Laboratory/FYA, Wright-Patterson AFB OH 45433
12. REPORT DATE: October 1974
13. NUMBER OF PAGES: 90
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Distribution limited to U.S. Government agencies only; test and evaluation; statement applied July 1974. Other requests for this document must be referred to AF Flight Dynamics Laboratory (FYA), Wright-Patterson AFB OH 45433
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
18. SUPPLEMENTARY NOTES:
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
1402 Laboratories, Test Facilities, and Test Equipment
1402 Measuring Devices (Electrical & Electronic)
Strain gage, Strain measurement,
High Temperature,
Temperature measurement
20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

This report covers the Development of Instrumentation Techniques for Strain and Temperature Measurements on aerospace test structures in a combined high temperature and acoustic noise environment. Techniques for attaching instrumentation to test panels for vibratory testing up to 1400°F were developed and evaluated at the AFFDL Sonic Fatigue Facility. Methods for measuring static strains for short periods (up to one hour) at 1200°F were also developed. Strain gages, temperature sensor lead wire selections and installation techniques are covered in the report.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

☆U.S.Government Printing Office: 1974 - 657-016/282