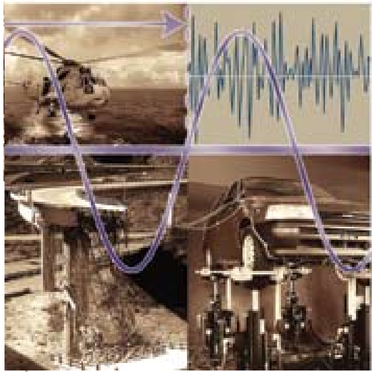

ERI News

your reliability newsletter

August 2006 | Equipment Reliability Institute | Volume 24

In this issue...

Making Strain Measurements in a Three-dimensional World using One-dimensional Strain Gages

by Udell Merritt

What is a strain gage?

The principle by which a strain gage works (a wire such as Nichrome that changes resistance when strained or stretched), was recognized by Lord Kelvin in the 1850's; however, the first practical application did not occur until the 1930's. From that time until now strain gage uses have soared. You might have some in your bathroom scale, if it has a digital readout. Your local deli has some in the small scale on the counter that weighs your bologna and displays a price based on the weight and price per pound.

Strain gages are used in higher tech engineering to assure safety and durability of aircraft engines and airframes, automobiles, shipping, oil pipelines and refineries, bridges, roads, buildings, dams and many other structures. Strain gages are used in transducers that measure load, pressure, acceleration, etc. Strain gages have such wide use because they are inexpensive, accurate, small and lightweight, can function in severe environments (with proper protection) and in temperature extremes from cryogenic to 2000oF.

Most gages in use today are photo-etched (techniques similar to those used for printed circuits and integrated electronics) onto thin foil that has been rolled from selected metal alloys. The gage is cemented to a thin organic backing such as polyimide or epoxy. The user cements the assembly (see Figure 1) onto the structure he is investigating.

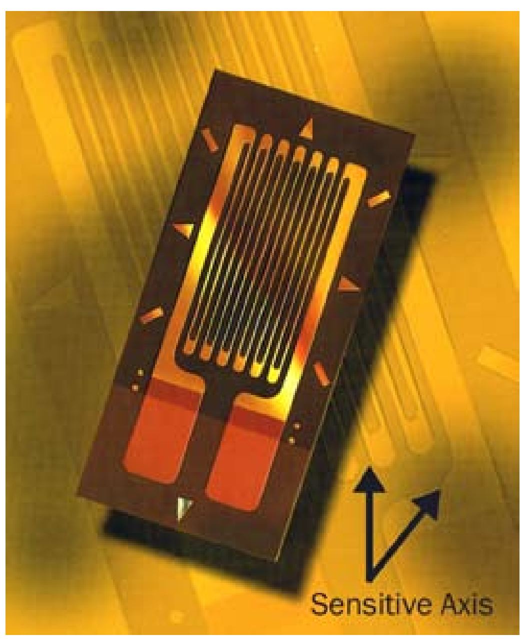

Figure 1 - Metallic foil strain gage – ready to cement onto structure being investigated. (courtesy of Vishay Micro-Measurements)

Voice of the President

No change in the signal being measured is the usual criterion for passing an environmental test or a HALT/HASS screen.

But some digital built-in self test (BIST) circuits and some laboratory measuring instruments are remarkably stable in their display, even when the signal being measured **does** change. Brief (1 microsecond, for example) shifts often wrongly indicate **no change**.

Suppose a signal continually checks "ok" on BIST or on external test equipment. Does that mean a specific circuit really **is** ok? Not necessarily. Has the device under test (DUT) any "automatic retry" features? Turn them off. Was the specific circuit that you are monitoring designed to tolerate some noise? Is there much averaging involved? That "noise" may be what you seek; it may indicate an intermittent connection; that unit should be rejected.

If you are conducting an environmental test or a HALT/HASS screen, call the foregoing to your client's attention.

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In some special or high temperature uses the gage may be formed from very small diameter wire looped back and forth to form the measuring grid, as in Figure 2.

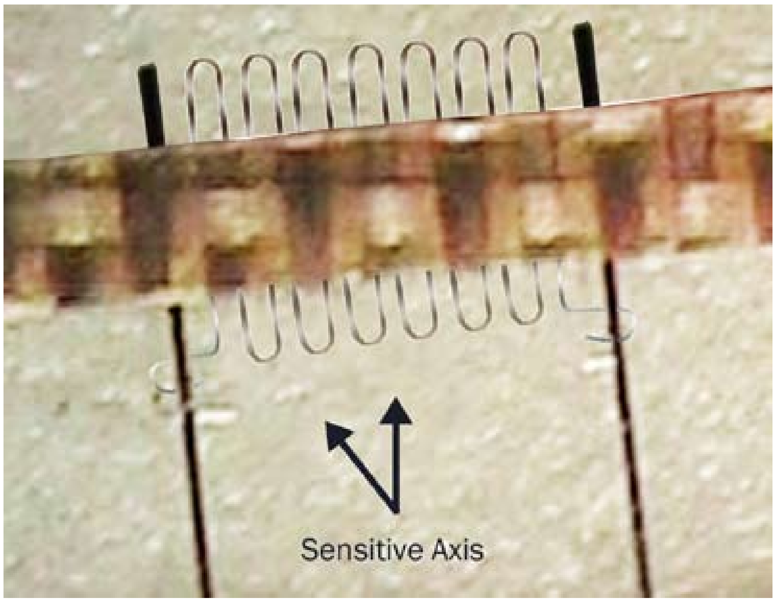

Figure 2 - Nichrome wire strain gage – ready to cement onto structure being investigated. (Courtesy of Hitec Products, Inc.)

The user attaches lead wires to the small tabs shown. This connects his gage to the electrical circuits needed to:

1. Provide power to the gage and

2. Sense the resulting output voltages that result from strain in the structure he is investigating.

I'll concede that the title of this article implies that a strain gage is truly sensitive in only one direction. Unfortunately, there is some output due to lateral strain, transverse sensitivity. Transverse sensitivity is usually only a fraction of one percent, and is generally ignored. However, it can be corrected during data recording or reduction. In the third-axis, thickness, strain gages are almost completely inert. So in a practical sense, a strain gage is a one-dimensional measuring device. See the arrows alongside Figures 1 and 2.

But I need stress information

Well, OK, so strain gages are versatile, wonderful devices, but what can they do for me?

The parameter most wanted by analysts and design engineers is stress. If stress levels from operating loads and working conditions are known, safety margins and life-limits can be projected for your engineered parts and structures. Unfortunately, stresses cannot be measured directly. However, strains can be measured, then stresses calculated using (1) Hooke's laws, (2) material constants modulus of elasticity and (3) Poisson's ratio.

Getting from strain to stress

Here is how it works. We live in a three-dimensional world (four if you include time). On any given object from which we desire stress data, we can cement strain gages on the surface. This is good because for the vast majority of cases the highest stresses will occur on the surface. (The most notable exception is a rolling element on a hard surface such as train tracks or bearing races. In these two examples, the high stress occurs beneath the surface where a gage cannot be mounted, but for all others it is on the surface.) Now, further simplifying, the problem, although our hardware has three dimensions we are actually only interested in two, the x- and y-axes, because the stress on the surface in the perpendicular direction (z-axis) must be zero.

To summarize, we are only interested in the strains on the surface, and only in two axes. We have a strain gage that is only sensitive in one direction and we want to measure strains in two directions, so

Vibration and Shock courses coming up

Wayne will teach short courses on vibration testing, shock testing, measurement, analysis, calibration, HALT, ESS and HASS at the following locations:

August 22-24, 2006, Santa Barbara, California

September 19-21, 2006, Montreal, Canada

October 16-18, 2006, Las Vegas, Nevada

December 5-7, 2006, Detroit, Michigan

Upcoming courses taught by ERG teachers

Steve Brenner, who has been working in the field of environmental simulation and reliability testing for over 30 years, will teach:

- "Vibration and Shock Test Fixture Design" November 14-16, 2006, at Las Vegas, NV.
- "Fundamentals of Climatics Testing, ESS, and HALT/HASS", October 25-27, 2006, Massa Martana (Perugia), Italy

Charles "Chuck" Wright, who has three decades of successful experience in the design and operation of advanced multichannel, computer-driven measurement systems for test and evaluation, will teach

- Applied Measurements Engineering November 6-8, 2006, Las Vegas, Nevada the questions becomes how do we know what direction to point the gages to get the information that we want, and where do we put them? To answer these questions we have to know a little more about what we are attempting to measure. The strain (stress) that we want to measure is called the maximum principal; it is the highest strain in any direction at a given point. Ninety degrees to the maximum is the minimum principal strain, and it is the lowest strain in any direction. The strains in all other directions will lie somewhere between the maximum and minimum principal strain values, but we need the value of both the max and min strains to calculate both max and min principal stresses.

So, how do we know where and in what directions do we locate the strain gages? There are several answers to these questions. A part that has failed in service is excellent if we are sure that it failed from a normal operating circumstance. If it is cracked or separated we know that the maximum principal stress is perpendicular to the crack or the edge of the separation giving us the direction. Where the failure initiated along the crack or edge can sometimes be determined by failure or material analysis, or simply by geometry of the part and knowledge of the loading. The locations for the gages may also be measured either by a full-field techniques such as Stresscoat or photo-elastic coatings, or calculated by finite difference analysis.

Don't know direction of maximum strain?
If we don't know exactly in what direction to mount our gage, or if the directions of the principal strain might change during loading, then we'll make our strain measurement with a three-element rosette gage (not shown). This will give us three unknown strains, the maximum and minimum principal strains and their directions (recall that minimum is 90^{o} from maximum). The three strain measurements allow us to calculate the maximum and minimum strain from rosette equations. These can be found in strength of materials texts or from the gage manufacturer's tech notes, if they are not already loaded into a data recording computer.

Finally, what about time?
Strain gages are unexcelled in measuring time-varying strain signals. The gage itself is frequency limited only as strain wavelength approaches gage length as gages measure the average strain under the gage. We can measure strain into the hundreds kilohertz. Frequency range is limited only by the data system.

Udell has vast experience in structural testing performing static tests on cases, shafting, pressure vessels, gears, etc., besides long time work on high speed and high temperature strain measurements utilizing slip rings and telemetry for data transmission. For more information about this ERI specialist, please visit http://www.equipment-reliability.com/consultants/spec9.htm.

*Udell Merritt will be teaching a "***Strain Gages***" on November 1-2, 2006, in Las Vegas, Nevada. Please visit http://www.equipment-reliability.com/course1.htm for detailed information about this course. Enroll by October 1st to take advantage of a $100 discount. If you and two more people from your organization enroll before October 1st, each person can take another $100 discount. Visit http://www.equipment-reliability.com/regist_form.htm to register.*

John Starr, with over 35 years of continuous and varied experience in structural capabilities in Nuclear, Chemical, and Defense industries, will teach "Designing Reliable & Rugged Electronics":

- ► October 3-5, 2006, Minneapolis, Minnesota
- ► December 5-7, 2006, Las Vegas, Nevada

Ignacio "Mel" Mella, who's been working in environmental testing for over 25 years, will teach:

- ► "Fundamentals of Random Vibration and Shock Testing" December 5-7, 2006, Orlando, Florida

Udell Merritt, who has over 30 years experience in structural instrumentation and testing, will teach

- ► "Strain Gages" November 1-2, 2006, Las Vegas, Nevada

Free Web-based training Presentations by Wayne Tustin

The next time you have a few free moments and access to "the web," go to the articles section of Vibration & Shock website and choose one or more of the presentations listed there. Below are some of the subjects you'll find there:

► Vibration and Shock Isolation - Trends and Solutions

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Estimating Allowable Circuit Board Temperature Levels

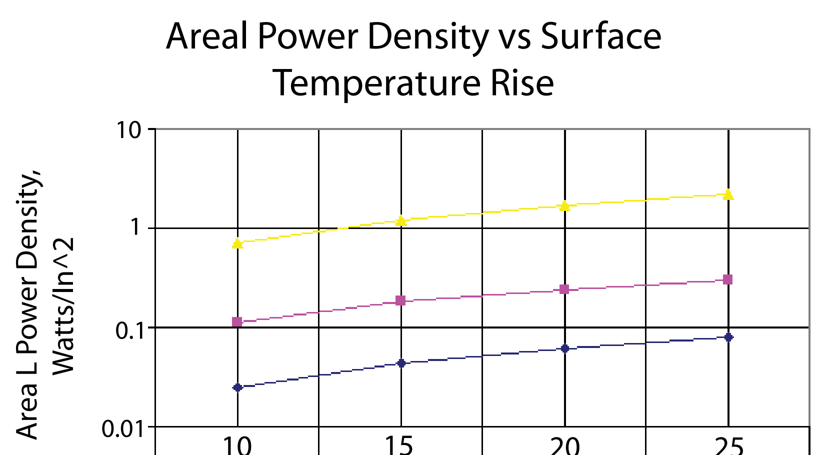
by Joel Newberger

This article identifies a simple to use graph that shows the relationship between areal power density (watts/in^2) and surface temperature rise (DELTA T) above surrounding coolant (air or liquid). The graph is based on the following assumptions and constraints:

1. Spatially invariant heat load
2. Atmospheric pressure, sea level
3. Temperature rise, DELTA T = Tsurface-Tcoolant, C
4. Characteristic length ~ 6-8 inches
5. Radiation thermal transfer neglected

Use of the graph approximates circuit board component thermal profiles when thermally conditioned as follows:

1. Upper curve, immersed in liquid (3M Flourinert)
2. Middle curve, forced convection at 500 ft/min air velocity
3. Lower curve, natural convection



	10	15	20	25
◆ (lower)	0.025	0.043	0.062	0.08
■ (middle)	0.112	0.18	0.24	0.3
▲ (upper)	0.7	1.2	1.7	2.2

Board mounted component temperature rise above ambient (or liquid coolant) obtained from graph does not include the thermal effect of lead(s) conduction and/or use of thermal VIAs.

Consider a fully populated circuit board with a 54 in^2 planar area (one side) that dissipates a board total of 15 watts and is naturally convection cooled with maximum chip surface temperature rise limited to below 15C. As a result, the areal power density is 15watts/54in^2=0.28 watts/in^2. Data obtained from graph shows that at 0.28 watts/in^2, a 15C component case surface rise is not possible. At 15C temperature rise, the areal power density, when (natural) convectively cooled, must be limited to below 0.043 watts/in^2. In this example, the areal power density is more than six times the allowable 15C limit. However, in order to condition components to required 15C rise levels, the following types of thermal enhancements should be considered:

1. Use of component (chip) heat sinks
2. Use of thermal VIAs that conductively couple heat to convection cooled ground plane.

The thermal enhancements described above increase the effective thermal transfer surface area, and as a result, board areal power density levels are reduced.

When forced convection is

► Designing PCBs to Withstand Harsh Environments

► What is Resonance all about?

► Fixtures for Vibration and Shock Testing

You'll need to download Real Player to see the video clips and animations.

Lead-free electronics- Rugged & reliable

Instructor John Starr recently completed life-use / damage analysis of vibration tests of electronic systems with various solder types conducted by JCAA/JGPP, "Joint Council for Aged Aircraft/Joint Group for Pollution Prevention" (this is a consortium that includes all branches of the military, Boeing, Lockheed, Rockwell, NASA, Marshall Flight Center, Sandia Labs and others). The JCAA/JG-PP Consortium is the first group to test the reliability of lead-free solder joints against the requirements of the aerospace/military community. These tests were conducted to investigate some of the impact of changes required for lead-free designs (RoHS). Preliminary evaluation of the results by Boeing concluded that many leadfree solders failed below tin-lead solder control and that new development models and methods are needed for developing reliable rugged electronics for leadfree considered at a bulk air velocity of 500 ft/min, the component surface temperature rise at 0.28 watts/in^2 is limited to 23C. If a 15C rise limit is required, use of above thermal enhancements apply and/or increase bulk velocity while limiting acoustical signature to acceptable levels.

When immersion cooled, the allowable areal power density is 1.2 watts/in^2 when surface temperature rise is limited to 15C. For this example, liquid immersion is not a cost-effective thermal solution and should only be considered when power density levels are noticeably higher.

Joel is President of Thermalogics, Inc., and a principal in SNA Engineering. SNA specializes in mechanical design/packaging and in thermal/structural analysis of electronic equipment. For more information about this ERI specialist, please visit http://www.equipment-reliability.com/consultants/spec3.htm.

Test Lab Musings (part 13)

by Robert L. Renz

When you run into tests you can't run in your lab, and you need to go to an outside lab, think about the following:

▪ What kind of difficulty will you have getting your test support equipment (test computers, etc) to the lab? Do they have a loading dock, forklift, etc?

▪ What hours does the lab work? I can come in on weekends or evenings to finish a test fairly easily, but many labs either shut down at 5:00, or charge a real penalty for OT.

▪ What kind of equipment does the lab have? Is it reasonably new? Regardless of how old it is, is it well maintained? Is it operational when you visit the lab, or must it be repaired first?

▪ Look at lab cleanliness. If your customer wants to witness the testing, will you have to apologize for the outside lab?

▪ Where is the lab? Can you get there without 3 plane changes? Will it take a week for a truck to deliver your equipment there?

▪ Check out the lab's equipment calibration program carefully. When you tour the lab to see if they can run your tests, look at calibration tags. If you see equipment that's out of calibration that isn't red-tagged, it might be time to look for another lab.

▪ Do they know what they are doing? Do you have to explain what a MIL-STD is, or do they regularly run similar tests for other customers.

▪ Do they have the fixtures and instruments needed to run your test, or will you have to buy them as an add on to their quote.

▪ Be careful to look at all the costs – if the lab quotes you a rate per hour for a temperature chamber, be sure that that's the total rate. If they give you a great rate for a chamber, and it turns out to be LN2 cooled, and you pay extra for every carboy of LN2 you use, maybe the rate isn't so great after all.

▪ How fast do they prepare and issue the test report?

designs. The original Boeing Phantom Works report [JCAA/JG-PP Lead-Free Solder Project: Vibration Test] and Starr's report [JCAA/JG-PP Lead-Free Solder Project: Vibration Test, Solder Comparison by Component Level Life-Use Analysis] are published on the NASA website.

However, in the above report, John Starr demonstrated that methods taught in his course "Designing Reliable & Rugged Electronics" (Las Vegas December 5-7, 2006) which are used in development Sn/Pb products also apply to leadfree products. However, with the increased risk of bad solder joints associated with leadfree products (non-wetting, insufficient solder, cold joints, etc.) the need for using these advanced development methods has significantly increased. In-depth product understanding is needed for design qualification and production quality verification. Vibration is very effective in environmental screening at finding bad solder joints, but levels must be determined with a full understanding of the product so that imposed vibration is effective without being destructive.

As part of the evaluation of the component failures, Starr's methods were used to predict failure times for components at different locations in the design. These predictions were compared to actual test time.

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When you setup a new profile and run it for the first time, how do you keep track of your setup? A separate Word file somewhere? Paper notes? Post-It notes on the side of the test request? Unholtz Dickie's latest upgrade to their VWIN-II controller software now includes a notes page that lets you include a Word document as part of your test setup file, including photos, log sheets, comments, and all the rest of the information that would otherwise be relegated to red lined notes in a margin.

Robert L. Renz of General Dynamics - Advanced Information Systems at Bloomington, Minnesota.

Measurement Certainty

Dr. Vivian Crouch of the University of South Australia recently commented on Chuck Wright's article "Measurements Uncertainty? I Prefer Measurement Certainty", published at ERI News - vol 17, November 2004. Here is what he wrote.

Having spent nearly 30 years working with the flight test community in Australia I can only richly concur with the concerns you have raised.

I moved into 'semi-retirement' last June and am now lecturing the post-graduate Test and Evaluation course at the University of South Australia - where I am also supervising a number of Master's students.

In my own personal experience, the concerns you have raised are not really new - but the inattention to them has grown remarkably with the advent of 'digital technology' in the late 1970's - in which the analysts have subsequently placed misguided faith. {I.e; it's just so easy these days to produce truckloads of flight test data that looks real to inexperienced analysts - but is fundamentally flawed - and where the terms 'resolution' and 'certainty' are either not addressed or are supremely confused.)

Worse - both the analysts and the regulators (such as ICAO) - have become victims to this - irrespective of whether we are talking about 'airworthiness certification' or even the 'certification of synthetic training devices' such as flight simulators.

Looking across wider applications, I also do not believe that the flight test 'community of practice' is the 'Lone Ranger' - but rather that we are witnessing something that is now endemic across all systems and platform developments destined for application in the air, land, sea and space environments (or combinations of these environments). And on this topic Chuck is 'dead right' - in that the environmental influences (natural, induced and threat) on measurement 'certainty' are (at best) poorly considered - or (at worst) not even considered at all.

To 'cut to the chase' I would like your permission to use your web-based article in Vol 17 as reading material for the T&E course that I conduct. It was succinct - I can broaden its application beyond 'flight test' - and it just might strike at the heart or conscience of someone - to inspire or invite sponsorship for 'someone somewhere' to conduct some quality research into the topic. (Having witnessed this serious lapse of attention since the late 1970's - it would great if we could inspire someone to take a giant leap of understanding into the 1980's!!!)

As things stand, I teach in my course that T&E enables 'evidence-based decision-making' all the way from concept genesis to realisation for next-generation systems. I therefore feel that I have a good context into which I can fit any serious concerns about 'the perpetuation of unreliable evidence' - and hence the need for a

Requests for Table of Contents

For more than a year now, we have offered a sample of chapter 1 of Wayne's 2005 text on random vibration and related subjects to our readers and site visitors. Lately we've been asked to provide with the book's table of contents.

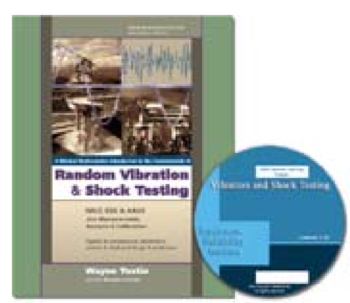
An overview of the table of contents is shown at our site, at the end of the page. If you'd like to receive an expanded version of the book contents, please send Wayne an e-mail.

New Distance Learning Program 2006

The updated Distance Learning Program with 33 lessons now, plus new video-clips, pictures and animations is ready for you.

For detailed information about this Program and how to purchase it, visit our site.

We're also releasing a package with both Distance Learning CD and Wayne's "Random Vibration and Shock Testing" book. Click here for more info.



'get well' plan to address the shortfalls in understanding. Like most academics though - who would like to critically examine evidence that is trans-disciplinary and inter-regulatory, I await any serious sponsorship of such research and any empassioned students to do it. Your article just might help to pull the trigger on this.

In all of this, I also see that a critical issue is the current ease of access to digital information – which is being increasingly used in 'data mining' operations' – where this leads to models and simulations (at the platform and mission levels) being populated in the first place. However, in the absence of an agreed method for tagging and storing the uncertainty of this information with the digital data in the first place - it's a bit like a real mining operation where the art of distinguishing between the 'real gold' and the 'fools gold' has been lost. This is serious and non-trivial issue – which if unremedied – can rapidly lead to proliferation of data without information, information without knowledge, knowledge without wisdom and wisdom without conscience.

Dr Vivian Crouch is a Senior Lecturer at the University of South Australia's Systems Engineering and Evaluation Centre (SEEC) and is also President of the Southern Cross Chapter of the International Test and Evaluation Association (ITEA). You can contact Dr Vivian at vivian.crouch@unisa.edu.au

Announcements

New course outlines

Visit our online course outlines page for Harry Schwab's new courses in "Stress Analysis" and "Developing Random Vibration Tests from Field Data", and also for Charles Hunter's "Pressure Calibration for the Standards Laboratory" and "Temperature Calibration for the Standards Laboratory".

ASTR 2006

ASTR 2006 (Workshop on Accelerated Stress Testing & Reliability) meets October 4-6 at Fisherman's Wharf, San Francisco. This is co-sponsored by the IEEE/CPMT Committee and the IEEE Reliability Society.

My tentative title is "Analog, not Digital, Monitoring during AST." I plan to raise serious questions about the present condition of many of the DUTs that we ship. Quite possibly we've not found all our existing problems.