HIGH-ELONGATION STRAIN MEASUREMENTS

Application Note TT-605

Introduction

Experimental stress analysis of structural materials sometimes requires testing to complete failure. In such cases, particularly with ductile materials, failure is often preceded by large local strains, the magnitudes of which are of interest to the test engineer.

High-elongation strain measurements place severe demands on the gage installation, and necessitate special gage and adhesive selection and surface preparation procedures. This Application Note outlines recommendations for gage and adhesive selection, surface preparation, gage bonding and wiring, and protective coating selection for high-elongation strain measurements.

High elongations are usually expressed as percentages: 1% elongation is equal to 10 000 microstrain; 5% elongation is equal to 50 000 microstrain. The maximum rated elongation of any bonded strain gage is based on a single tensile measurement. Cyclic strains of high levels must be limited to a value much lower than maximum due to fatigue limitations on the strain gage foil. Consult Vishay Micro-Measurements Tech Note TN-508, "Fatigue Characteristics of Micro-Measurements Strain Gages," for details on strain gage performance under repetitive loading conditions.

Gage Selection

Selection of proper strain gages for use in high-elongation testing is based on both anticipated strain levels and test temperature. Polyimide (E) backing is normally selected for this type of service because it has superior elongation capabilities and an operating temperature range suitable for most high-elongation testing. The E-backing is available with constantan (A) foil or fully annealed constantan (P) foil.

EA-Series

Properly installed and wired EA-Series (polyimide-backed constantan foil) strain gages are capable of measuring maximum elongations in the range of 3% – 5%. While gage lengths of 1/8 in (*3 mm*) or longer will normally achieve 5%, shorter gage lengths may be limited to 3%. Since most structural materials (e.g., metals) yield well below this limit, the EA-Series is a popular choice for use in obtaining yield point information on these materials.

EP-Series

EP-Series gages are recommended when measurement requirements are beyond the 3% – 5% elongation capability of the EA-Series. P-alloy is a fully annealed constantan foil processed for very high ductility. A properly bonded and wired EP-Series strain gage is capable of strain measurements to 20% (200 000 microstrain) or greater. As in the EA-Series, smaller gages will exhibit a lower maximum elongation capability.

Options

Any leadwire attachment option, such as Option W (encapsulated gages with integral terminals) or Option LE (encapsulated gages with leadwires), will lower the maximum elongation capability of EP-Series gages. But because the elongation limits of EA-Series strain gages are more moderate (3% – 5%), and because options will normally withstand at least the lower end of this range, they are not generally a limitation in the selection of EA-Series gages.

To obtain maximum possible elongation, select EP-Series gages without options.

Adhesive Selection

High-elongation strain measurements place severe demands on the adhesive system. The adhesive must be rigid enough to prevent gage relaxation (creep), yet flexible enough to permit large deformations without cracking. Recommended adhesives are listed in the selection chart on the following page.

Surface Preparation

The selection and implementation of proper surface preparation procedures is equally as important as using proper gages and adhesives. High-elongation measurements demand closer attention to recommended procedures than do normal elastic strain measurements.

Vishay Micro-Measurements Instruction Bulletin B-129, *Surface Preparation for Strain Gage Bonding*, outlines steps for surface preparation on a variety of materials. These procedures produce a smooth, clean surface, usually having been abraded in a single direction during preparation. Because of higher bondline forces involved in high-elongation measurements, the surface should be altered further for greater bond strength, as indicated in the following procedures:

ADHESIVE TYPE	GENERAL DESCRIPTION	PREFERRED CURE	ELONGATION CAPABILITIES		
			–320°F (*–195°C*)	+75°F (*+24°C*)	+200°F (*+95°C*)
M-BOND 200	Special pretested grade of cyanoacrylate, certified for strain gage use. Fast room-temperature cure.	3 min at +75°F (+24°C)	Not applicable	6% Up to 15% for installations less than 30 minutes old	Not applicable
M-BOND AE-10	Tw-component, 100%-solids exposy system. Capable of room-temperature cure. Transparent, medium-viscosity adhesive.	6 hr at +75°F (+24°C)	1%	6 – 10%	10 – 15%
M-BOND AE-15	Two-component, 100%-solids epoxy system. Moderately elevated temperature cure. Transparent, medium-viscosity adhesive.	2 hr at +150°F (+65°C)	2%	15%	15%
M-BOND GA-2	Two-component, partially filld, 100%-solids epoxy system. May be cured at room temperature. Higher viscosity than AE system.	6 min at +75°F (+24°C) followed by 1 hr at +125°F (+50°C)	4%	10 – 15%	15 – 20%
M-BOND A-12	Two-component, filled, 100%-solids epoxy sytem. Paste-like consistency. Specifically recommended for elongations above 10% on steel.	2 hr at +165°F (+75°C)	Not applicable	15 – 20%	15 – 20%

For additional specifications, consult Vishay Micro-Measurements Accessories Catalog A-110 and specific adhesive instruction bulletin.

1. Completely prepare the surface of the test specimen as described in Bulletin B-129.
2. Abrade the specimen surface in a direction 45° to the intended axis of strain measurement. On soft materials, such as aluminum, use 320-grit silicon-carbide paper; on harder materials, such as steel, use 60-grit.
3. Lightly abrade, with the appropriate grit paper as indicated in Step 2, in a direction 90° to the first abrasion. This will produce a cross-hatched abraded surface. Typical surface roughness desired approximates 250μin (*6.4 μm*) rms.
4. Repeat the degreasing steps outlined in Bulletin B-129.
5. Condition the surface with Vishay Micro-Measurements M-Prep Conditioner A (if appropriate for the specimen materials as detailed in B-129), scrubbing with cotton-tipped applicators. Wipe dry with a gauze sponge.
6. Neutralize the surface with Vishay Micro-Measurements M-Prep Neutralizer 5A (if appropriate for the specimen material), scrubbing with cotton-tipped applicators. Wipe dry with a gauze sponge.

Many materials oxidize readily in air. If allowed to form on the surface, oxidation will greatly reduce bond strength and elongation capabilities. It is strongly recommended that the gage bonding operation be completed as soon as possible after the surface is prepared.

Gage Bonding

Follow the standard bonding procedures outlined in the respective instruction bulletin for the adhesive selected.

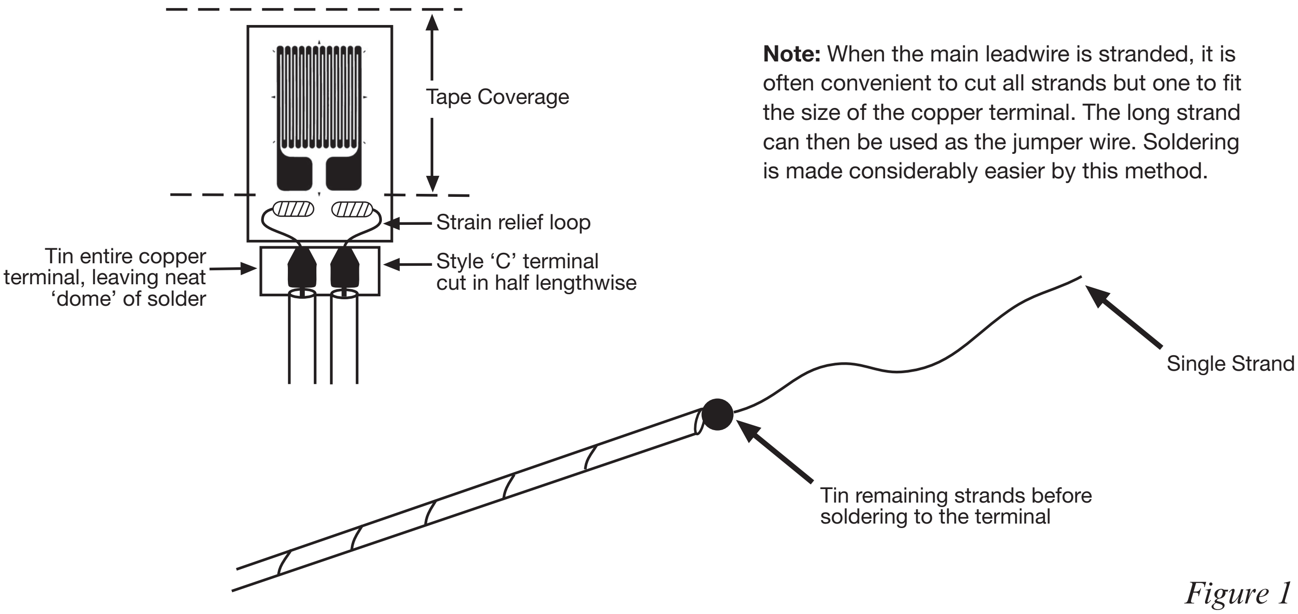
Gage Wiring

Relatively high displacements occur with high-elongation strain measurements, suggesting the use of an external terminal strip. The strain gage should be wired to the terminal strip with a small-diameter, single-conductor wire no larger than 30 AWG (*0.25 mm diameter*) as shown in Figure 1. Drafting tape (Vishay Micro-Measurements PDT-1) applied over the gage during soldering is recommended to restrict the flow of solder to the tab ends.

Adequate strain relief loops, as shown in the illustration below, are of particular importance in high-elongation measurements. Note also that the leads attached to the strain gage tabs approach in a direction 90° from the maximum principal strain axis.

After soldering, all tape and soldering flux should be removed with several brush applications of rosin solvent (Vishay Micro-Measurements RSK-1).

HALF-TERMINAL TECHNIQUE FOR USING BONDED TERMINALS IN HIGH STRAIN FIELDS



Note: When the main leadwire is stranded, it is often convenient to cut all strands but one to fit the size of the copper terminal. The long strand can then be used as the jumper wire. Soldering is made considerably easier by this method.

Figure 1

Gage Linearity

A discussion of high-elongation strain gage measurements is not complete without including the subject of gage linearity under plastic straining conditions.

Although constantan alloy is one of the most linear of all strain gage alloys, it does exhibit small changes in gage factor during high elongation.

Without treating this subject in detail, it can be shown in theory that the gage factor of the strain gage approaches a value of $2+\varepsilon$ when the gage alloy is strained beyond its elastic range. The elastic range for constantan is approximately 0.5%.

Using the $2+\varepsilon$ guideline, the gage factor at a strain level of 10% would be close to 2.1 in tension and 1.9 in compression. At a 20% strain level, the gage factor approaches 2.2 in tension and 1.8 in compression.

While these numbers are correct in theory, they have not, to our knowledge, been substantiated by actual test results.

Instrumentation

Wheatstone bridge circuits are commonly used in strain gage measurements. These circuits are inherently nonlinear when large gage resistance changes are encountered. Consult Vishay Micro-Measurements Tech Note TN-507, *Errors Due to Wheatstone Bridge Nonlinearity*, for correction procedures.

Common Installation Problems

Unbonding of the Gage

Assuming the proper adhesive has been selected (see Chart, page 2), loss of bond before maximum gage elongation is reached can usually be traced to a contaminated or improperly prepared surface. A visual examination of the bond area will usually detect this. Cured adhesive on the back of the strain gage but not on the specimen generally indicates improper or incomplete surface preparation.

It is important to note that some materials, like polyethylene, are difficult to bond; and it will not be possible to reach maximum gage elongation before bond failure.

Unbonding of the Gage Tabs

Gage tab unbonding is often due to an excessive amount of solder, which reinforces the gage tabs, and causes them to unbond as a result of their inflexibility. Drafting tape is recommended for restricting the amount of solder (see ***Gage Wiring***).

Excessive soldering temperatures, or terminals placed too close to gage tabs, can also contribute to this problem.

Gage Grid Failure (Open Circuit)

Assuming that the strain gage readings were within the strain range capability of the gage, and that the backing remains bonded, premature grid failures are often the result of high local strains within the area covered by the gage. Since the strain gage is an averaging device, it will indicate *average* strain along its grid length. Steep strain gradients can cause localized excessive strain damage while the gage may have been indicating a strain that was well within its elongation limits.

Grid failures may also result from strain concentrations caused by inclusions in the adhesive layer (unmixed adhesive particles, dirt, etc.) or by uneven gluelines, often caused by irregular or pitted specimen surfaces or uneven clamping pressures.

Elongations Exceeding 20%

Strain measurements, particularly on materials such as plastic or rubber, sometimes surpass the capability of the EP-Series strain gage. Measurements in this range can be obtained through simple flexure devices designed to reduce the strain level on the gages. These devices, commonly referred to as *clip gages*, are shown in Figures 2A and 2B. Strain gages are installed on the top and bottom of the clip, and the clip mounted to the specimen by bonding or spot welding, depending on the specimen material. The displacement of the "feet" under strain causes corresponding resistance changes in the strain gages. With the gages wired into either a half or full Wheatstone bridge, their resistance changes are additive, thereby increasing the amount of available signal. Wherever space permits, full bridges are recommended because the effective bridge output is twice the half-bridge signal for the same foot displacement.

Since the clip gage is normally a nonlinear device, the gage output is calibrated against known displacements before installation. The gage "zero" reading is monitored during the calibration, since a permanent zero offset after calibration can usually be traced to localized yielding of the metal strip. If this is indicated, the calibration should be repeated several times to check for reproducibility.

A clip gage is particularly useful in measuring very large specimen strains or actual displacements occurring between two bodies, as with expansion joints or crack openings.

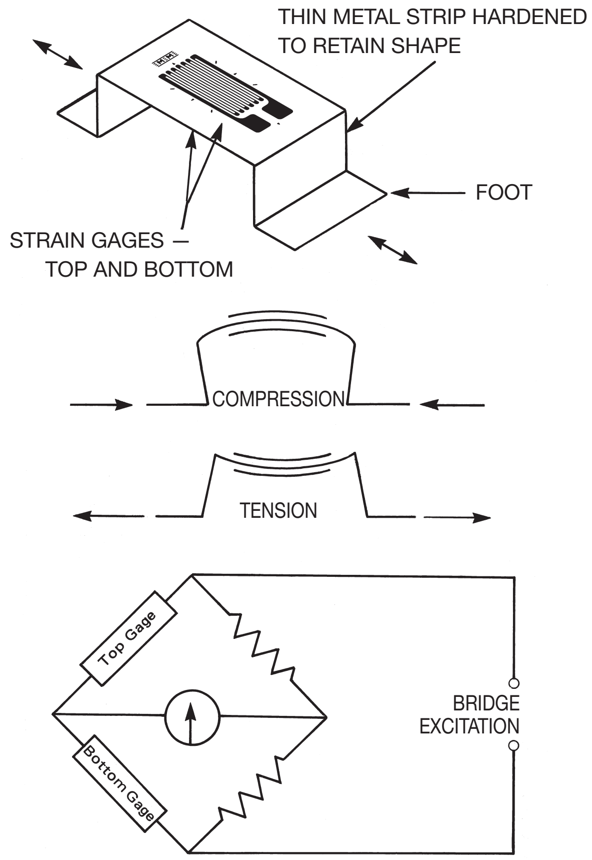


Figure 2A – Clip Gage (Half Bridge)

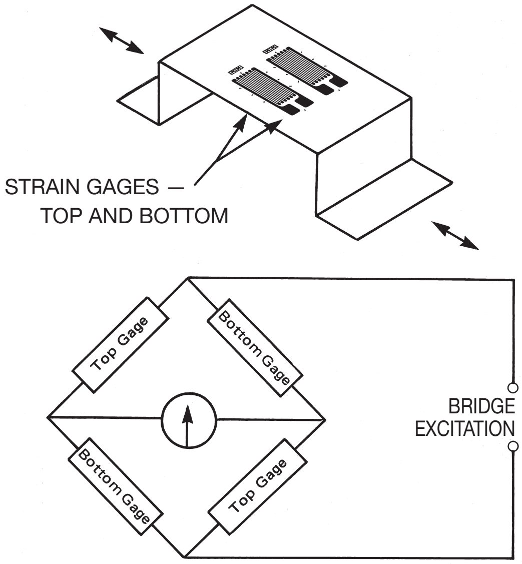


Figure 2B – Clip Gage (Full Bridge)