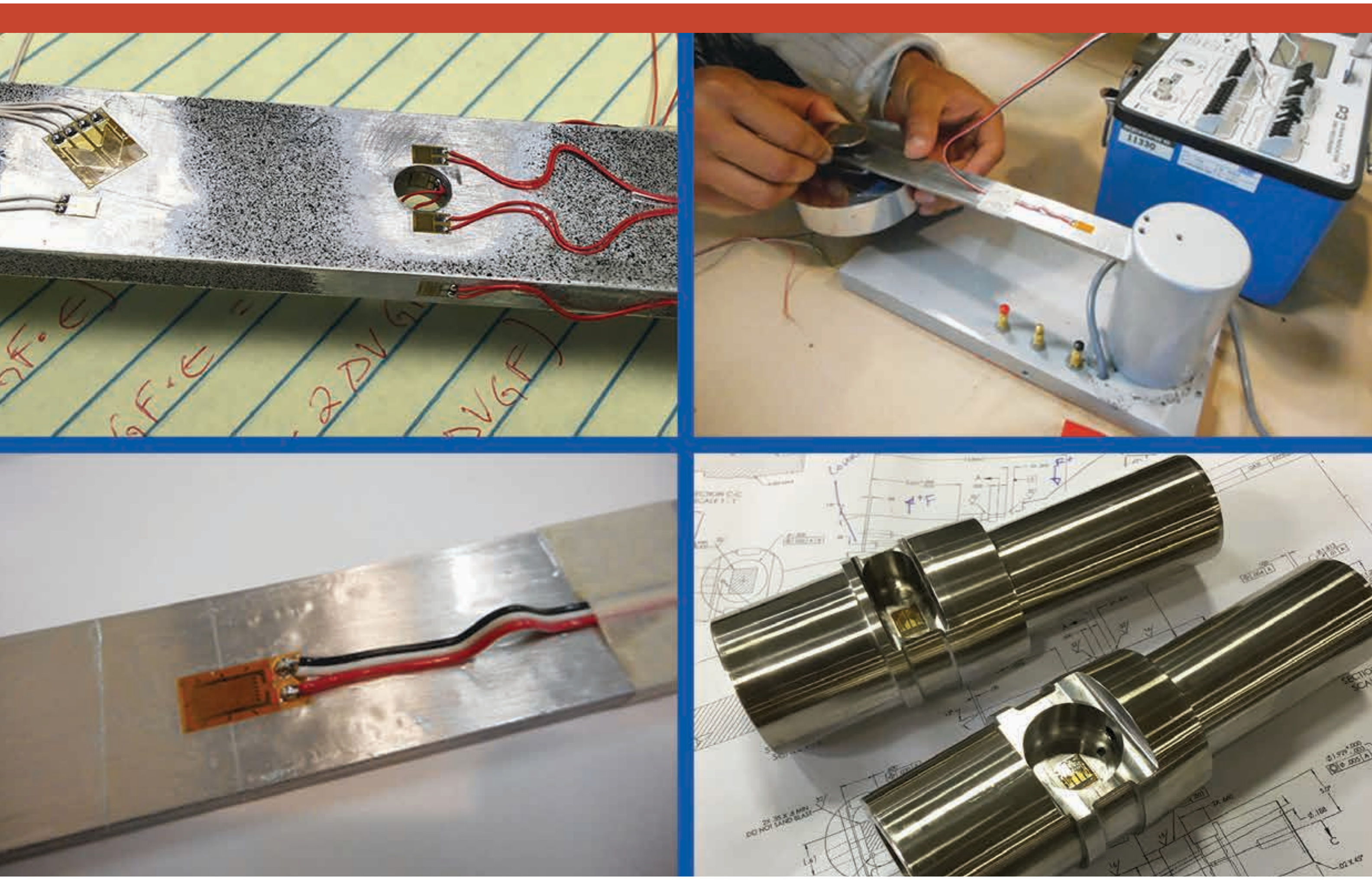
Strain Gage Technology

Student Manual



An introduction and guide to:

- Selection
- Installation
- Instrumentation

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Precision Strain Gages

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Stress Analysis Strain Gages

Experimental Stress Analysis is an established, popular engineering tool, routinely used in the design of safe and reliable products and engineering structures. The techniques of experimental stress analysis may be applied at different stages in the life of a product, from preliminary design concepts to testing of a finished product; in proof and overload testing; and in failure analysis of products already in service. Within the broad field of experimental stress analysis, several practical techniques are available, including photoelastic coatings and models, and electrical resistance strain gages.

Of these techniques, the modern bonded electrical resistance strain gage is widely recognized as the most practical technology for testing of load-bearing parts, members, and structures. Because both excellent accuracy and repeatability can be achieved, strain gages are also becoming increasingly important as primary sensing elements in load cells as well as in pressure, force, torque, displacement, and other transducers.

To make strain measurements of acceptable quality —whether for structural testing or for transducer applications — requires the consideration of several well-defined parameters: quality of the strain gage itself; proper selection of the strain gage, bonding adhesive, environmental protection and other strain gage accessories; proper circuit design, proper installation of the strain gage; and quality of the strain gage instrumentation. While the importance of these parameters is well understood by the experienced stress analyst, their significance may be less obvious to those unfamiliar with strain gage technology. The purpose of this manual is to familiarize students with the proper techniques of strain measurements with electrical resistance strain gages.

In addition to providing high-quality, state-of-art strain gages and strain gage instrumentation, Micro-Measurements maintains an extensive selection of technical and product literature describing the techniques, equipment, and practical application of strain gage technology. This manual is a compendium of Micro-Measurements strain gage literature, specially selected to provide the student with a sound introduction to the hardware and procedures of strain gage methods. It includes the following topics:

- **Strain Gage Selection Criteria, Procedures, Recommendations:** The parameters for gage selection — including sensing alloy, backing material, gage length and pattern, self-temperature compensation, gage resistance, and gage options — are detailed. Examples are given of gage selections made in actual application.
- **Strain Gage Installations with M-Bond 200 and AE-10 Adhesive Systems:** Steps used in professional stress analysis in preparing the test specimen and making gage installations with M-Bond 200 cyanoacrylate and M-Bond AE-10 epoxy adhesive systems are described in detail. Also included is a section on two- and three-leadwire strain gage circuits and a troubleshooting guide. By Following the detailed illustrated steps, the first-time strain gage user can make dependable installations.

In later sections, the hardware of the strain gage technology is described:

- **Strain Gage Soldering Techniques:** A step by step guide that illustrates the proper soldering techniques for successful strain gage installations.
- **The Three Wire Quarter-Bridge Circuit:** A look into the advantages of adding the third wire onto a quarter-bridge strain gage measurement.
- **Description of Strain Gage Instrumentation:** The range of instrumentation- including static, dynamic, and computer-controlled stress analysis systems- is shown. Details are provided in table for quick reference and comparison of the various choices.
- **Strain Gage Installation Checklists:** A quick reference guide for selecting products for common strain gage applications on steel, concrete, aluminum, composites, and plastics.

Stress Analysis Strain Gages

HOW TO USE THE LISTINGS

General-use Micro-Measurements strain gages are listed in groups according to grid geometry:

- Linear patterns
- Tee rosettes
- Rectangular rosettes
- Delta rosettes
- Shear/torque patterns

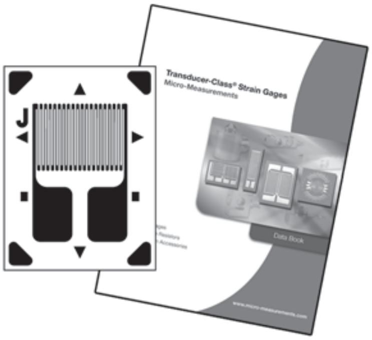
For each of these grid geometries, those patterns most commonly used by our customers are listed first with complete specifications. Additional listings with partial specifications follow for the less commonly used patterns. In both listings, the gage patterns appear in alpha-numeric order, increasing from the shortest grid lengths to the longest.

Separate listings are provided for special-use strain gages and sensors:

- Residual stress
- Magnetic fields
- Weldable gages
- High temperature gages
- Manganin pressure gages
- Shear modulus gages
- Embedment gages
- Temperature sensors
- Crack detection sensors
- Crack propagation sensors
- Displacement sensors

ADVANCED SENSORS GAGES

Customers whose application requires gages for the manufacture of precision commercial transducers are strongly encouraged to contact our Applications Engineering Department. They can provide assistance in the selection of the proper Advanced Sensor for your particular application.

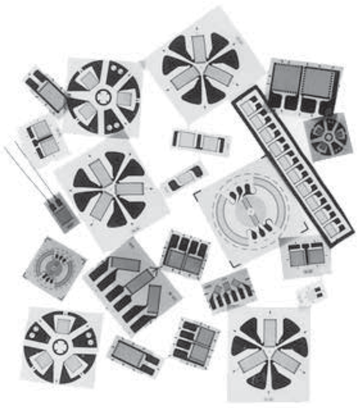


CUSTOM GAGES

Micro-Measurements maintains the most extensive variety of catalog strain gages available today. Whether for stress analysis, transducer manufacturing, or special-purpose applications, we have not only a wide selection, but also a large and varied inventory that is readily available for immediate delivery.

However, many of our customers have applications requiring gages that are manufactured to their individual specifications. While we believe our wide variety of standard catalog gages will satisfy most requirements, we recognize the need for custom products and are committed to serving it well.

To request a quotation for a custom gage, please contact our Applications Engineering Department.



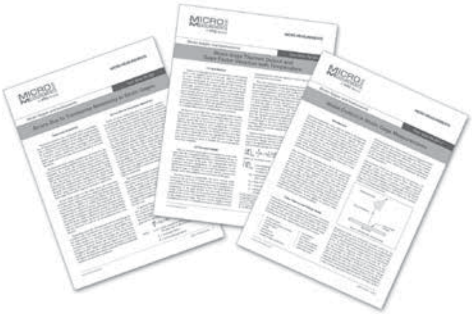
Stress Analysis Strain Gages

APPLICATIONS SUPPORT

Micro-Measurements maintains an experienced and highly trained applications engineering staff. Our Applications Engineers are as close as your telephone, and we urge you to call them for recommendations in strain gage selection to satisfy your particular test requirements.

TECHNICAL INFORMATION

Detailed technical information about the selection and application of strain gages can be found in the special series of Tech Notes, Tech Tips, and Instruction Bulletins on strain gage technology. Thorough familiarity with these publications will help ensure consistent success in the use of Micro-Measurements strain gages.



We also offer our customers an extensive assortment of additional product and technical literature, available in the strain gage technology knowledge base on our website at:

micro-measurements.com/knowledge-base

STRAIN GAGE ACCESSORIES AND INSTRUMENTATION

Strain Gage Instrumentation
Micro-Measurements

Strain Gage Accessories
Micro-Measurements

Data Book

In addition to an extensive selection of strain gages, Micro-Measurements offers a complete range of complementary products. Strain gage accessories include surface preparation materials, adhesives, installation tools, protective coatings, leadwire, and a host of other application tools, hardware, and supplies. Instruments range from portable, digital strain indicators, to sophisticated computer-controlled systems for the acquisition, storage, and reduction of test data. Both static and dynamic measuring instruments are available—each uniquely designed to provide stable, accurate, and reliable strain measurement.

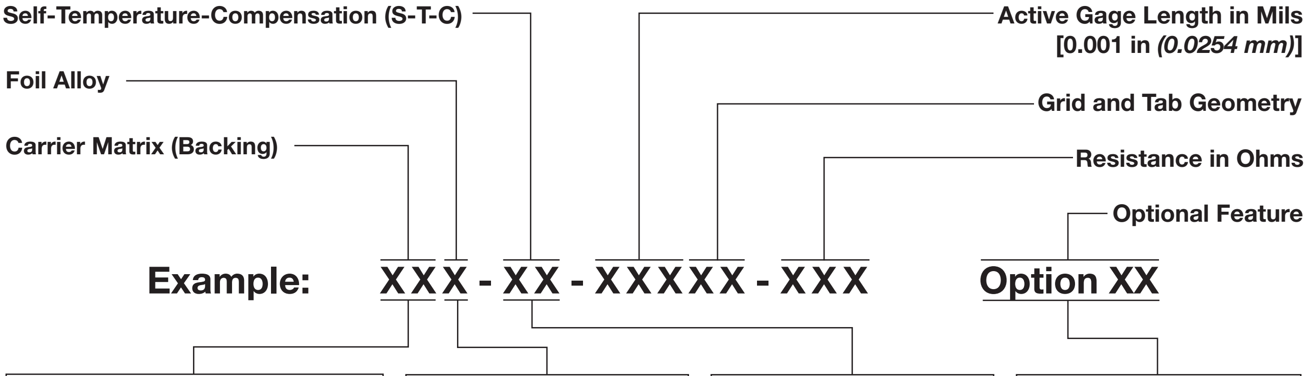
TRAINING PROGRAMS

Training customers in the proper use of strain measurement techniques is an essential part of the Micro-Measurements philosophy. In support of this principle, Micro-Measurements conducts an extensive series of regularly scheduled technical seminars, workshops, and short courses. Course instructors are recognized authorities in their field. Training sessions are conducted at our facilities in the United States and Europe, as well as at hotels and educational institutions around the world.
For schedules, go to:

https://micro-measurements.com/training

Stress Analysis Strain Gages

The Strain Gage Designation System described below applies to Micro-Measurements General-Use Strain Gages.



E: Open-faced cast polyimide backing.

CE: Thin, flexible gages with a cast polyimide backing and encapsulation featuring large, rugged, copper-coated solder tabs. This construction provides optimum capability for direct leadwire attachment.

L2: Thin, laminated, polyimide-film backing featuring encapsulated grids with preattached leadwire ribbons.

C4: Thin, laminated, polyimide-film backing featuring encapsulated grids with leadwire cables.

W: Fully encapsulated, glass-fiber-reinforced epoxy phenolic resin. High endurance leadwires.

N2: The ‘N2’ matrix provides an open faced gage on a thin, high-performance laminated polyimide film backing.

S2: Gage grid and solder tabs fully encapsulated in a thin, flexible, laminated polyimide film. Provided with large [0.030 in *(0.75 mm)*] solder pads for ease of leadwire attachment.

S: Full encapsulation identical to the W matrix, but with solder dot connections instead of leadwires.

A: Constantan alloy in self-temperature-compensated form.

P: Annealed Constantan.

D: Isoelastic alloy.

K: Nickel-chromium alloy (similar to Karma).

The S-T-C number is the approximate thermal expansion coefficient in ppm/°F of the structural material on which the gage is to be used. The following S-T-C numbers are available:

A: 00, 03, 05, 06, 09, 13, 15, 18, 30, 50

P: 08, 40

K: 00, 03, 05, 06, 09, 13, 15

D: Not available in self-temperature-compensated form. ‘DY’ is used instead.

W: Integral printed circuit terminal, polyimide encapsulation.

E: Polyimide encapsulation, leaving a portion of solder tab exposed.

SE: Solder dots plus polyimide encapsulation.

L: Preattached, soft, formable copper leads.

LE: Leads plus polyimide encapsulation.

P: Preattached leadwire cables and encapsulation.

P2: Preattached leadwire cables for CEA-Series gages.

Stress Analysis Strain Gages

GAGE SERIES	DESCRIPTION AND PRIMARY APPLICATION	TEMPERATURE RANGE	STRAIN RANGE	FATIGUE LIFE	
				STRAIN LEVEL IN $\mu\varepsilon$	NUMBER 0F CYCLES
EA	Constantan foil in combination with a tough, flexible, polyimide backing. Wide range of options available. Primarily intended for general-purpose static and dynamic stress analysis. Not recommended for highest accuracy transducers.	Normal: –100° to +350°F (–75° to +175°C) Special or short term: –320° to +400°F (–195° to +205°C)	±3% for gage lengths under 1/8 in (3.2 mm) ±5% for 1/8 in and over	±1800 ±1500 ±1200	10^5 10^6 10^8
CEA	Universal general-purpose strain gages. Constantan grid completely encapsulated in polyimide, with large, rugged copper-coated tabs. Primarily used for general-purpose static and dynamic stress analysis.	Normal: –100° to +350°F (–75° to +175°C) Stacked rosettes limited to +150°F (+65°C)	±3% for gage lengths under 1/8 in (3.2 mm) ±5% for 1/8 in and over	±1500 ±1500	10^5 10^{6*}
				*Fatigue life improved using low-modulus solder.	
C4A	General-purpose stress analysis strain gages. Supplied with preattached cables for direct connection to instrumentation. RoHS compliant, lead-free solder.	–60° to +180°F (–50° to +80°C)	±3%	±1700 ±1500	10^5 10^6
L2A	General-purpose stress analysis strain gages. Supplied with preattached leadwire ribbons. RoHS compliant, lead-free solder.	–100° to +250°F (–75° to +120°C)	±3%	±1700 ±1500	10^5 10^6
W2A IPX8S Rated	For water-exposure applications. Based on the CEA Series with Option P2 preattached cables, W2A strain gages are fully enclosed with a silicone rubber coating and tested to 10 GΩ insulation resistance, 1 meter water depth, 30 minutes duration. Other requirements can be addressed on demand. RoHS compliant, lead-free solder.	–60° to +180°F (–50° to +80°C)	±3%	±1500	10^5
N2A	Open-faced constantan foil gages with a thin, laminated, polyimide-film backing. Primarily recommended for use in precision transducers, the N2A Series is characterized by low and repeatable creep performance. Also recommended for stress analysis applications employing large gage patterns, where the especially flat matrix eases gage installation.	Normal static transducer service: –100° to +200°F (–75° to +95°C)	±3%	±1700 ±1500	10^6 10^7
WA	Fully encapsulated constantan gages with high-endurance leadwires. Useful over wider temperature ranges and in more extreme environments than EA Series. Option W available on some patterns, but restricts fatigue life to some extent.	Normal: –100° to +400°F (–75° to +205°C) Special or short term: –320° to +500°F (–195° to +260°C)	±2%	±2000 ±1800 ±1500	10^5 10^6 10^7
SA	Fully encapsulated constantan gages with solder dots. Same matrix as WA Series. Same uses as WA Series but derated somewhat in maximum temperature and operating environment because of solder dots.	Normal: –100° to +400°F (–75° to +205°C) Special or short-term: –320° to +450°F (–195° to +230°C)	±2%	±1800 ±1500	10^6 10^7

Stress Analysis Strain Gages

GAGE SERIES	DESCRIPTION AND PRIMARY APPLICATION	TEMPERATURE RANGE	STRAIN RANGE	FATIGUE LIFE	
				STRAIN LEVEL IN με	NUMBER OF CYCLES
EP	Specially annealed constantan foil with tough, high-elongation polyimide backing. Used primarily for measurements of large post-yield strains. Available with Options E, L, and LE (may restrict elongation capability).	–100° to +400°F (–75° to +205°C)	±10% for gage lengths under 1/8 in (3.2 mm) ±20% for 1/8 in and over	±1000	10^4
				EP gages show zero shift under high-cyclic strains.	
ED	Isoelastic foil in combination with tough, flexible polyimide film. High gage factor and extended fatigue life excellent for dynamic measurements. Not normally used in static measurements due to very high thermal-output characteristics.	Dynamic: –320° to +400°F (–195° to +205°C)	±2% Nonlinear at strain levels over ±0.5%	±2500 ±2200	10^6 10^7
WD	Fully encapsulated isoelastic gages with high-endurance leadwires. Used in wide-range dynamic strain measurement applications in severe environments.	Dynamic: –320° to +500°F (–195° to +260°C)	±1.5% Nonlinear at strain levels over ±0.5%	±3000 ±2500 ±2200	10^5 10^7 10^8
SD	Equivalent to WD Series, but with solder dots instead of leadwires.	Dynamic: –320° to +400°F (–195° to +205°C)	±1.5% Nonlinear at strain levels over ±0.5%	±2500 ±2200	10^6 10^7
EK	K-alloy foil in combination with a tough, flexible polyimide backing. Primarily used where a combination of higher grid resistances, stability at elevated temperature, and greatest backing flexibility are required. Supplied with Option DP.	Normal: –320° to +350°F (–195° to +175°C) Special or short term: –452° to +400°F (–269° to +205°C)	±1.5%	±1800	10^7
WK	Fully encapsulated K-alloy gages with high endurance leadwires. Widest temperature range and most extreme environmental capability of any general-purpose gage when self-temperature compensation is required. Option W available on some patterns, but restricts both fatigue life and maximum operating temperature.	Normal: –452° to +550°F (–269° to +290°C) Special or short term: –452° to +750°F (–269° to +400°C)	±1.5%	±2200 ±2000	10^6 10^7
SK	Fully encapsulated K-alloy gages with solder dots. Same uses as WK Series, but derated in maximum temperature and operating environment because of solder dots.	Normal: –452° to +450°F (–269° to +230°C) Special or short term: –452° to +500°F (–269° to +260°C)	±1.5%	±2200 ±2000	10^6 10^7
S2K	K-alloy foil laminated to 0.001 in (0.025 mm) thick, high-performance polyimide backing, with a laminated polyimide overlay fully encapsulating the grid and solder tabs. Provided with large solder dots for ease of leadwire attachment.	Normal: –100° to +250°F (–75° to +120°C) Special or short term: –300° to +300°F (–185° to +150°C)	±1.5%	±1800 ±1500	10^6 10^7

Notes:
The performance data given here are nominal, and apply primarily to gages of 0.125-in (3-mm) gage length or larger.
See individual data sheets for RoHS compliance of all Gage Series.

Strain Gage Selection: Criteria, Procedures, Recommendations

1.0 Introduction

The initial step in preparing for any strain gage installation is the selection of the appropriate gage for the task. It might at first appear that gage selection is a simple exercise, of no great consequence to the stress analyst; but quite the opposite is true. Careful, rational selection of gage characteristics and parameters can be very important in: optimizing the gage performance for specified environmental and operating conditions, obtaining accurate and reliable strain measurements, contributing to the ease of installation, and minimizing the *total* cost of the gage installation.

The installation and operating characteristics of a strain gage are affected by the following parameters, which are selectable in varying degrees:

- strain-sensitive alloy
- backing material (carrier)
- grid resistance
- gage pattern
- self-temperature compensation number
- gage length
- options

Basically, the gage selection process consists of determining the particular available combination of parameters which is most compatible with the environmental and other operating *conditions*, and at the same time best satisfies the installation and operating *constraints*. These constraints are generally expressed in the form of requirements such as:

- accuracy
- stability
- temperature
- elongation
- test duration
- cyclic endurance
- ease of installation
- environment

The cost of the strain gage itself is not ordinarily a prime consideration in gage selection, since the significant economic measure is the total cost of the complete installation, of which the gage cost is usually but a small fraction. In many cases, the selection of a gage series or optional feature which increases the gage cost serves to decrease the total installation cost.

It must be appreciated that the process of gage selection generally involves compromises. This is because parameter choices which tend to satisfy one of the constraints or requirements may work against satisfying others. For example, in the case of a small-radius fillet, where the space available for gage installation is very limited, and the strain gradient extremely high, one of the shortest available gages might be the obvious choice. At the same time, however, gages shorter than about 0.125 in (3 mm) are generally characterized by lower maximum elongation, reduced fatigue life, less stable behavior, and greater installation difficulty. Another situation which often influences gage selection, and leads to compromise, is the stock of gages at hand for day-to-day strain measurements. While compromises are almost always necessary, the stress analyst should be fully aware of the effects of such compromises on meeting the requirements of the gage installation. This understanding is necessary to make the best overall compromise for any particular set of circumstances, and to judge the effects of that compromise on the accuracy and validity of the test data.

The strain gage selection criteria considered here relate primarily to stress analysis applications. The selection criteria for strain gages used on transducer spring elements, while similar in many respects to the considerations presented here, may vary significantly from application to application and should be treated accordingly. The Micro-Measurements Applications Engineering Department can assist in this selection.

2.0 Gage Selection Parameters

2.1 Strain-Sensing Alloys

The principal component which determines the operating characteristics of a strain gage is the strain-sensitive alloy used in the foil grid. However, the alloy is not in every case an independently selectable parameter. This is because each Micro-Measurements strain gage series (identified by the first two, or three, letters in the alphanumeric gage designation) is designed as a complete system. That system is comprised of a particular foil and backing combination, and usually incorporates additional gage construction features (such as encapsulation, in-

Strain Gage Selection: Criteria, Procedures, Recommendations

tegral leadwires, or solder dots) specific to the series in question.

Micro-Measurements supplies a variety of strain gage alloys as follows (with their respective letter designations):

A: Constantan in self-temperature-compensated form.
P: Annealed constantan.
D: Isoelastic.
K: Nickel-chromium alloy, a modified Karma in self-temperature-compensated form.

2.1.1 Constantan Alloy

Of all modern strain gage alloys, constantan is the oldest, and still the most widely used. This situation reflects the fact that constantan has the best overall combination of properties needed for many strain gage applications. This alloy has, for example, an adequately high strain sensitivity, or *gage factor*, which is relatively insensitive to strain level and temperature. Its resistivity is high enough to achieve suitable resistance values in even very small grids, and its temperature coefficient of resistance is not excessive. In addition, constantan is characterized by good fatigue life and relatively high elongation capability. It must be noted, however, that constantan tends to exhibit a continuous drift at temperatures above +150°F (+65°C); and this characteristic should be taken into account when zero stability of the strain gage is critical over a period of hours or days.

Very importantly, constantan can be processed for self-temperature-compensation (see box at right) to match a wide range of test material expansion coefficients. A alloy is supplied in self-temperature-compensation (S-T-C) numbers 00, 03, 05, 06, 09, 13, 15, 18, 30, 40 and 50, for use on test materials with corresponding thermal expansion coefficients (expressed in ppm/°F).

For the measurement of very large strains, 5% (50 000 $\mu\varepsilon$) or above, annealed constantan (P alloy) is the grid material normally selected. Constantan in this form is very ductile; and, in gage lengths of 0.125 in (3 mm) and longer, can be strained to >20%. It should be borne in mind, however, that under high *cyclic* strains the P alloy will exhibit some permanent resistance change with each cycle, and cause a corresponding zero shift in the strain gage. Because of this characteristic, and the tendency for premature grid failure with repeated straining, P alloy is not ordinarily recommended for cyclic strain applications. P alloy is available with S-T-C numbers of 08 and 40 for use on metals and plastics, respectively.

2.1.2 Isoelastic Alloy

When purely dynamic strain measurements are to be made — that is, when it is not necessary to maintain a stable reference zero — isoelastic (D alloy) offers certain advantages. Principal among these are superior fatigue life, compared to A alloy, and a high gage factor (approximately 3.2) which improves the signal-to-noise ratio in dynamic testing.

D alloy is not subject to self-temperature-compensation. Moreover, as shown in the graph (see box), its thermal output is so high (about 80 $\mu\varepsilon$/°F (145 $\mu\varepsilon$/°C) that this alloy is not normally usable for static strain measurements. There are times, however, when D alloy finds application in special-purpose transducers where a high output is needed, and where a full-bridge arrangement can be used to achieve reasonable temperature compensation within the circuit.

Self-Temperature-Compensation

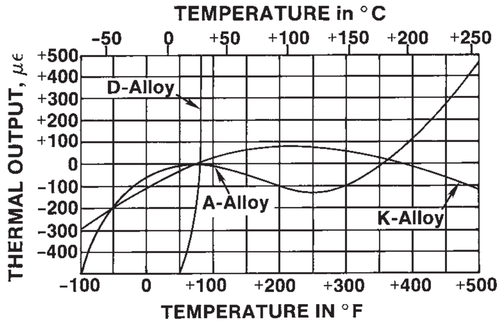
An important property shared by constantan and modified Karma strain gage alloys is their responsiveness to special processing for self-temperature-compensation. Self-temperature-compensated strain gages are designed to produce minimum thermal output (temperature-induced apparent strain) over the temperature range from about –50° to +400°F (–45° to +200°C). When selecting either constantan (A-alloy) or modified Karma (K-alloy) strain gages, the self-temperature-compensation (S-T-C) number must be specified. The S-T-C number

Strain Gage Selection: Criteria, Procedures, Recommendations

is the approximate thermal expansion coefficient in ppm/°F of the structural material on which the strain gage will display minimum thermal output.

The accompanying graph illustrates typical thermal output characteristics for A and K alloys. The thermal output of uncompensated isoelastic alloy is included in the same graph for comparison purposes. In normal practice, the S-T-C number for an A- or K-alloy gage is selected to most closely match the thermal expansion coefficient of the test material. However, the thermal output curves for these alloys can be rotated about the room-temperature reference point to favor a particular temperature range. This is done by intentionally mismatching the S-T-C number and the expansion coefficient in the appropriate direction. When the selected S-T-C number is lower than the expansion coefficient, the curve is rotated counterclockwise. An opposite mismatch produces clockwise rotation of the thermal output curve. Under conditions of S-T-C mismatch, the thermal output curves for A and K alloys do not apply, of course, and it will generally be necessary to calibrate the installation for thermal output as a function of temperature.

For additional information on strain gage temperature effects, see Tech Note TN-504.Other properties of D alloy should also be noted when considering the selection of this grid material. It is, for instance, magnetoresistive; and its response to strain is somewhat nonlinear, becoming significantly so at strains beyond ±5000 $\mu\varepsilon$.



Other properties of D alloy should also be noted when considering the selection of this grid material. It is, for instance, magnetoresistive; and its response to strain is somewhat nonlinear, becoming significantly so at strains beyond ±5000 $\mu\varepsilon$.

2.1.3 Karma Alloy

Modified Karma, or K alloy, with its wide areas of application, represents an important member in the family of strain gage alloys. This alloy is characterized by good fatigue life and excellent stability; and is the preferred choice for accurate static strain measurements over long periods of time (months or years) at room temperature, or lesser periods at elevated temperature. It is recommended for extended static strain measurements over the temperature range from –452° to +500°F (–269° to +260°C). For short periods, encapsulated K-alloy strain gages can be exposed to temperatures as high as +750°F (+400°C). An inert atmosphere will improve stability and extend the useful gage life at high temperatures.

Among its other advantages, K alloy offers a much flatter thermal output curve than A alloy, and thus permits more accurate correction for thermal output errors at temperature extremes. Like constantan, K alloy can be self-temperature-compensated for use on materials with different thermal expansion coefficients. The available S-T-C numbers in K alloy are limited, however, to the following: 00, 03, 05, 06, 09, 13, and 15. K alloy is the normal selection when a temperature-compensated gage is required that has environmental capabilities and performance characteristics not attainable in A-alloy gages.

Due to the difficulty of soldering directly to K alloy, the duplex copper feature, which was formerly offered as an option, is now standard on all Micro-Measurements open-faced strain gages produced with K alloy. The duplex copper feature is a precisely formed copper soldering pad (DP) or dot (DD), depending on the available tab area. All K-alloy gages which do not have leads or solder dots

Strain Gage Selection: Criteria, Procedures, Recommendations

are specified with DP or DD as part of the designation (in place of, or in addition to, the option specifier). The specific style of copper treatment will be advised when the Customer Service Department is contacted. Open-faced K-alloy gages may also be ordered with solder dots.

2.2 Backing Materials

Conventional foil strain gage construction involves a photo-etched metal foil pattern mounted on a plastic backing or carrier. The backing serves several important functions:

- provides a means for handling the foil pattern during installation
- presents a readily bondable surface for adhering the gage to the test specimen
- provides electrical insulation between the metal foil and the test object

Backing materials supplied on Micro-Measurements strain gages are of two basic types: polyimide and glass-fiber-reinforced epoxy-phenolic. As in the case of the strain-sensitive alloy, the backing is not completely an independently specifiable parameter. Certain backing and alloy combinations, along with special construction features, are designed as systems, and given gage series designations. As a result, when arriving at the optimum gage type for a particular application, the process does not permit the arbitrary combination of an alloy and a backing material, but requires the specification of an available gage series. Micro-Measurements gage series and their properties are described in the following *Section 2.3*. Each series has its own characteristics and preferred areas of application; and selection recommendations are given in the tables that follow. The individual backing materials are discussed here, as the alloys were in the previous section, to aid in understanding the properties of the series in which the alloys and backing materials occur.

The Micro-Measurements polyimide E backing is a tough and extremely flexible carrier, and can be contoured readily to fit small radii. In addition, the high peel strength of the foil on the polyimide backing makes polyimide-backed gages less sensitive to mechanical damage during installation. With its ease of handling and its suitability for use over the temperature range from –320° to +350°F (–195° to +175°C), polyimide is an ideal backing material for general-purpose static and dynamic stress analysis. This backing is capable of large elongations, and can be used to measure plastic strains in excess of 20%. Polyimide backing is a feature of Micro-Measurements EA-, CEA-, EP-, EK-, S2K-, N2A-, and ED-Series strain gages.

Micro-Measurements also offers the C2- and L2 laminated polyimide backing—a tough, flexible carrier, provided with an encapsulation layer to protect the grid. These backings can conform to a small radius or fillet and are typically found with Micro-Measurements pre-leaded and pre-cabled strain gages.

For outstanding performance over the widest range of temperatures, the glass-fiber-reinforced epoxy-phenolic backing material is the most suitable choice. This backing can be used for static and dynamic strain measurement from –452° to +550°F (–269° to +290°C). In short-term applications, the upper temperature limit can be extended to as high as +750°F (+400°C). The maximum elongation of this carrier material is limited, however, to about 1 to 2%. Reinforced epoxy-phenolic backing is employed on the following gage series: WA, WK, SA, SK, WD, and SD.

2.3 Gage Series

As noted in *Sections 2.1 and 2.2*, the strain-sensing alloy and backing material are not subject to completely independent selection and arbitrary combination. Instead, a selection must be made from among the available gage systems, or series, where each series generally incorporates special design or construction features, as well as a specific combination of alloy and backing material. For convenience in identifying the appropriate gage series to meet specified test requirements, the information on gage series performance and selection is presented in the two tables below, in condensed form.

Strain Gage Selection: Criteria, Procedures, Recommendations

The first table gives brief descriptions of all general-purpose Micro-Measurements gage series — including in each case the alloy and backing combination and the principal construction features. This table defines the performance of each series in terms of operating temperature range, strain range, and cyclic endurance as a function of strain level. It must be noted, however, that the performance data are *nominal*, and apply primarily to gages of 0.125 in (3 mm) or longer gage length.

Standard Strain Gage Series Selection Chart

Gage Series	Description and Primary Application	Temperature Range	Strain Range	Fatigue Life	
				Strain Level in $\mu\varepsilon$	Number of Cycles
EA	Constantan foil in combination with a tough, flexible, polyimide backing. Wide range of options available. Primarily intended for general-purpose static and dynamic stress analysis. Not recommended for highest accuracy transducers.	Normal: –100° to +350°F (–75° to +175°C) Special or Short-Term: –320° to +400°F (–195° to +205°C)	±3% for gage lengths under 1/8 in (3.2 mm); ±5% for 1/8 in and over	±1800 ±1500 ±1200	10^5 10^6 10^8
CEA	Universal general-purpose strain gages. Constantan grid completely encapsulated in polyimide, with large, rugged copper-coated tabs. Primarily used for general-purpose static and dynamic stress analysis. 'C'-Feature gages are specially highlighted throughout the gage listings of our Precision Strain Gages Data Book.	Normal: –100° to +350°F (–75° to +175°C) Stacked rosettes limited to +150°F (+65°C)	±3% for gage lengths under 1/8 in (3.2 mm); ±5% for 1/8 in and over	±1500 ±1500 *Fatigue life improved using low-modulus solder.	10^5 10^6*
C4A	General purpose stress analysis strain gages. Supplied with preattached cables for direct connection to instrumentation. RoHS compliant, lead-free solder.	–60° to +180°F (–50° to +80°C)	±3%	±1700 ±1500	10^5 10^6
L2A	General-purpose stress analysis strain gages. Supplied with preattached leadwire ribbons. RoHS compliant, lead-free solder.	–100° to +250°F (–75° to +120°C)	±3%	±1700 ±1500	10^5 10^6
W2A IPX8S Rated	For water-exposure applications. Based on the CEA Series with Option P2 preattached cables, W2A strain gages are fully enclosed with a silicone rubber coating and tested to 10 GΩ insulation resistance, 1 meter water depth, 30 minutes duration. Other requirements can be addressed on demand. RoHS compliant, lead-free solder.	–60° to +180°F (–50° to +80°C)	±3%	±1500	10^5
N2A	Open-faced constantan foil gages with a thin, laminated, polyimide-film backing. Primarily recommended for use in precision transducers, the N2A Series is characterized by low and repeatable creep performance. Also recommended for stress analysis applications employing large gage patterns, where the especially flat matrix eases gage installation.	Normal Static Transducer Service: –100° to +200°F (–75° to +95°C)	±3%	±1700 ±1500	10^6 10^7
WA	Fully encapsulated constantan gages with high-endurance leadwires. Useful over wider temperature ranges and in more extreme environments than EA Series. Option W available on some patterns, but restricts fatigue life to some extent.	Normal: –100° to +400°F (–75° to +205°C) Special or Short-Term: –320° to +500°F (–195° to +260°C)	±2%	±2000 ±1800 ±1500	10^5 10^6 10^7
SA	Fully encapsulated constantan gages with solder dots. Same matrix as WA Series. Same uses as WA Series but derated somewhat in maximum temperature and operating environment because of solder dots.	Normal: –100° to +400°F (–75° to +205°C) Special or Short-Term: –320° to +450°F (–195° to +230°C)	±2%	±1800 ±1500	10^6 10^7
EP	Specially annealed constantan foil with tough, high-elongation polyimide backing. Used primarily for measurements of large post-yield strains. Available with Options E, L, and LE (may restrict elongation capability).	–100° to +400°F (–75° to +205°C)	±10% for gage lengths under 1/8 in (3.2 mm); ±20% for 1/8 in and over	±1000 EP gages show zero shift under high-cyclic strains.	10^4

The performance data given here are *nominal*, and apply primarily to gages of 0.125-in (3-mm) gage length or larger.
See individual data sheets for RoHS compliance of all Gage Series.

Strain Gage Selection: Criteria, Procedures, Recommendations

Standard Strain Gage Series Selection Chart (cont.)

Gage Series	Description and Primary Application	Temperature Range	Strain Range	Fatigue Life	
				Strain Level in $\mu\varepsilon$	Number of Cycles
ED	Isoelastic foil in combination with tough, flexible polyimide backing. High gage factor and extended fatigue life excellent for dynamic measurements. Not normally used in static measurements due to very high thermal-output characteristics.	Dynamic: –320° to +400°F (–195° to +205°C)	±2% Nonlinear at strain levels over ±0.5%	±2500 ±2200	10^6 10^7
WD	Fully encapsulated isoelastic gages with high-endurance leadwires. Used in wide-range dynamic strain measurement applications in severe environments.	Dynamic: –320° to +500°F (–195° to +260°C)	±1.5% Nonlinear at strain levels over ±0.5%	±3000 ±2500 ±2200	10^5 10^7 10^8
SD	Equivalent to WD Series, but with solder dots instead of leadwires.	Dynamic: –320° to +400°F (–195° to +205°C)	±1.5% See above note	±2500 ±2200	10^6 10^7
EK	K-alloy foil in combination with a tough, flexible polyimide backing. Primarily used where a combination of higher grid resistances, stability at elevated temperature, and greatest backing flexibility are required.	Normal: –320° to +350°F (–195° to +175°C) Special or Short-Term: –452° to +400°F (–269° to +205°C)	±1.5%	±1800	10^7
WK	Fully encapsulated K-alloy gages with high-endurance leadwires. Widest temperature range and most extreme environmental capability of any general-purpose gage when self-temperature-compensation is required. Option W available on some patterns, but restricts both fatigue life and maximum operating temperature.	–452° to +550°F (–269° to +290°C) Special or Short-Term: –452° to +750°F (–269° to +400°C)	±1.5%	±2200 ±2000	10^6 10^7
SK	Fully encapsulated K-alloy gages with solder dots. Same uses as WK Series, but derated in maximum temperature and operating environment because of solder dots.	Normal: –452° to +450°F (–269° to +230°C) Special or Short-Term: –452° to +500°F (–269° to +260°C)	±1.5%	±2200 ±2000	10^6 10^7
S2K	K-alloy foil laminated to 0.001 in (0.025 mm) thick, high-performance polyimide backing, with a laminated polyimide overlay fully encapsulating the grid and solder tabs. Provided with large solder pads for ease of leadwire attachment.	Normal: –100° to +250°F (–75° to +120°C) Special or Short-Term: –300° to +300°F (–185° to +150°C)	±1.5%	±1800 ±1500	10^6 10^7

The performance data given here are *nominal*, and apply primarily to gages of 0.125-in (3-mm) gage length or larger.
See individual data sheets for RoHS compliance of all Gage Series.

The second table below gives the recommended gage series for specific test “profiles,” or sets of test requirements, categorized by the following criteria:

- type of strain measurement (static, dynamic, etc.)
- operating temperature of gage installation
- test duration
- accuracy required
- cyclic endurance required

This table provides the basic means for preliminary selection of the gage series for most conventional applications. It also includes recommendations for adhesives, since the adhesive in a strain gage installation becomes part of the gage system, and correspondingly affects the performance of the gage. This selection table, supplemented by the information in the first table, is used in conjunction with our Precision Strain Gages Data Book, to arrive at the complete gage selection. The procedure for accomplishing this is described in *Section 3.0* of this Tech Note.

When a test profile is encountered that is beyond the ranges specified in the above table, it can usually be assumed that the test requirements approach or exceed the performance limitations of available gages. Under these conditions, the interactions between gage performance characteristics become too complex for presentation in a simple table. In such cases, the user should consult our Applications Engineering Department for assistance in arriving at the best compromise.

Strain Gage Selection: Criteria, Procedures, Recommendations

Type of Test or Application	Operating Temperature Range	Test Duration in Hours	Accuracy Required **	Cyclic Endurance Required		Typical Selection	
				Maximum Strain, $\mu\varepsilon$	Number Of Cycles	Gage Series	M-Bond Adhesive
General Static or Static-Dynamic Stress Analysis*	–50° to +150°F (–45° to +65°C)	$<10^4$	Moderate	±1300	$<10^6$	C4A, L2A, W2A, CEA, EA	200 or AE-10
		$<10^4$	Moderate	±1300	$<10^6$	C4A, L2A, W2A, CEA, EA	AE-10 or AE-15
		$<10^4$	Very High	±1600	$<10^6$	WA, SA	AE-15 or 610
		$<10^4$	High	±2000	$<10^6$	WK, SK	AE-15 or 610
	–50° to +400°F (–45° to +205°C)	$<10^3$	Moderate	±1600	$<10^6$	WA, SA	600 or 610
		$<10^3$	High	±2000	$<10^6$	WK, SK	600 or 610
	–452° to +450°F (–269° to +230°C)	$<10^3$	Moderate	±2000	$>10^6$	WK, SK	610
	<600°F (<315°C)	$<10^2$	Moderate	±1800	$<10^6$	WK	610
	<700°F (<370°C)	<10	Moderate	±1500	$<10^6$	WK	610
High-Elongation (Post-Yield)	–50° to +150°F (–45° to +65°C)	<10	Moderate	±50 000	1	CEA, EA	AE-10
		$>10^3$	Moderate	±100 000	1	EP	AE-15
		$>10^3$	Moderate	±200 000	1	EP	A-12
	0° to +500°F (–20° to +260°C)	$<10^2$	Moderate	±15 000	1	SA, SK, WA, WK	610
	–452° to +500°F (–269° to +260°C)	$<10^3$	Moderate	±10 000	1	SK, WK	600 or 610
Dynamic (Cyclic) Stress Analysis	–100° to +150°F (–75° to +65°C)	$<10^4$	Moderate	±2000	10^7	ED	200 or AE-10
		$<10^4$	Moderate	±2400	10^7	WD	AE-10 or AE-15
	–320° to +500°F (–195° to +260°C)	$<10^4$	Moderate	±2000	10^7	WD	600 or 610
		$<10^4$	Moderate	±2300	10^6	WD	600 or 610
Transducer Gaging	–50° to +150°F (–45° to +65°C)	$<10^4$	1 to 5%	±1300	$<10^6$	CEA, EA	AE-10 or AE-15
		$<10^6$	1 to 5%	±1300	$<10^6$	CEA	AE-15
	–50° to +200°F (–45° to +95°C)	$<10^4$	Better than 0.2%	±1500	10^6	N2A	600, 610, or 43B
	–50° to +300°F (–45° to +150°C)	$<10^4$	0.2 to 0.5%	±1600	10^6	WA, SA	610
	–320° to +350°F (–195° to +175°C)	$<10^4$	Better than 0.5%	±1800	10^6	WK. SK	610

* This category includes most testing situations where some degree of stability under static test conditions is required. For absolute stability with constantan gages over long periods of usage and temperatures above +150°F (+65°C), it may be necessary to employ half- or full-bridge configurations. Protective coatings may also influence stability in cases other than transducer applications where the element is hermetically sealed.

** It is inappropriate to quantify "accuracy" as used in this table without consideration of various aspects of the actual test program and the instrumentation used. In general, "moderate" for stress analysis purposes is in the 2 to 5% range, "high" in the 1 to 3% range, and "very high" 1% or better.

Strain Gage Selection: Criteria, Procedures, Recommendations

As indicated in the previous table, the CEA Series is usually the preferred choice for routine strain-measurement situations, not requiring extremes in performance or environmental capabilities (and not requiring the very smallest in gage lengths, or specialized grid configurations). CEA-Series strain gages are polyimide-encapsulated A-alloy gages, featuring large, rugged, copper-coated tabs for ease in soldering leadwires directly to the gage (below). These thin, flexible gages can be contoured to almost any radius. In overall handling characteristics, for example, convenience, resistance to damage in handling, etc., CEA-Series gages are outstanding. The C4A Series strain gages have been a popular choice in particular for field applications where time is of the essence. The C4A Series gages are a laminated polyimide-encapsulated A-alloy gage with 10 feet of preattached vinyl cable which helps to save time during the gage installation, whether in the lab or in the field.

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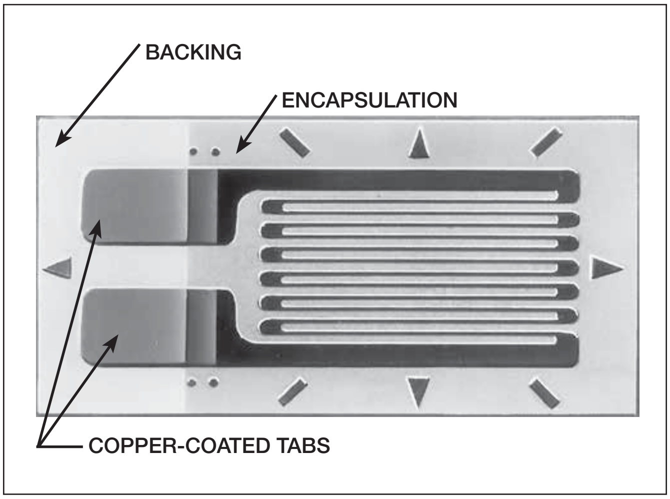
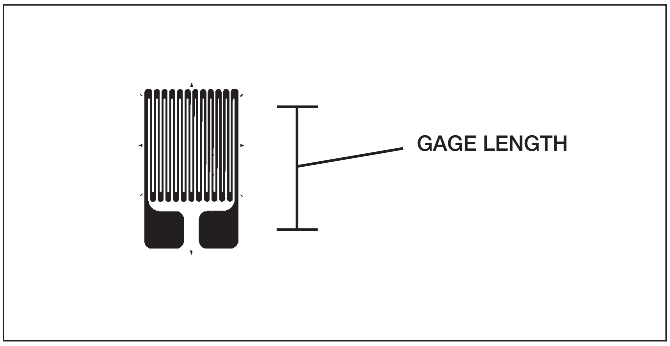


The W2A is one of Micro-Measurements' newest products that offers water resistance by adding a layer of RTV silicone rubber applied over the top of a traditional CEA Series gage pattern.

2.4 Gage Length

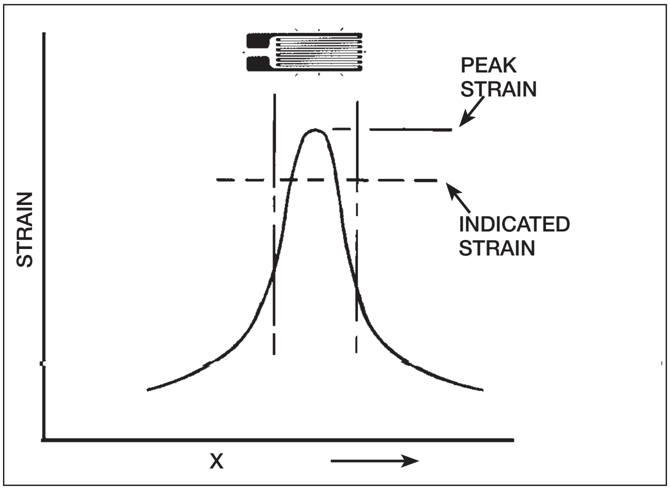
The gage length of a strain gage is the active or strain-sensitive length of the grid, as shown below. The end loops and solder tabs are considered insensitive to strain because of their relatively large cross-sectional area and low electrical resistance. To satisfy the widely varying needs of experimental stress analysis and transducer applications, Micro-Measurements offers gage lengths ranging from 0.008 in (0.2 mm) to 4 in (100 mm).



Gage length is often a very important factor in determining the gage performance under a given set of circumstances. For example, strain measurements are usually made at the most critical points on a machine part or structure — that is, at the most highly stressed points. And, very commonly, the highly stressed points are associated with stress concentrations, where the strain gradient is quite steep and the area of maximum strain is restricted to a very small region. The strain gage tends to integrate, or average, the strain over the area covered by the grid. Since the average of any nonuniform strain distribution is always less than the maximum, a strain gage which is noticeably larger than the maximum strain region will indicate a strain magnitude that is too low. The sketch above illustrates a representative strain distribution in the vicinity of a stress concentration, and

Strain Gage Selection:
Criteria, Procedures, Recommendations

demonstrates the error in strain indicated by a gage which is too long with respect to the zone of peak strain.



As a rule of thumb, *when practicable*, the gage length should be no greater than 0.1 times the radius of a hole, fillet, or notch, or the corresponding dimension of any other stress raiser at which the strain measurement is to be made. With stress-raiser configurations having the significant dimension less than, say, 0.5 in (13 mm), this rule of thumb can lead to very small gage lengths. Because the use of a small strain gage may introduce a number of other problems, it is often necessary to compromise.

Strain gages of less than about 0.125 in (3 mm) gage length tend to exhibit degraded performance — particularly in terms of the maximum allowable elongation, the stability under static strain, and endurance when subjected to alternating cyclic strain. When any of these considerations outweigh the inaccuracy due to strain averaging, a larger gage may be required.

When they can be employed, larger gages offer several advantages worth noting. They are usually easier to handle (in gage lengths up to, say, 0.5 in or 13 mm) in nearly every aspect of the installation and wiring procedure than miniature gages. Furthermore, large gages provide improved heat dissipation because they introduce, for the same nominal gage resistance, lower wattage per unit of grid area. This consideration can be very important when the gage is installed on a plastic or other substrate with poor heat transfer properties. Inadequate heat dissipation causes high temperatures in the grid, backing, adhesive, and test specimen surface, and may noticeably affect gage performance and accuracy (see Tech Note TN-502, Optimizing Strain Gage Excitation Levels).

Still another application of large strain gages — in this case, often very large gages — is in strain measurement on non-homogeneous materials. Consider concrete, for example, which is a mixture of aggregate (usually stone) and cement. When measuring strains in a concrete structure it is ordinarily desirable to use a strain gage of sufficient gage length to span several pieces of aggregate in order to measure the representative strain in the structure. In other words, it is usually the average strain that is sought in such instances, not the severe local fluctuations in strain occurring at the interfaces between the aggregate particles and the cement. In general, when measuring strains on structures made of composite materials of any kind, the gage length should normally be large with respect to the dimensions of the inhomogeneities in the material.

As a generally applicable guide, when the foregoing considerations do not dictate otherwise, gage lengths in the range from 0.125 to 0.25 in (3 to 6 mm) are preferable. The largest selection of gage patterns and stock gages is available in this range of lengths. Furthermore, larger or smaller sizes generally cost more, and larger gages do not noticeably improve fatigue life, stability, or elongation, while shorter gages are usually inferior in these characteristics.

2.5 Gage Pattern

The gage pattern refers cumulatively to the shape of the grid, the number and orientation of the grids in a multiple-grid gage, the solder tab configuration, and various construction features which are standard for a particular pattern. All details of the grid and solder tab configurations are illustrated in the “Gage Pattern” columns of our strain gage data book.

Strain Gage Selection:
Criteria, Procedures, Recommendations

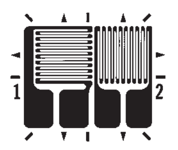
The wide variety of patterns in the list is designed to satisfy the full range of normal gage installation and strain measurement requirements.

With single-grid gages, pattern suitability for a particular application depends primarily on the following:

> *Solder tabs* — These should, of course, be compatible in size and orientation with the space available at the gage installation site. It is also important that the tab arrangement be such as to not excessively tax the proficiency of the installer in making proper leadwire connections.
>
> *Grid width* — When severe strain gradients perpendicular to the gage axis exist in the test specimen surface, a narrow grid will minimize the averaging error. Wider grids, when available and suitable to the installation site, will improve the heat dissipation and enhance gage stability — particularly when the gage is to be installed on a material or specimen with poor heat transfer properties.
>
> *Gage resistance* — In certain instances, the only difference between two gage patterns available in the same series is the grid resistance — typically 120 ohms vs. 350 ohms. When the choice exists, the higher-resistance gage is preferable in that it reduces the heat generation rate by a factor of three (for the same applied voltage across the gage). Higher gage resistance also has the advantage of decreasing leadwire effects such as circuit desensitization due to leadwire resistance, and unwanted signal variations caused by leadwire resistance changes with temperature fluctuations. Similarly, when the gage circuit includes switches, slip rings, or other sources of random resistance change, the signal-to-noise ratio is improved with higher resistance gages operating at the same power level.

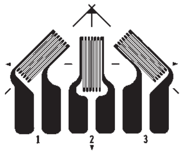
In experimental stress analysis, a single-grid gage would normally be used only when the stress state at the point of measurement is known to be uniaxial and the directions of the principal axes are known with reasonable accuracy (±5°).

These requirements severely limit the meaningful applicability of single-grid strain gages in stress analysis; and failure to consider biaxiality of the stress state can lead to large errors in the stress magnitude inferred from measurements made with a single-grid gage.



90-degree rosette

For a biaxial stress state — a common case necessitating strain measurement — a two- or three-element rosette is required in order to determine the principal stresses. When the directions of the principal axes are known in advance, a two-element 90-degree (or “tee”) rosette can be employed with the gage axes aligned to coincide with the principal axes. The directions of the principal axes can sometimes be determined with sufficient accuracy from one of several considerations. For example, the shape of the test object and the mode of loading may be such that the directions of the principal axes are obvious from the symmetry of the situation, as in a cylindrical pressure vessel. The principal axes can also be defined by PhotoStress® testing.

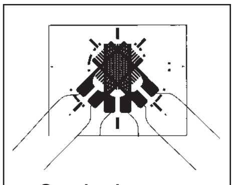


45-degree rosette

In the most general case of surface stresses, when the directions of the principal axes are not known from other considerations, a three-element rosette must be used to obtain the principal stress magnitudes. The rosette can be installed with any orientation, but is usually mounted so that one of the grids is aligned with some significant axis of the test object. Three-element rosettes are available in both 45-degree rectangular and 60-degree delta configurations. The usual choice is the rectangular rosette since the data-reduction task is somewhat simpler for this configuration.

60-degree rosette

Strain Gage Selection: Criteria, Procedures, Recommendations



Stacked rosette

When a rosette is to be employed, careful consideration should always be given to the difference in characteristics between single-plane and stacked rosettes. For any given gage length, the single-plane rosette is superior to the stacked rosette in terms of heat transfer to the test specimen, generally providing better stability and accuracy for static strain measurements. Furthermore, when there is a significant strain gradient perpendicular to the test surface (as in bending), the single-plane rosette will produce more accurate strain data because all grids are as close as possible to the test surface. Still another consideration is that stacked rosettes are generally less conformable to contoured surfaces than single-plane rosettes.

On the other hand, when there are large strain gradients in the plane of the test surface, as is often the case, the single-plane rosette can produce errors in strain indication because the grids sample the strain at different points. For these applications the stacked rosette is ordinarily preferable. The stacked rosette is also advantageous when the space for mounting the rosette is limited.

2.6 Optional Features

Micro-Measurements offers a wide selection of optional features for its general-purpose strain gages and special-purpose sensors. The addition of options to the basic gage construction usually increases the cost, but this is generally offset by the benefits. Examples are:

- Significant reduction of installation time and costs
- Reduction of the skill level necessary to make dependable installations
- Simplified installation of sensors in difficult locations on components or in the field
- Increased protection, both in handling during installation and shielding from the test environment
- Achievement of special performance characteristics

Availability of each option varies with gage series and pattern. Standard options are noted for each sensor in the product listing.

2.6.1 Standard Options

The optional features shown below are considered standard when they are listed with the gage series and pattern in the strain gage product datasheets. If the option desired is not listed, it may be available as a special order. Please contact our Applications Engineering Department for specific information.

Standard Option	Brief Description	Available on Gage Series
W	Integral Terminals and Encapsulation	As shown in the individual strain gage datasheet
E	Encapsulation with Exposed Tabs	
SE	Solder Dots and Encapsulation	
L	Preattached Leads	
LE	Preattached Leads and Encapsulation	
P	Preattached Leadwire Cables and Encapsulation	
P2	Preattached Leadwire Cables for CEA-Series Gages	
SP20	Increases solid-copper jumper wire length to 20 in.	C4A
SP35	10 feet of preattached 30 AWG, twisted, etched Teflon® leadwires	CEA, WK
R	Individually Furnished Resistance Value	Special order required
S	Solder Dots	
W3	Special Terminals	

Note 1: Products with designations and options shown in **bold** are not RoHS compliant.

Strain Gage Selection: Criteria, Procedures, Recommendations

2.6.2 Special Options

The following applies:

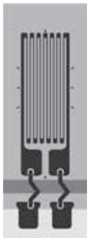
1. Availability will depend on the specific gage series and pattern.
2. A quotation is required and can be requested from our Customer Service Department.
3. A minimum order quantity may be required.
4. Whenever more than one Special Option is required, a custom part number will be assigned to the gage/option combination.

Special Option	Brief Description	Available on Gage Series
SP11-14	Single Batch of Foil per Order	All
SP21-24	'Modulus-Compensating' Foil	EK, WK, SK, S2K
SP30	Round Ni-Clad Copper Leads	EA, WA, ED, WD, EK, WK, EP
SP60	Special Encapsulation	Only on Manganin Gages
SP61	Preattached Leads and Encapsulation	N2A, N2P

2.6.3 Standard Options Descriptions

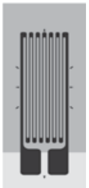
OPTION W **SERIES AVAILABILITY: EA, EP, WA, ED, WD, EK, WK**

General Description: This option provides encapsulation, and thin, printed circuit terminals at the tab end of the gage. Beryllium copper jumpers connect the terminals to the gage tabs. The terminals are 0.0014 in (0.036 mm) thick copper on polyimide backing nominally 0.0015 in (0.038 mm) thick. Option W gages are rugged and well protected, and permit the direct attachment of larger leadwires than would be possible with open-faced gages. This option is primarily used on EA-Series gages for general-purpose applications. **Solder:** +430°F (+220°C) tin-silver alloy solder joints on E-backed gages, +570°F (+300°C) lead-tin-silver alloy solder joints on W-backed gages. **Temperature Limit:** +350°F (+175°C) for E-backed gages, +450°F (+230°C) for W-backed gages. **Grid Protection:** Entire grid and part of terminals are encapsulated with polyimide. **Fatigue Life:** Some loss in fatigue life unless strain levels at the terminal location are below ±1000με. **Size:** Option W extends from the soldering tab end of the gages and thereby increases gage size. With some patterns, width is slightly greater. **Strain Range:** With some gage series, notably E-backed gages, strain range will be reduced. This effect is greatest with EP gages, and Option W should be avoided with them if possible. **Flexibility:** Option W adds encapsulation, making gages slightly thicker and stiffer. Conformance to curved surfaces will be somewhat reduced. In the terminal area itself, stiffness is markedly increased. **Resistance Tolerance:** On E-backed gages, resistance tolerance is normally doubled.



OPTION E **SERIES AVAILABILITY: EA, ED, EK, EP**

General Description: Option E consists of a protective encapsulation of polyimide film approximately 0.001 in (0.025 mm) thick. This provides ruggedness and excellent grid protection, with little sacrifice in flexibility. Soldering is greatly simplified since the solder is prevented from tinning any more of the gage tab than is deliberately exposed for lead attachment. Option E protects the grid from fingerprints and other contaminating agents during installation and, therefore, contributes significantly to long-term gage stability. Heavier leads may be attached directly to the gage tabs for simple static load tests. Supplementary protective coatings should still be applied after lead attachment in most cases. **Temperature Limit:** No degradation. **Grid Protection:** Entire grid and part of tabs are encapsulated. **Fatigue Life:** When gages are properly wired with small jumpers, maximum endurance is easily obtained. **Size:** Gage size is not affected. **Strain Range:** Strain range of gages will be reduced because the additional reinforcement of the polyimide encapsulation can cause bond failure before the gage reaches its full strain capability. **Flexibility:** Option E gages are almost as conformable on curved surfaces as open-faced gages, since no internal leads or solder are present at the time of installation. **Resistance Tolerance:** Resistance tolerance is normally doubled when Option E is selected.

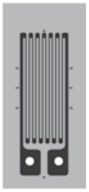


Strain Gage Selection: Criteria, Procedures, Recommendations

OPTION SE

SERIES AVAILABILITY: EA, ED, EK, EP

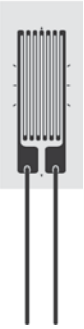
General Description: Option SE is the combination of solder dots on the gage tabs with a 0.001 in (0.025 mm) polyimide encapsulation layer that covers the entire gage. The encapsulation is removed over the solder dots providing access for lead attachment. These gages are very flexible, and well protected from handling damage during installation. Option SE is primarily intended for small gages that must be installed in restricted areas, since leadwires can be routed to the exposed solder dots from any direction. The option does not increase overall gage dimensions, so the matrix may be field-trimmed very close to the actual pattern size. Option SE is sometimes useful on miniature transducers of medium- or low-accuracy class, or in stress analysis work on miniature parts. **Solder:** +570°F (+300°C) lead-tin-silver alloy. To prevent loss of long-term stability, gages with Option SE must be soldered with noncorrosive (rosin) flux, and all flux residue should be carefully removed with *M-LINE* Rosin Solvent after wiring. Protective coatings should then be used. **Temperature Limit:** No degradation. **Grid Protection:** Entire gage is encapsulated. **Fatigue Life:** When gages are properly wired with small jumpers, maximum endurance is easily obtained. **Size:** Gage size is not affected. **Strain Range:** Strain range of gages will be reduced because the additional reinforcement of the polyimide encapsulation can cause bond failure before the gage reaches its full strain capability. **Flexibility:** Option SE gages are almost as conformable on curved surfaces as open-faced gages. **Resistance Tolerance:** Resistance tolerance is normally doubled when Option SE is selected.



OPTION L

SERIES AVAILABILITY: EA, ED, EK, EP

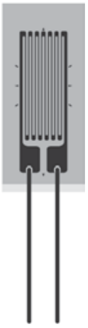
General Description: Option L is the addition of soft copper lead ribbons to open-faced polyimide-backed gages. The use of this type of ribbon results in a thinner and more conformable gage than would be the case with round wires of equivalent cross section. At the same time, the ribbon is so designed that it forms almost as readily in any desired direction. **Leads:** Nominal ribbon size for most gages is 0.012 wide x 0.004 in thick (0.30 x 0.10 mm). Leads are approximately 0.8 in (20 mm) long. **Solder:** +430°F (+220°C) tin-silver alloy. **Temperature Limit:** +400°F (+200°C). **Fatigue Life:** Fatigue life will normally be degraded by Option L. This occurs primarily because the copper ribbon has limited cyclic endurance. When it is possible to carefully dress the leads so that they are not bonded in a high strain field, the performance limitation will not apply. Option L is not often recommended for very high endurance gages such as the ED Series. **Size:** Matrix size is unchanged. **Strain Range:** Strain range will usually be reduced by the addition of Option L. **Flexibility:** Gages with Option L are not as conformable as standard gages. **Resistance Tolerance:** Not affected.



OPTION LE

SERIES AVAILABILITY: EA, ED, EK, EP

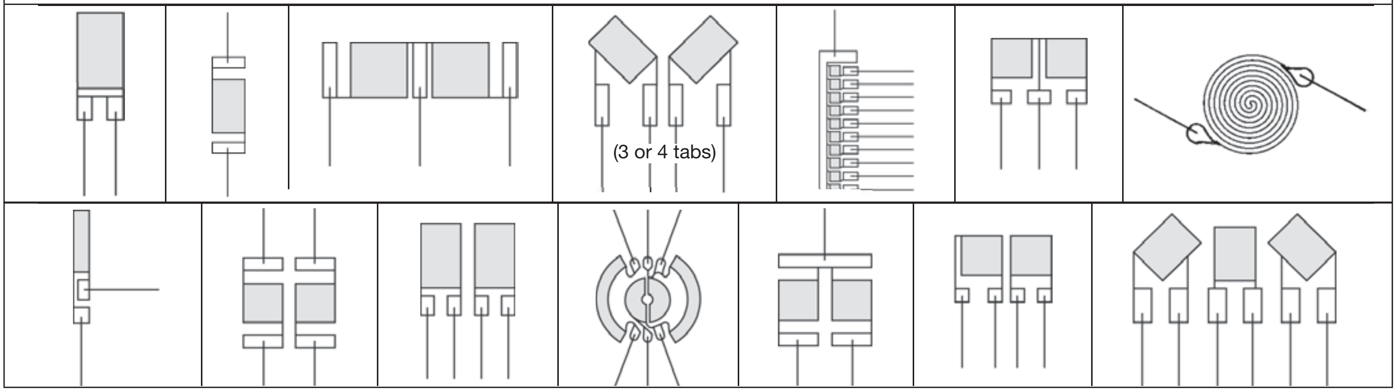
General Description: This option provides the same conformable soft copper lead ribbons as used in Option L, but with the addition of a 0.001 in (0.025 mm) thick encapsulation layer of polyimide film. The encapsulation layer provides excellent protection for the gage during handling and installation. It also contributes greatly to environmental protection, though supplementary coatings are still recommended for field use. Gages with Option LE will normally show better long-term stability than open-faced gages which are “waterproofed” only after installation. A good part of the reason for this is that the encapsulation layer prevents contamination of the grid surface from fingerprints or other agents during handling and installation. The presence of such contaminants will cause some loss in gage stability, even though the gage is subsequently coated with protective compounds. **Leads:** Nominal ribbon size for most gages is 0.012 wide x 0.004 in thick (0.30 x 0.10 mm) copper ribbons. Leads are approximately 0.8 in (20 mm) long. **Solder:** +430°F (+220°C) tin-silver alloy. **Temperature Limit:** +400°F (+200°C). **Grid Protection:** Entire gage is encapsulated. A short extension of the backing is left uncovered at the leadwire end to prevent contact between the leadwires and the specimen surface. **Fatigue Life:** Fatigue life will normally be degraded by Option LE. This occurs primarily because the copper ribbon has limited cyclic endurance. Option LE is not often recommended for very high endurance gages such as the ED Series. **Size:** Matrix size is unchanged. **Strain Range:** Strain range will usually be reduced by the addition of Option LE. **Flexibility:** Gages with Option LE are not as conformable as standard gages. **Resistance Tolerance:** Resistance tolerance is normally doubled by the addition of Option LE.



Strain Gage Selection: Criteria, Procedures, Recommendations

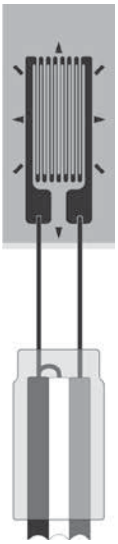
LEADWIRE ORIENTATION FOR OPTIONS L AND LE

These illustrations show the standard orientation of leadwires relative to the gage pattern geometry for Options L and LE. The general rule is that the leads are parallel to the longest dimension of the pattern. The illustrations also apply to leadwire orientation for WA-, WK- and WD-Series gages, when the pattern shown is available in one of these series.



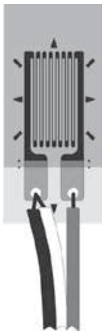
OPTION P — SERIES AVAILABILITY: EA, N2A

General Description: Option P is the addition of preattached leadwire cables to many patterns of EA Series strain gages. Encapsulation seals small "jumper" leadwires at gage end, and cable insulation protects solder joints at cable end. Option P virtually eliminates need for soldering during gage installation. **Leads:** A pair of 1 in (25 mm) *M-LINE* 134-AWP (solid copper, polyurethane enamel) single conductor "jumper" leadwires. **Cable:** 10 ft (3.1 m) of color-coded, flat, three-conductor 26-gauge (0.404 mm dia.), stranded, tinned copper with vinyl insulation (similar to M-LINE 326-DFV). Solder: +430°F (+220°C) tin-silver alloy solder joints, "jumper" to gage. Cable conductors and "jumpers" joined with +361°F solder beneath cable insulation. Exposed leadwires on unattached end of cable are pretinned for ease of hookup. **Temperature Limit:** –60° to +180°F (–50° to +80°C); limited by vinyl insulation on cable. **Grid Encapsulation:** Entire grid and tabs are encapsulated. **Fatigue Life:** Fatigue life will normally be degraded by Option P, primarily because the copper "jumper" wires have limited cyclic endurance. **Pattern Availability:** Most EA-Series single-grid patterns that are 0.062 in (1.5 mm) or greater gage length, with parallel solder tabs on one end of the grid, and suitable for encapsulation. (Consult our Applications Engineering Department for availability of Option P on other gage series/patterns, and for nonstandard cable lengths.) **Size:** Matrix size is unchanged. **Strain Range:** Strain range will usually be reduced by the addition of Option P. **Flexibility:** E-backed gages with Option P are not as conformable as standard gages. **Resistance Considerations:** Each conductor of the cable has a nominal resistance of 0.04 ohm/ft (0.13 ohm/m). Gage resistance is measured at gage tabs. **Gage Factor:** Gage factor is determined for gages without preattached cable. **Resistance Tolerance:** Resistance tolerance is normally ±0.5% for single-element gages, and ±0.6% for multiple-grid gages.



OPTION P2 — SERIES AVAILABILITY: CEA

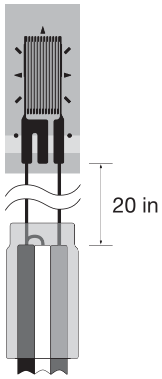
General Description: Option P2 is the addition of preattached leadwire cables to CEA-Series strain gages. Option P2 virtually eliminates need for soldering during gage installation. **Cable:** 10 ft (3.1 m) of color-coded, flat, three-conductor 30-gauge (0.255 mm), stranded, tinned copper with vinyl insulation (similar to *M-LINE* 330-DFV). Solder: +361°F (+180°C) tin-lead alloy solder joints. Exposed leadwires on unattached end of cable are pretinned for ease of hookup. **Temperature Limit:** –60° to +180°F (–50° to +80°C); limited by vinyl insulation on cable. **Grid Encapsulation:** Entire grid is encapsulated. (Solder tabs are not encapsulated.) **Fatigue Life:** Fatigue life will normally be unchanged by Option P2. **Pattern Availability:** Most CEA-Series single- and multiple-grid patterns. **Size:** Matrix size is unchanged. **Strain Range:** Standard for CEA-Series gages. **Flexibility:** No appreciable increase in stiffness. **Resistance Considerations:** Each conductor of the cable has a nominal resistance of 0.1 ohm/ft (0.35 ohm/m). Gage resistance is measured at gage tabs. **Gage Factor:** Gage factor is determined for gages without preattached cable. **Resistance Tolerance:** Not affected.



Strain Gage Selection:
Criteria, Procedures, Recommendations

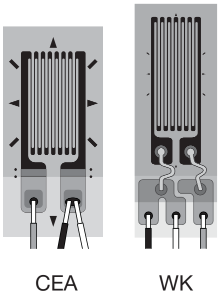
OPTION SP20	SERIES AVAILABILITY: C4A

General Description: This option provides preattached instrument cables which have been optimized for Printed Circuit Board (PCB) testing. The jumper wire between gage and instrument cable is the same 34 AWG single conductor, polyurethane insulated copper wire as the standard C4A-Series gages, but the length has been increased with this option to 20 in (0.5 m). This length of wire permits ease of routing the wires on the PCB and through the seal on vacuum test fixtures. The jumper wire transitions to the C4A-Series standard 10-ft (3-m) 26-AWG stranded instrument cable. On multi-grid strain gages, the instrument cable is numbered to match the grid numbering to which the cable is attached. This option does not change any other specifications of the standard C4A-Series. **Temperature range:** –60°F to +180°F (–50°C to +80°C).



OPTION SP35	SERIES AVAILABILITY: CEA, WK

General Description: Option SP35 provides 10 feet of 30 AWG, twisted, etched Teflon® leadwires (330-FTE) preattached to applicable CEA and WK series gages. This allows for a higher temperature rating compared to similar vinyl insulated preattached leaded gages (Option P, Option P2 and C4A series). CEA series gages will use our +430°F (+220°C) tin-silver alloy solder joints. WK series gages will have the standard Option W or W3 added as appropriate for the gage geometry (see Option W or W3 specifications), and will use our +450°F (+232°C) tin-alloy solder. **Temperature Limit:** +350°F (+177°C) for CEA gages, +400°F (+204°C) for WK gages. **Grid Protection:** Both the CEA and WK versions have an encapsulating layer over the grids. This helps to protect the sensing grids during the installation. **Fatigue Life:** The fatigue life will be the same as standard CEA series fatigue tables. While the WK series is slightly reduced (same as adding option W to the WK series gages). **Size:** The CEA versions will have the same dimensions as the parent gage. The WK versions with the option W will add to the matrix length dimension of the parent gage (varies slightly by pattern). **Strain Range:** CEA and WK with Option W strain range should be unaffected. **Flexibility:** The flexibility will be slightly affected by the Teflon as it is stiffer than a typical vinyl insulated wire of the same AWG. **Resistance Tolerance:** The resistance tolerance is increased to ±0.5% for planar gages and ±0.6% for stacked gages.



OPTION R	SERIES AVAILABILITY: ALL

The resistance of each gage is separately measured with an accurate digital ohmmeter and the exact value is recorded on the transparent folder that contains the gage. Resistance is given to the nearest 0.01 ohm, and the overall absolute accuracy is ±0.05% or better for gages of 60-ohm or greater resistance; thus allowing the user to select gages very closely matched in resistance from the total group of gages purchased. The necessary order quantity can be estimated for any matching requirements by assuming an even distribution of resistance values through the tolerance band, which is unchanged. Note: This feature is less effective for open-faced gages without leadwires or solder dots because of the uncertainty in leadwire position on the tabs with user-installed leadwires.

OPTION S	SERIES AVAILABILITY: EA, ED, EP

Precisely formed hemispherical solder dots are installed in the center of each solder tab. This feature facilitates soldering by providing a pretinned area for lead attachment. A film of adhesive or appropriate protective coating is normally applied over the gage before soldering, and this prevents the solder from spreading on the tab when leads are reinstalled. After the top coating has been cured, the solder dot is easily exposed for soldering by scraping with a scalpel or by simply post-tinning. Solder used for the dots is +570°F (+300°C) lead-tin-silver alloy. Dot diameter varies somewhat with tab size but is usually about 0.02 in (0.5 mm). Temperature limit for this feature is +500°F (+260°C). Because the solder dots result in much greater soldering uniformity, the variable fatigue life factor, which results from excessive solder on the gage tabs, is eliminated. Solder dots are small and interfere very little with flexibility and conformability of strain gages.

Strain Gage Selection: Criteria, Procedures, Recommendations

OPTION W3	SERIES AVAILABILITY: EA, EP, WA, ED, EK, WK

This feature is identical to Standard Catalog Option W, except that the printed circuit wiring terminals have three solder pads, two of which are electrically common. These terminals facilitate the connection of three-conductor cable for single active gage circuits using the three-wire lead system. Many of the gage patterns which are marked as available with Option W in the General-Purpose Strain Gage Listings are available with three-pad terminals.

2.6.4 Special Options Descriptions

OPTIONS SP11, 12, 13, 14	SERIES AVAILABILITY: ALL

These options specify that all sensors are supplied from a single process batch and lot of foil. They are primarily used to obtain the closest possible matching of performance characteristics from a large group of gages.

SP11: One sensor type from a single batch of processed foil
SP12: Two sensor types from a single batch of processed foil
SP13: Three sensor types from a single batch of processed foil
SP14: Four sensor types from a single batch of processed foil

OPTIONS SP21, 22, 23, 24	SERIES AVAILABILITY: EK, WK, SK, S2K

This option series provides strain gages with ‘Modulus Compensation’ features through use of specially modified lots of K alloy. The ‘Mod-Comp’ match will be quite close for the materials specified, although thermal output characteristics may not be ideal.

When force-responsive type transducers are manufactured from the metals listed, and the appropriate Special Option gages are used, the result is a transducer which demonstrates very little span change with temperature.

NOMINAL GAGE FACTOR SLOPE

Option	%/100°F	%/100°C	For Use On
SP21	–1.50	–2.70	Stainless Steels
SP22	–2.35	–4.25	Aluminum
SP23	–1.25	–2.25	Tool Steels
SP24	–1.35	–2.45	Tool Steels

OPTION SP30	SERIES AVAILABILITY: EA, WA, ED, WD, EK, WK, EP

General Description: This option consists of special leadwires, either added to open-faced gages, or substituted for lead ribbons on WA-, WK-, or WD-Series gages. The wire is very formable, and may be spot-welded or soldered to main leadwires. The primary advantages are easy handling and excellent resistance to oxidation at the highest temperatures the gages can withstand. **Leads:** 0.8 in (20 mm) long nickel-clad copper wires 0.005 in (0.13 mm) diameter. For some gage types, usually small patterns, wire size must be reduced to 0.0035 in (0.09 mm) diameter. **Solder:** EA-, ED-, EK-, EP-Series gages: +430°F (+220°C) tin-silver alloy; WA-Series gages: +570°F (+300°C) lead-tin-silver alloy; WK- and WD-Series gages: +770°F (+410°C) solder. **Temperature Limit:** E-backed gages: +400°F (+200°C); WA-Series gages: +500°F (+260°C); WKand WD-Series gages: +750°F (+400°C). **Fatigue Life:** Fatigue life will normally be degraded by Option SP30. This occurs primarily because the copper wire has limited cyclic endurance. Option SP30 should therefore not be used when best fatigue life is required, unless the tab area of the gage is in a low strain area (±1000με or less). Loss of cyclic endurance is experienced particularly with WA-, WK-, and WD-Series gages. **Size:** Matrix size is unchanged. On W-backed gages, SP30 leads are substituted for the normal beryllium copper ribbon leads. One wire lead per tab is supplied. **Strain Range:** Option SP30 normally reduces the strain range of E-backed gages but does not similarly affect W-backed gages. **Flexibility:** E-backed gages with SP30 leads are not as conformable as standard gages. W-backed gages are not affected. **Resistance Tolerance:** Not affected.

OPTION SP60	SERIES AVAILABILITY: ONLY ON MANGANIN GAGES

SP60 is an encapsulation option available for L-backed manganin gages. The end of each tab includes a thin copper coating that is left exposed for lead attachment.

Strain Gage Selection:
Criteria, Procedures, Recommendations

OPTION SP61	SERIES AVAILABILITY: N2A, N2P

General Description: This option provides conformable, soft copper lead ribbons and a 0.0005 in (0.013 mm) thick encapsulation layer of polyimide film. The encapsulation layer provides excellent protection for the gage during handling and installation. It also contributes greatly to environmental protection, though supplementary coatings are still recommended for field use. Gages with Option SP61 will normally show better long-term stability than open-faced gages which are “waterproofed” only after installation. A good part of the reason for this is that the encapsulation layer prevents contamination of the grid surface from fingerprints or other agents during handling and installation. The presence of such contaminants will cause some loss in gage stability, even though the gage is subsequently coated with protective compounds. **Leads:** 0.010 wide x 0.002 in thick (0.25 x 0.05 mm) soft copper ribbons. Leads are approximately 0.8 in (20 mm) long. **Solder:** +430°F (+220°C) tin-silver alloy. The solder is confined to small, well-defined areas at the end of each ribbon. **Temperature Limit:** +400°F (+200°C). **Grid Protection:** Entire gage is encapsulated. A short extension of the backing is left uncovered at the leadwire end to prevent contact between the leadwires and the specimen surface. **Size:** Matrix size is unchanged. **Strain Range:** Strain range will usually be reduced by the addition of Option SP61. **Flexibility:** Gages with Option SP61 are not as conformable as standard gages. **Resistance Tolerance:** Resistance tolerance is normally doubled by the addition of Option SP61.

2.7 Characteristics of Standard Catalog Options on EA-Series Gages

As in other aspects of strain gage selection, the choice of options ordinarily involves a variety of compromises. For instance, an option which maximizes a particular gage performance parameter such as fatigue life may at the same time require greater skill in installing the gage. Because of the many interactions between installation attributes and performance parameters associated with the options, the relative merits of all standard options are summarized qualitatively in the chart on page 60 as an aid to option selection. For comparison purposes, the corresponding characteristics of the CEA Series are given in the right-most column of the table.

Since, in strain measurement for stress analysis, the standard options are most frequently applied to EA-Series strain gages, the information supplied in this section is directed primarily toward such option applications.

When contemplating the application of an EA-Series gage with an option, the first consideration should usually be whether there is an equivalent CEA-Series gage that will satisfy the test requirements. Comparing, for example, an EA-Series gage equipped with Option W and a similar CEA-Series pattern, it will be found that the latter is characterized by lower cost, greater flexibility and conformability, and superior fatigue life. The only possible advantages for the selection of Option W are the wider variety of available patterns and the occasional need for large soldering terminals.

It should also be noted that many standard strain gage types, without options, are normally available from stock; while gages with options are commonly manufactured to order, and may thus involve a minimum order requirement.

In the following table, the respective performance parameters for an open-faced EA-Series gage without options are arbitrarily assigned a value of 5. Numbers greater than 5 indicate a particular parameter is improved by addition of the option, while smaller numbers indicate a reduction in performance.

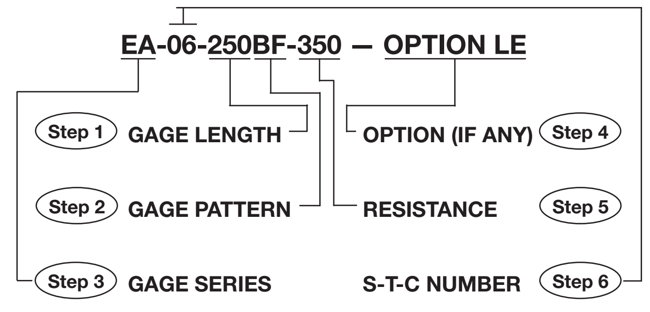
Installation Attribute or Performance Parameter	Standard Options					CEA Series
	W	E	SE	L	LE	
Overall Ease of Gage Installations	8	7	6	5	6	10
Ease of Leadwire Attachment	10	8	7	7	8	10
Protection of Grid from Environmental Attack	8	8	8	5	8	8
Cyclic Strain Endurance	2	7	8	3	4	4
Elongation Capability	2	3	3	4	3	3
Resistance Tolerance	3	3	3	5	3	3
Reinforcement Effects	2	3	3	5	3	3

Strain Gage Selection: Criteria, Procedures, Recommendations

3.0 Gage Selection Procedure

The performance of a strain gage in any given application is affected by every element in the design and manufacture of the gage. Micro-Measurements offers a great variety of gage types for meeting the widest range of strain measurement needs. Despite the large number of variables involved, the process of gage selection can be reduced to only a few basic steps. From the following diagram that explains the gage designation code, it is evident that there are but five parameters to select, not counting options. These are: the gage series, the S-T-C number, the gage length and pattern, and the resistance.

Strain Gage Selection Steps



Of the preceding parameters, the gage length and pattern are normally the first and second selections to be made, based on the space available for gage mounting and the nature of the stress field in terms of biaxiality and expected strain gradient. A good starting point for initial consideration of gage length is 0.125 in (3 mm). This size offers the widest variety of choices from which to select remaining gage parameters such as pattern, series and resistance. The gage and its solder tabs are large enough for relatively easy handling and installation. At the same time, gages of this length provide performance capabilities comparable to those of larger gages.

	CONSIDERATIONS FOR PARAMETER SELECTION
Selection Step: **1** *Parameter:* **Gage Length**	☐ strain gradients ☐ area of maximum strain ☐ accuracy required ☐ static strain stability ☐ maximum elongation ☐ cyclic endurance ☐ heat dissipation ☐ space for installation ☐ ease of installation
Selection Step: **2** *Parameter:* **Gage Pattern**	☐ strain gradients (in-plane and normal to surface) ☐ biaxiality of stress ☐ heat dissipation ☐ space for installation ☐ ease of installation ☐ gage resistance availability
Selection Step: **3** *Parameter:* **Gage Series**	☐ type of strain measurement application (static, dynamic, post-yield, etc.) ☐ operating temperature ☐ test duration ☐ cyclic endurance ☐ accuracy required ☐ ease of installation
Selection Step: **4** *Parameter:* **Options**	☐ type of measurement (static, dynamic, post-yield, etc.) ☐ installation environment — laboratory or field ☐ stability requirements ☐ soldering sensitivity of substrate (plastic, bone, etc.) ☐ space available for installation ☐ installation time constraints
Selection Step: **5** *Parameter:* **Gage Resistance**	☐ heat dissipation ☐ leadwire desensitization ☐ signal-to-noise ratio
Selection Step: **6** *Parameter:* **S-T-C Number**	☐ test specimen material ☐ operating temperature range ☐ accuracy required

The principal reason for selecting a longer gage would commonly be one of the following: (a) greater grid area for better heat dissipation; (b) improved strain averaging on inhomogeneous materials such as fiber-reinforced composites; or (c) slightly easier handling and installation [for gage lengths up to 0.50 in (13 mm)]. On the other hand, a shorter gage length may be necessary when the object is

Strain Gage Selection: Criteria, Procedures, Recommendations

to measure localized peak strains in the vicinity of a stress concentration, such as a hole or shoulder. The same is true, of course, when the space available for gage mounting is very limited.

In selecting the gage pattern, the first consideration is whether a single-grid gage or rosette is required (see Section 2.5). Single-grid gages are available with different aspect (length-to-width) ratios and various solder tab arrangements for adaptability to differing installation requirements. Two-element 90-degree rosettes, when applicable, can also be selected from a number of different grid and solder tab configurations. With three-element rosettes (rectangular or delta), the primary choice in pattern selection, once the gage length has been determined, is between planar and stacked construction, as described in Section 2.5.

The format of our strain gage data book is designed to simplify selection of the gage length and pattern. Similar patterns available in each gage length are grouped together, and listed in order of size. The strain gages in the main listing (large pictures) are the most widely used for stress analysis applications. This section should always be reviewed first to locate an appropriate gage.

With an initial selection of the gage size and pattern completed, the next step is to select the gage series, thus determining the foil and backing combination, and any other features common to the series. This is accomplished by referring to the earlier chart, which gives the recommended gage series for specific test “profiles”, or sets of test requirements. If the gage series is to have a standard option applied, the option should be tentatively specified at this time, since the availability of the desired option on the selected gage pattern in that series requires verification during the procedure outlined in the following paragraph.

After selecting the gage series (and option, if any), reference is made again to our Precision Strain Gages Data Book to record the gage designation of the desired gage size and pattern in the recommended series. If this combination is not listed as available in the catalog, a similar gage pattern in the same size group, or a slightly different size in an equivalent pattern, can usually be selected for meeting the installation and test requirements. In extreme cases, it may be necessary to select an alternate series and repeat this process. Quite frequently, and especially for routine strain measurement, more than one gage size and pattern combination will be suitable for the specified test conditions. In these cases, it is wise to select a gage from the main listings (large pictures) to eliminate the likelihood of extended delivery time or a minimum order requirement.

As noted under the gage pattern discussion on page 55, there are often advantages from selecting the 350-ohm resistance if this resistance is compatible with the instrumentation to be used. This decision may be influenced, however, by cost considerations, particularly in the case of very small gages. Some reduction in fatigue life can also be expected for the high-resistance small gages. Finally, in recording the complete gage designation, the S-T-C number should be inserted from the list of available numbers for each alloy given in this Tech Note.

This completes the gage selection procedure. In each step of the procedure, the Strain Gage Selection Checklist provided in Section 4.0 should be referred to as an aid in accounting for the test conditions and requirements which could affect the selection.

4.0 Strain Gage Selection Checklist

This checklist is provided as a convenient, rapid means for helping make certain that no critical requirement of the test profile which could affect gage selection is overlooked. It should be borne in mind in using the checklist that the “considerations” listed apply to relatively routine and conventional stress analysis situations, and do not embrace exotic applications involving nuclear radiation, intense magnetic fields, extreme centrifugal forces, and the like.

Strain Gage Selection:
Criteria, Procedures, Recommendations

5.0 Gage Selection Examples

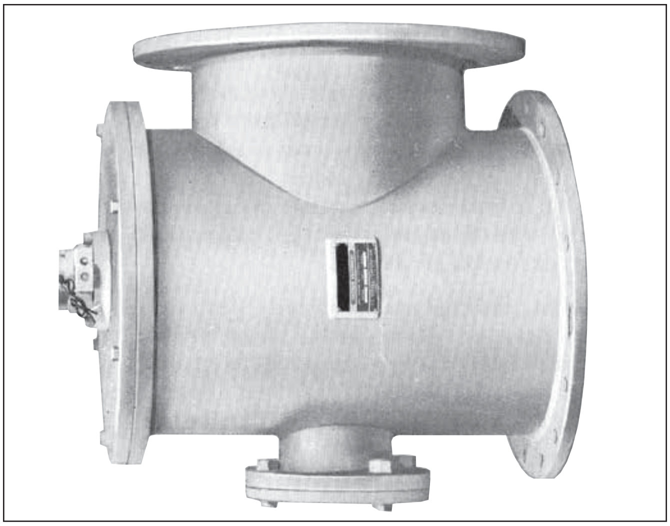
In this section, three examples are given of the gage-selection procedure in representative stress analysis situations. An attempt has been made to provide the principal reasons for the particular choices which are made. It should be noted, however, that an experienced stress analyst does not ordinarily proceed in the same step-by-step fashion illustrated in these examples. Instead, simultaneously keeping in mind the test conditions and environment, the gage installation constraints, and the test requirements, the analyst reviews our strain gage data book and quickly segregates the more likely candidates from among the available gage-pattern and series combinations in the appropriate sizes. The selection criteria are then refined in accordance with the particular strain-measurement task to converge on the gage or gages to be specified for the test program. Whether formally or otherwise, the knowledgeable practitioner does so in the light of parameter selection considerations such as those itemized in the preceding checklist.

A. Design Study of a Pressure Vessel

Strain measurements are to be made on a scaled-down plastic model of a pressure vessel. The model will be tested statically at, or near, room temperature; and, although the tests may be conducted over a period of several months, individual tests will take only a few hours to run.

Gage Selection:

1. *Gage Length* — Very short gage lengths should be avoided in order to minimize heat dissipation problems caused by the low thermal conductivity of the plastic. The model is quite large, and apparently free of severe strain gradients; therefore, a 0.25-in (6.3-mm) gage length is specified, because the widest selection of gage patterns is available in this length.
2. *Gage Pattern* — In some areas of the model, the directions of the principal axes are obvious from considerations of symmetry, and single-grid gages can be employed. Of the patterns available in the selected gage length, the 250BF pattern is a good compromise because of its high grid resistance which will help minimize heat dissipation problems.



3. In other areas of the model, the directions of the principal axes are not known, and a three-element rosette will be required. For this purpose, a “planar” rosette should be selected, since a stacked rosette would contribute significantly to reinforcement and heat dissipation problems. Because of its high-resistance grid, the 250RD pattern is a good choice.
4. *Gage Series* — The polyimide (E) backing is preferred because its low elastic modulus will minimize reinforcement of the plastic model. Because the normal choice of grid alloy for static strain measurement at room temperature is the A alloy, the EA Series should be selected for this application.
5. *Options* — Excessive heat application to the test model during leadwire attachment could damage the material. Option L (preattached leads) is therefore selected so that the instrument cable can be attached directly to the leads without the application of a soldering iron to the gage proper. Option L is preferable over Options LE and P because the encapsulation in the latter options would add reinforcement.

Strain Gage Selection: Criteria, Procedures, Recommendations

6. *Resistance* — In this case, the resistance was determined in Step 2 when the higher resistance alternative was selected from among the gage patterns; i.e., in selecting the 250BF over the 250BG, and the 250RD over the 250RA. The selected gage resistance is thus 350 ohms.
7. *S-T-C Number* — Ideally, the gages should be self-temperature-compensated to match the model material, but this is not always feasible, since plastics — particularly reinforced plastics — vary widely in thermal expansion coefficient. For unreinforced plastic, S-T-C 30, 40 or 50 should usually be selected.

8. If a mismatch between the model material and the S-T-C number is necessary, S-T-C 13 should be selected (because of stock status), and the test performed at constant temperature.

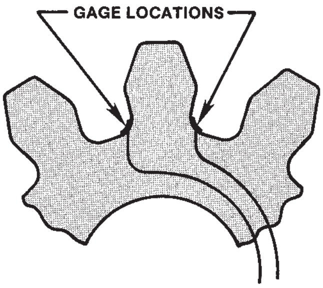
Gage Designations:

From the above steps, the strain gages to be used are:

EA-30-250BF-350/Option L (single-grid)
EA-30-250RD-350/Option L (rosette)

B. Dynamic Stress Analysis Study of a Spur Gear in an Hydraulic Pump

Strain measurements are to be made at the root of the gear tooth while the pump is operating. The fillet radius at the tooth root is 0.125 in (or about 3 mm) and test temperatures are expected to range from 0° to +180°F (–20° to +80°C).



Gage Selection:

1. *Gage Length* — A gage length which is small with respect to the fillet radius should be specified for this application. A length of 0.015 in (0.38 mm) is preferable, but reference to our strain gage data book indicates that such a choice severely limits the available gage patterns and grid alloys. Anticipating problems which would otherwise be encountered in Steps 2 and 3, a gage length of 0.031 in (0.8 mm) is selected.
2. *Gage Pattern* — Because the gear is a spur gear, the directions of the principal axes are known, and single-grid gages can be employed. A gage pattern with both solder tabs at the same end should be selected so that leadwire connections can be located in the clearance area along the root circle between adjacent teeth. In the light of these considerations, the 031CF pattern is chosen for the task.
3. *Gage Series* — Low strain levels are expected in this application; and, furthermore, the strain signals must be transmitted through slip rings or through a telemetry system to get from the rotating component to the stationary instrumentation. Isoelastic (D alloy) is preferred for its higher gage factor (nominally 3.2, in contrast to 2.1 for A and K alloys). Because the gage must be very flexible to conform to the small fillet radius, the E backing is the most suitable choice. The maximum test temperature is not a consideration in this case, since it is well within the recommended temperature range for any of the standard backings. The combination of the E backing and the D alloy defines the ED gage series.
4. *Options* — For protection of the gage grid in the test environment, Option E, encapsulation, should be specified. Because of the limited clearance between the outside diameter of one gear and the root circle of the mating gear, a particularly thin gage installation must be made; and very small leadwires will be attached to the gage tabs at 90° to the grid direction, and run over the sides of the gear for connection to larger wires. This requirement necessitates attachment of the small

Strain Gage Selection: Criteria, Procedures, Recommendations

leadwires after gage bonding, and prevents the use of preattached leads.

5. *Resistance* — In the ED-Series version of the 031CF gage pattern, our strain gage data book lists the resistance as 350 ohms. The higher resistance should usually be selected whenever the choice exists, and will be advantageous in this instance in improving the signal-to-noise ratio when slip rings are used.
6. *S-T-C Number* — D alloy is not subject to self-temperature-compensation, nor is compensation needed for these tests since only dynamic strain is to be measured. In the ED-Series designation the two-digit S-T-C number is replaced by the letters DY for "dynamic."

Gage Designation:

Combining the results of the above selection procedure, the gage to be employed is:

ED-DY-031CF-350/Option E

C. Flight-Test Stress Analysis of a Titanium Aircraft Wing Tip Section — With, and Without, a Missile Module Attached

The operating temperature range for strain measurements is from –65° to +450°F (–55° to +230°C), and will be a dominant factor in the gage selection.

Gage Selection:

1. *Gage Length* — Preliminary design studies using the PhotoStress® photoelastic coating technique indicate that a gage length of 0.062 in (1.6 mm) represents the best compromise in view of the strain gradients, areas of peak strain, and space for gage installation.
2. *Gage Pattern* — With information about the stress state and directions of principal axes gained from the photoelastic coating studies, there are some areas of the wing tip where single-grid gages and two-element "tee" rosettes can be employed. In other locations, where principal strain directions vary with the nature of the flight maneuver, 45-degree rectangular rosettes are required.

   The strain gradients are sufficiently steep that stacked rosettes should be selected. From our strain gage data book, the foregoing requirements suggest the selection of 060WT and 060WR gage patterns for the stacked rosettes, and the 062AP pattern for the single-grid gage. In making this selection, attention was given to the fact that all three patterns are available in the WK Series, which is compatible with the specified operating temperature range.
3. *Gage Series* — The maximum operating temperature, along with the requirement for static as well as dynamic strain measurement, clearly dictates use of K alloy for the grid material. Either the SK or WK Series could be selected, but the WK gages are preferred because they have integral leadwires.
4. *Options* — For ease of gage installation, Option W, with integral soldering terminals, is advantageous. This option is not applicable to stacked rosettes, however, and is therefore specified for only the single-grid gages.
5. *Resistance* — When available, as in this case, 350-ohm gages should be specified because of the benefits associated with the higher gage resistance.
6. *S-T-C Number* — The titanium alloy used in the wing tip section is the 6Al-4V type, with a thermal expansion coefficient of 4.9 × 10–6 per °F (8.8 × 10–6 per °C). K alloy of S-T-C number 05 is the appropriate choice.

Gage Designations:

WK-05-062AP-350/Option W
WK-05-060WT-350
WK-05-060WR-350

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General Information and Selection Guide

General Information and Selection

Materials List

- Solvent cleaners
- Water-based cleaners
- Surface-abrasion materials
- Special-purpose materials

Description

For proper bonding of strain gages and temperature sensors, the workpiece surface must be chemically clean and totally free of contaminants before applying the adhesive. Recommended surface cleaning procedures for all common structural materials are described in Instruction Bulletin B-129, “Surface Preparation for Strain Gage Bonding”.

In the case of steel and aluminum parts with finish-machined or formed surfaces, the surface cleaning procedure can be summarized briefly as follows:

1. Removal of oily contaminants with a solvent cleaner. **Note:** Immersion of the workpiece in a degreaser is, by itself, inadequate; and, if done as a preliminary step, must be followed by cleaning with an uncontaminated solvent (one which is never returned to the container or otherwise reapplied after contact with the workpiece).
2. Light abrasion in the presence of a mildly acidic wash, to dislodge and remove oxides and mechanically bound contaminants.

3. Thorough surface scrubbing with an alkaline solution, to finish the cleaning process and leave the surface at the appropriate pH level for optimum bonding.

When the cleaning procedure is performed strictly according to the instructions in Instruction Bulletin B-129, and when the proper high-quality cleaning agents are used, the surface will be left in a condition best suited for bonding.

Following is a complete assortment of cleaning supplies, selected specifically for surface preparation in the installation of strain gages and bondable temperature sensors.

SOLVENT CLEANERS	
MODEL/PART NO.	TYPE/DESCRIPTION
CSM-3	**Degreaser:** A powerful environmentally friendly degreaser. Readily attacks general-purpose lubricating and hydraulic oils. 20-oz (0.56-kg) pressured spray can. Dispensing solvents from “one way” containers prevents contamination buildup. Two-year shelf life.
GC-6	**Isopropyl Alcohol:** Frequently used as a solvent degreaser where other solutions are restricted, such as with most plastics. Flammable. 4-oz (120-ml) bottle.

General Information and Selection

WATER-BASED CLEANERS

Final surface preparation for most materials is accomplished with M-Prep Conditioner A immediately followed by M-Prep Neutralizer 5A

MODEL/PART NO.	TYPE/DESCRIPTION
CONDITIONER A: A mild phosphoric-acid compound. Acts as a mild etchant and accelerates the cleaning process. Shelf Life: 1 year at +75°F (+24°C).	
MCA-1	2-oz* (60-ml) plastic squeeze bottle with on/off dispenser nozzle cap.
MCA-2	Same as MCA-1 except 16 oz (0.5 l).
MCA-3	Same as MCA-1 except 32 oz (0.95 l).
NEUTRALIZER 5A: An ammonia-based material. Neutralizes any chemical reaction introduced by Conditioner A, and produces optimum surface conditions for most strain gage adhesives. Shelf Life: 1 year at +75°F (+24°C).	
MN5A-1	2-oz* (60-ml) plastic squeeze bottle with on/off dispenser nozzle bottle cap.
MN5A-2	Same as MN5A-1 except 16 oz (0.5 l).
MN5A-3	Same as MN5A-1 except 32 oz (0.95 l).

*__Note:__ The 2-oz (60-ml) size is recommended for bench use and is easily refilled from the 16-oz (0.5-l) bottle.

SURFACE-ABRASION MATERIALS

Abrading is often necessary to dislodge contaminants and to remove rust, scale, etc. When grit-blasting is necessary, use fine alumina powder and high-quality filters, and never recycle used grit. In general, wet-or-dry silicon-carbide paper is most suitable.

MODEL/PART NO.	TYPE/DESCRIPTION
SCP-1	**220-grit Wet-or-Dry Silicon-Carbide Paper:** Suited to most steels. 1 in x 100 ft (25 mm x 30 m) roll.
SCP-2	**320-grit Wet-or-Dry Silicon-Carbide Paper:** Suited to most steels. Also suited to aluminum alloys and other soft metals. 1 in x 100 ft (25 mm x 30 m) roll.
SCP-3	**400-grit Wet-or-Dry Silicon-Carbide Paper:** Suited to aluminum alloys and other soft metals. 1 in x 100 ft (25 mm x 30 m) roll.
GC-5	**Pumice Powder:** Produces a dull, matte finish. Recommended for minimal removal of surface material. 1/2 oz (15 ml) bottle.

SPECIAL-PURPOSE MATERIALS

MODEL/PART NO.	TYPE/DESCRIPTION
TEC-1	**Tetra-Etch® Compound:** Used for etching Teflon® to render the surface bondable. Shelf life 3 months at +32°F (0°C). 2 oz (60 ml) can.
CSP-1	**Cotton Tip Applicators:** 100 single-ended applicators per package [6 in (150 mm) long, wooden stick].
GSP-1	**Gauze Sponges:** 200 sponges [3 x 3 in (75 x 75 mm)] per package.

TetraEtch is a Registered Trademark of W. L. Gore.
Teflon is a Registered Trademark of DuPont.

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Strain Gage Adhesives and Cements Chart

General Information and Selection Guide

Because a strain gage can perform no better than the adhesive with which it is bonded to the test member, the adhesive is a vitally important component in every strain gage installation. Although there is no single adhesive ideally suited to all applications, Micro-Measurements offers a wide selection of adhesives to cover the spectrum of stress analysis testing, and for use in transducer manufacturing. Micro-Measurements adhesives are specially formulated and selected for highest performance under the recommended environmental conditions, and are packaged to provide for ease of mixing and application.

Each adhesive is accompanied by specific instructions for its proper handling—storage, mixing, application, curing, and, if appropriate, post-curing. The adhesive containers are also dated to assure freshness of the contents.

Note: It is usually misguided economy to attempt installing strain gages with outdated adhesive, or adhesive that has not been stored as recommended. It should also be noted that conventional industrial and consumer adhesives are not generally suitable for bonding strain gages.

Since different adhesives are intended for different types of applications and different environmental conditions, it is obviously important to select the most appropriate adhesive for each strain measurement task. The table below lists all of the Micro-Measurements adhesives, while the table on the following page is provided as a guide for selecting the most appropriate adhesive for compatibility with a particular strain gage series and test environment.

TYPES AND FEATURES	
M-BOND 200	Most widely used general-purpose adhesive. Easiest to handle. Fast room-temperature curing.
M-BOND AE-10	General-purpose adhesive highly resistant to moisture and most chemicals. Room-temperature curing.
M-BOND GA-2	Special-purpose adhesive primarily used on very rough and irregular surfaces. Room-temperature curing.
RTC-2 EPOXY	General-purpose, room-temperature curing adhesive for lab and field applications with high-elongation strain gages. Also excellent for strain measurement at cryogenic temperatures.
M-BOND A-12	Special-purpose, very high-elongation adhesive. Used only when other adhesives cannot meet elongation requirements. Elevated-temperature curing.
M-BOND AE-15	Similar to AE-10. Recommended for more critical applications, including transducer gaging. Moderately elevated-temperature curing.
M-BOND GA-61	Special-purpose adhesive with a higher operating temperature range than GA-2, and more viscous. Also used to fill irregular surfaces and to anchor leadwires. Elevated-temperature curing.
EPOXYLITE 813	Used for long term, high temperature applications requiring a filled glueline. Wider temperature range than GA-61.
EPY-500	Two-part, heat-curing, filled epoxy system with a wide temperature range.
QA-500	Two-component, clear liquid and powder adhesive for use with strain gages. Has excellent moisture and chemical resistance.
M-BOND 610	Used primarily in stress analysis applications over a wide temperature range, and in precision transducers. Elevated-temperature curing.
M-BOND 600	Similar to 610, but faster reacting. Can be cured at somewhat lower temperatures than 610.
M-BOND 43-B	Normally used in precision transducers. Highly resistant to moisture and chemical attack. Elevated-temperature curing.
M-BOND 450	Special-purpose, high-performance epoxy for higher-temperature transducer applications.
DENEX #3	One-part epoxy for lab and transducer work requiring minimal creep. Elevated temperature curing.
P	Single-part solvent thinned polyimide adhesive. Excellent for long-term high temperature applications.
M-BOND 300	Special-purpose polyester adhesive used primarily when low-temperature curing is required. Sensitive to solvents. Not recommended as a general-purpose adhesive.

General Information and Selection Guide

TYPES AND FEATURES (cont.)	
NCC-3	Ceramic cement for bonding free-filament strain gages. Has superior bond strength to super-alloy materials, stainless steel, and titanium. Not for use on mild steel.
WC-16	Ceramic cement for bonding free-filament strain gages to materials with low thermal expansion coefficients. Not for use on iron-based alloys.
HG-1	Ceramic cement for bonding free-filament strain gages to most metals. Thermal expansion coefficient closely matches that of steel.
GC	Single-part ceramic cement used for free-filament gages. Recommended for use on low TCE materials, such as carbon.
H CEMENT	One-part ceramic cement/coating used for free filament strain gages. Good adhesion to most metals.
PBX	Two-part ceramic cement/coating used for free-filament strain gages. Good adhesion to most metals.
SAUEREISEN DKS-8	Single-part chemical setting zircon-based cement used for free-filament strain gages. High electrical insulation and thermal conductivity.

Because a strain gage can perform no better than the adhesive with which it is bonded to the test member, the adhesive is a vitally important component in every strain gage installation. Although there is no single adhesive ideally suited to all applications, Micro-Measurements offers a wide selection of adhesives to cover the spectrum of stress analysis testing, and for use in transducer manufacturing. Micro-Measurements adhesives are specially formulated and selected for highest performance under the recommended environmental conditions, and are packaged to provide for ease of mixing and application.

Each adhesive is accompanied by specific instructions for its proper handling—storage, mixing, application, curing, and, if appropriate, post-curing. The adhesive containers are also dated to assure freshness of the contents.

Note: It is usually misguided economy to attempt installing strain gages with outdated adhesive, or adhesive that has not been stored as recommended. It should also be noted that conventional industrial and consumer adhesives are not generally suitable for bonding strain gages.

Since different adhesives are intended for different types of applications and different environmental conditions, it is obviously important to select the most appropriate adhesive for each strain measurement task. The table below lists all of the Micro-Measurements adhesives, while the table on the following page is provided as a guide for selecting the most appropriate adhesive for compatibility with a particular strain gage series and test environment.

RECOMMENDED ADHESIVES/STRAIN GAGE SERIES

TYPE OF TEST OR APPLICATION	OPERATING TEMPERATURE RANGE	GAGE SERIES	M-BOND ADHESIVE
GENERAL STATIC OR STATIC-DYNAMIC STRESS ANALYSIS	–50° to +150°F (–45° to +65°C)	C4A, L2A, W2A, CEA, EA	200 or AE-10 or AE-15 or RTC-2 Epoxy
		WA, SA, WK, SK	AE-15 or 610
	–50° to +400°F (–45° to +205°C)	WA, SA, WK, SK	600 or 610
	–452° to +450°F (–269° to +230°C)	WK	610
	<600°F (<315°C)	WK	610

General Information and Selection Guide

RECOMMENDED ADHESIVES/STRAIN GAGE SERIES (cont.)

TYPE OF TEST OR APPLICATION	OPERATING TEMPERATURE RANGE	GAGE SERIES	M-BOND ADHESIVE
HIGH ELONGATION (POST-YIELD)	–50° to +150°F (–45° to +65°C)	CEA, EA	200 or AE-10 or RTC-2 Epoxy
		EP	AE-15 or A-12
DYNAMIC (CYCLIC) STRESS ANALYSIS	–100° to +150°F (–75° to +65°C)	ED	200 or AE-10
		WD	AE-10 or AE-15
	–320° to +500°F (–195° to +260°C)	WD	600 or 610
TRANSDUCER GAGING	–50° to +150°F (–45° to +65°C)	CEA, EA	AE-10 or AE-15
	–50° to +200°F (–45° to +95°C)	N2A, J2A	600 or 610 or 43-B
	–50° to +300°F (–45° to +150°C)	WA, SA, TA, TK, J5K	610 or 450 or P Adhesive or Denex #3
	–320° to +350°F (–195° to +175°C)	WK, SK, TK, J5K	610 or 450 or P Adhesive or Denex #3
HIGH TEMPERATURE GAGING	–452° to +700°F (–269° to +370°C)	WK, RK	P Adhesive
	–320° to +1600°F (–195° to +870°C)	ZC, ZWP, ZWN, ZWH	NCC-3 or WC-16 or HG-1 or GC or PBX or DKS-8 or H Cement

MICRO MEASUREMENTS
A VPG Brand

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Strain Gage Adhesives

40............... **M-Bond 200 Adhesive**
44............... M-Bond AE-10, AE-15 and GA-2 Adhesive Systems

Strain Gage Installations with M-Bond 200 Adhesive

Introduction

Micro-Measurements Certified M-Bond 200 is an excellent general-purpose laboratory adhesive because of its fast room-temperature cure and ease of application. When properly handled and used with the appropriate strain gage, M-Bond 200 can be used for high-elongation tests in excess of 60 000 microstrain, for fatigue studies, and for one-cycle proof tests to over +200 °F [+95 °C] or below -300 °F [-185°C]. The normal operating temperature range is -25° to +150°F [-32° to +65°C]. M-Bond 200 is compatible with all Micro-Measurements strain gages and most common structural materials. When bonding to plastics, it should be noted that for best performance the adhesive flowout should be kept to a minimum. For best reliability, it should be applied to surfaces between the temperatures of +70° and +85°F [+20° to +30°C], and in a relative humidity environment of 30% to 65%.

M-Bond 200 catalyst has been specially formulated to control the reactivity rate of this adhesive. The catalyst should be used sparingly for best results. Excessive catalyst can contribute many problems; e.g., poor bond strength, age-embrittlement of the adhesive, poor glueline thickness control, extended solvent evaporation time requirements, etc.

Since M-Bond 200 bonds are weakened by exposure to high humidity, adequate protective coatings are essential. This adhesive will gradually become harder and more brittle with time, particularly if exposed to elevated temperatures. For these reasons, M-Bond 200 is not generally recommended for installations exceeding one or two years.

For proper results, the procedures and techniques presented here should be used with qualified Micro-Measurements installation accessory products. Those used in this procedure are:

- CSM Degreaser or GC-6 Isopropyl Alcohol
- Silicon Carbide Paper
- M-Prep Conditioner A
- M-Prep Neutralizer 5A
- GSP-1 Gauze Sponges
- CSP-1 Cotton Applicators
- PCT Gage Installation Tape

Shelf And Storage Life

M-Bond 200 adhesive has a minimum pot life of three months at +75°F [+24°C] (not to exceed the date of expiration) after opening and with the cap placed back onto the bottle immediately after each use.

Note: To ensure the cap provides a proper seal, the bottle spout should be wiped clean and dry before replacing the cap.

Unopened M-Bond 200 adhesive may be stored up to nine months at +75°F [+24°C] or twelve months at +40°F [+5°C].

HANDLING PRECAUTIONS

M-Bond 200 is a modified alkyl cyanoacrylate compound. Immediate bonding of eye, skin or mouth may result upon contact. Causes irritation. The user is cautioned to: (1) avoid contact with skin; (2) avoid prolonged or repeated breathing of vapors; and (3) use with adequate ventilation. For additional health and safety information, consult the Safety Data Sheet, which is available upon request.

Note: Condensation will rapidly degrade adhesive performance and shelf life; after refrigeration the adhesive must be allowed to reach room temperature before opening, and refrigeration after opening is not recommended.

Gage Application Techniques

The installation procedure presented on the following pages is somewhat abbreviated and is intended only as a guide in achieving proper gage installation with M-Bond 200. Micro-Measurements Instruction Bulletin B-129 presents recommended procedures for surface preparation, and lists

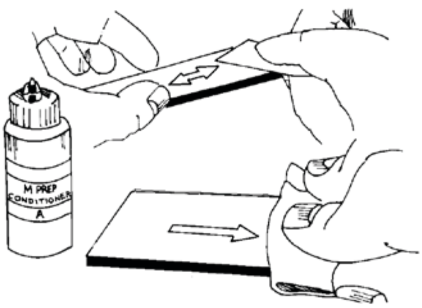
Strain Gage Installations with M-Bond 200 Adhesive

specific considerations which are helpful when working with most common structural materials.

Step 1

Thoroughly degrease the gaging area with solvent, such as CSM Degreaser or GC-6 Isopropyl Alcohol. The former is preferred, but there are some materials (e.g., titanium and many plastics) that react with strong solvents. In these cases, GC-6 Isopropyl Alcohol should be considered. All degreasing should be done with uncontaminated solvents-thus the use of “one-way” containers, such as aerosol cans, is highly advisable.

Step 2



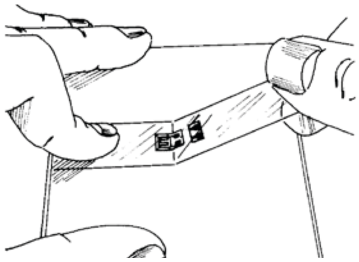
Preliminary dry abrading with 220- or 320-grit silicon-carbide paper is generally required if there is any surface scale or oxide. Final abrading is done by using 320-grit silicon-carbide paper on surfaces thoroughly wetted with M-Prep Conditioner A; this is followed by wiping dry with a gauze sponge. Repeat this wet abrading process with 400-grit silicon-carbide paper, then dry by slowly wiping through with a gauze sponge.

Using a 4H pencil (on aluminum) or a ballpoint pen (on steel), burnish (do not scribe) whatever alignment marks are needed on the specimen. Repeatedly apply M-Prep Conditioner A and scrub with cotton-tipped applicators until a clean tip is no longer discolored. Remove all residue and Conditioner by again slowly wiping through with a gauze sponge. Never allow any solution to dry on the surface because this invariably leaves a contaminating film and reduces chances of a good bond.

Step 3

Now apply a liberal amount of M-Prep Neutralizer 5A and scrub with a cotton-tipped applicator. With a single, slow wiping motion of a gauze sponge, carefully dry this surface. Do not wipe back and forth because this may allow contaminants to be redeposited.

Step 4

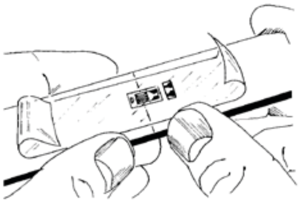


Using tweezers to remove the gage from the transparent envelope, place the gage (bonding side down) on a chemically clean glass plate or gage box surface. If a solder terminal will be used, position it on the plate adjacent to the gage as shown. A space of approximately 1/16 in [1.6 mm] or more where space allows or application requires should be left

Strain Gage Installations with M-Bond 200 Adhesive

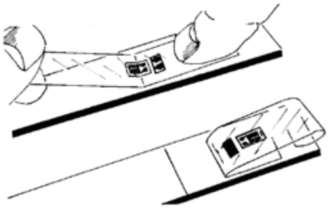
between the gage backing and terminal. Place a 4- to 6-in [100- to 150-mm] piece of Micro-Measurements PCT gage installation tape over the gage and terminal. Take care to center the gage on the tape. Carefully lift the tape at a shallow angle (about 45 degrees to specimen surface), bringing the gage up with the tape as illustrated above.

Step 5



Position the gage/tape assembly so that the triangle alignment marks on the gage are over the layout lines on the specimen. If the assembly appears to be misaligned, lift one end of the tape at a shallow angle until the assembly is free of the specimen. Realign properly, and firmly anchor at least one end of the tape to the specimen. Realignment can be done without fear of contamination by the tape mastic if Micro-Measurements PCT gage installation tape is used, because this tape will retain its mastic when removed.

Step 6



Lift the gage end of the tape assembly at a shallow angle to the specimen surface (about 45 degrees) until the gage and terminal are free of the specimen surface. Continue lifting the tape until it is free from the specimen approximately 1/2 in [10 mm] beyond the terminal. Tuck the loose end of the tape under and press to the specimen surface so that the gage and terminal lie flat, with the bonding surface exposed.

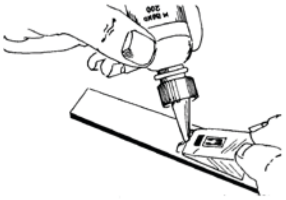
Note: Micro-Measurements gages have been treated for optimum bonding conditions and require no pre-cleaning before use unless contaminated during handling. If contaminated, the back of any gage can be cleaned with a cotton-tipped applicator slightly moistened with M-Prep Neutralizer 5A.

Step 7

M-Bond 200 catalyst can now be applied to the bonding surface of the gage and terminal. M-Bond 200 adhesive will harden without the catalyst, but less quickly and reliably. Very little catalyst is needed, and it should be applied in a thin, uniform coat. Lift the brush-cap out of the catalyst bottle and wipe the brush approximately 10 strokes against the inside of the neck of the bottle to wring out most of the catalyst. Set the brush down on the gage and swab the gage backing. Do not stroke the brush in a painting style, but slide the brush over the entire gage surface and then the terminal. Move the brush to the adjacent tape area prior to lifting from the surface. Allow the catalyst to dry at least one minute under normal ambient conditions of +75°F [+24°C] and 30% to 65% relative humidity before proceeding.

Note: The next three steps must be completed in the sequence shown, within 3 to 5 seconds. Read Steps 8, 9, and 10 before proceeding.

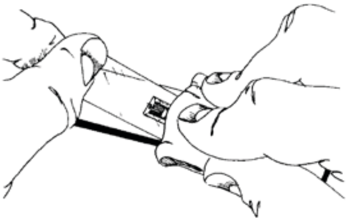
Step 8



Strain Gage Installations with M-Bond 200 Adhesive

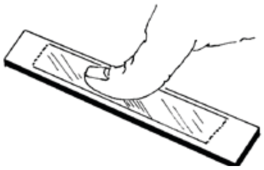
Lift the tucked-under tape end of the assembly, and, holding in the same position, apply one or two drops of M-Bond 200 adhesive at the fold formed by the junction of the tape and specimen surface. This adhesive application should be approximately 1/2 in [13 mm] outside the actual gage installation area. This will insure that local polymerization that takes place when the adhesive comes in contact with the specimen surface will not cause unevenness in the gage glueline.

Step 9



Immediately rotate the tape to approximately a 30-degree angle so that the gage is bridged over the installation area. While holding the tape slightly taut, slowly and firmly make a single wiping stroke over the gage/tape assembly with a piece of gauze bringing the gage back down over the alignment marks on the specimen. Use a firm pressure with your fingers when wiping over the gage. A very thin, uniform layer of adhesive is desired for optimum bond performance.

Step 10



Immediately upon completion of wipe-out of the adhesive, firm thumb pressure must be applied to the gage and terminal area. This pressure should be held for at least one minute. In low-humidity conditions (below 30%), or if the ambient temperature is below +70°F [+20°C], this pressure application time may have to be extended to several minutes.

Where large gages are involved, or where curved surfaces such as fillets are encountered, it may be advantageous to use preformed pressure padding during the operation. Pressure-application time should again be extended due to the lack of “thumb heat” which helps to speed adhesive polymerization. Wait two minutes before removing tape.

Step 11

The gage and terminal strip are now solidly bonded in place. It is not necessary to remove the tape immediately after gage installation. The tape will offer mechanical protection for the grid surface and may be left in place until it is removed for gage wiring. To remove the tape, pull it back directly over itself, peeling it slowly and steadily off the surface. This technique will prevent possible lifting of the foil on open-faced gages or other damage to the installation.

Final Installation Procedure

1. Select appropriate solder and attach leadwires. Prior to any soldering operations, open-faced gage grids should be masked with PDT drafting tape to prevent possible damage.
2. Remove the solder flux with M-Line Rosin Solvent.
3. Select and apply protective coating according to the protective coating selection chart found in the Micro-Measurements Strain Gage Accessories Data Book found at:

www.micro-measurements.com/knowledge-base/databooks

Strain Gage Applications with M-Bond AE-10, AE-15 and GA-2 Adhesive Systems

General Description

The three adhesives described in this bulletin, M-Bond AE-10, AE-15, and GA-2, are all 100%-solids epoxy systems for use with strain gages and special-purpose sensors. The gage installation procedure described is appropriate for each adhesive, the primary differences in the systems being in mixing instructions, pot life, cure cycles, and, to some extent, elongation properties. Each system is effective from the cryogenic region to +200°F [+95°C].

Note: Through extensive testing by our Micro-Measurements Engineering Department, the M-Bond AE-10 is now been qualified for use up to 400 deg. F (204 deg. C).

For proper results, the procedures and techniques presented in this bulletin should be used with qualified Micro-Measurements installation accessory products (refer to Micro-Measurements Strain Gage Accessories Data Book). Accessories used in this procedure are:

- CSM Degreaser or GC-6 Isopropyl Alcohol
- CSP-1 Cotton Applicators
- PCT Gage Installation Tape
- Silicon-Carbide Paper
- MJG-2 Mylar Tape
- M-Prep Conditioner A
- HSC Spring Clamp
- M-Prep Neutralizer 5A
- GT-14 Pads and Backup Plate
- GSP-1 Gauze Sponges

HANDLING PRECAUTIONS

While these bonding agents are considered relatively safe to handle, contact with skin and inhalation of their vapors should be avoided. Immediate washing with ordinary soap and water is effective in cleansing should skin contact occur. For eye contact, rinse thoroughly with a copious amount of water and consult a physician. For additional health and safety information, consult the Safety Data Sheet, which is available upon request.

Mixing Instructions and Adhesive Characteristics

A. General

1. Each kit contains materials for mixing six batches of adhesive. Mixing instructions for M-Bond AE-10 and M-Bond AE-15 Bulk are included below.
2. Any resin removed from refrigeration must be allowed attain room-temperature equilibrium before being opened.
3. Mix adhesives thoroughly for five minutes according to instructions. If a room-temperature cure is used, allow the freshly mixed adhesive to stand an additional five minutes before use.
4. The pot life for Systems AE-10 and GA-2 can be prolonged by occasionally stirring to prevent localized exotherm in the center of the resin system, or by pouring it out onto a chemically clean metal plate.

Note: During storage, crystals may form in the Resin AE. These crystals do not affect adhesive performance, but should be reliquefied prior to mixing by warming the resin jar to +120°F [+50°C] for approximately one-half hour. Allow the resin to return to room temperature before adding curing agent; excess heat will shorten mixed pot life.

B. M-Bond AE-10 Adhesive Kit

AE-10 will cure at +70°F [+20°C] in 6 hours, with approximately 6% elongation capability and essentially creep-free performance. Elongation capability of approximately 10% can be obtained by extending the cure time to 24 to 48 hours at +75°F [+24°C].* To mix, fill one of the calibrated droppers with Curing Agent 10 exactly to the number 10 and dispense the contents into the center of the jar of Resin AE. Immediately cap the bottle of Curing Agent 10 to avoid moisture absorption. Mix thoroughly for 5 minutes, using one of the plastic stirring rods. The pot life or working time after mixing is 15 to 20 minutes. Discard the dropper after use.

M-Bond AE-10 Bulk is packaged with 200 grams of resin,

Strain Gage Applications with M-Bond AE-10, AE-15 and GA-2 Adhesive Systems

40 grams of Curing Agent 10, and three calibrated pipettes. The mix ratio is 10.0 parts by weight of AE Resin to 1.7 parts by weight of Curing Agent 10. Mix thoroughly for five minutes, then allow the mixture to stand for an additional five minutes before use. When mixing quantities greater than 10 grams of AE Resin, the normal pot life of 15-20 minutes will be shortened accordingly.

* Refer to Instruction Bulletin B-129 and Application Note TT-605 for discussions of high-elongation strain measurements.

C. M-Bond AE-15 Adhesive Kit

AE-15 requires moderately elevated curing temperatures, and is recommended for critical installations, such as strain gage transducers, where zero shift and hysteresis must be minimized. The AE-15 system is also useful with high elongation strain gages at strain levels up to approximately 10% to 15% at +70°F [+20°C], and at strain levels up to 15% at +200°F [+95°C]. To mix, fill one of the calibrated droppers with Curing Agent 15 exactly to the number 15 and dispense the contents into the center of the jar of Resin AE. Immediately cap the bottle of Curing Agent 15 to avoid moisture absorption. Mix the Resin AE and the Curing Agent 15 thoroughly for 5 minutes, using one of the plastic stirring rods. The pot life is approximately 1-1/2 hours at +70°F [+20°C]. Discard the dropper after use.

M-Bond AE-15 Bulk is packaged with 200 grams of resin, 25 grams of Curing Agent 15, and three calibrated pipettes. The mix ratio is 10.0 parts by weight of AE Resin to 1.0 parts by weight of Curing Agent 15. Mix thoroughly for five minutes, then allow the mixture to stand for an additional five minutes before use. When mixing quantities greater than 10 grams of AE Resin, the normal pot life of 15-20 minutes will be shortened accordingly.

D. M-Bond GA-2 Kit

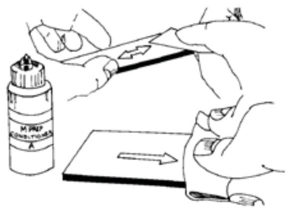
GA-2 is a partially filled 100%-solids epoxy adhesive. Resin GA-2 with Curing Agent 10-A will have approximately 10% to 15% elongation capabilities when cured for 40 hours at +70°F [+20°C], and approximately 6% elongation capabilities when cured for 6 hours at +70°F [+20°C]. To mix, fill one of the calibrated droppers with Curing Agent 10-A exactly to the number 10, and dispense the contents into the jar of Resin GA-2. Immediately cap the bottle of Curing Agent 10-A to prevent moisture absorption. Mix the Resin GA-2 and the Curing Agent 10-A thoroughly for 5 minutes using one of the plastic stirring rods. Pot life is approximately 15 minutes at +70°F [+20°C]. Discard the dropper after use.

Gage Installation Procedure

Step 1

The surface preparation technique used is the same basic cleaning procedure described in Micro-Measurements Instruction Bulletin B-129, “Surface Preparation for Strain Gage Bonding”. The initial step is to thoroughly degrease with solvents such as CSM Degreaser or GC-6 Isopropyl Alcohol. CSM Degreaser is preferred whenever possible since this is a very active degreaser. The substitution of GC-6 as a degreasing agent should be considered for materials that may be sensitive to strong solvents. Any degreasing should be done with clean solvents. Thus the use of a “one-way” container, such as the aerosol can, is highly advisable.

Step 2



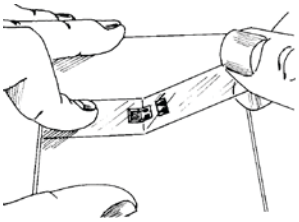
Strain Gage Applications with M-Bond AE-10, AE-15 and GA-2 Adhesive Systems

Dry-abrade the gaging area with 220- or 320-grit silicon-carbide paper to remove any scale or oxides on the base material. Apply M-Prep Conditioner A and wet-abrade the gage area. Keep the surface wet while abrading. Remove the residue and Conditioner by slowly wiping through the gaging area with a gauze sponge. The wet-abrade and wiping procedure should then be repeated with 400-grit silicon-carbide paper. With a 4H (hard) drafting pencil on aluminum or a ballpoint pen on steel, burnish whatever alignment marks are needed on the specimen. Rewet the surface with Conditioner A and scrub with cotton tipped applicators until a clean applicator is no longer discolored by the scrubbing. Remove the residue and Conditioner by slowly wiping through the gaging area with a gauze sponge. Do not wipe back and forth over the gage area since this may allow contaminants to be redeposited on the cleaned area.

Step 3

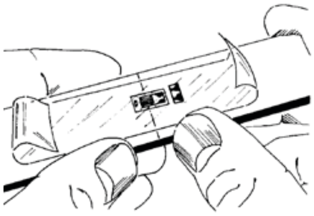
Apply a liberal amount of M-Prep Neutralizer 5A to the gage area. Keeping the surface wet, scrub with cotton tipped applicators. Do not allow evaporation of the cleaning material on the specimen surface since this would leave a thin, unwanted film between the adhesive and the specimen. Remove the Neutralizer by slowly wiping through the gage area, allowing the gauze sponge to absorb the Neutralizer. Do not wipe back and forth over the gage area since this may allow contaminants to be redeposited on the cleaned area.

Step 4



Remove the gage from its transparent envelope by grasping the edge of the gage backing with tweezers, and place bonding side down on a chemically clean glass plate or empty gage box. If a solder terminal is to be incorporated, position it on the plate adjacent to the gage as shown. A space of approximately 1/16 in [1.6 mm] should be left between the gage backing and terminal. Use 4 to 6 in [100 to 150 mm] of PCT Gage Installation tape as a carrier to aid in positioning the strain gage and terminal. [When cure temperatures exceed +175°F [+80°C], MJG-2 mylar tape must be substituted for the gage installation tape.] Tack one end of the tape to the glass plate behind the gage and terminal, and wipe forward onto the terminal and gage. Carefully lift the tape at a shallow angle (about 45 degrees to the glass plate), bringing the gage up with it.

Step 5

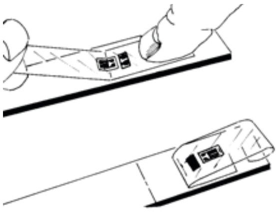


Position the gage/tape assembly so the triangle alignment marks on the gage are over the layout lines on the specimen. Holding the tape at a shallow angle, wipe the assembly onto the specimen surface. If the assembly appears to be misaligned, lift one end of the tape at a shallow angle until the assembly is free of the specimen. Realign properly and firmly anchor down at least one end of the tape to the specimen. This realignment can be done without fear of contamination by the tape mastic if the recommended gage

Strain Gage Applications with M-Bond AE-10, AE-15 and GA-2 Adhesive Systems

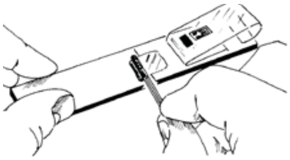
installation tape is used. This tape will retain the mastic when removed.

Step 6



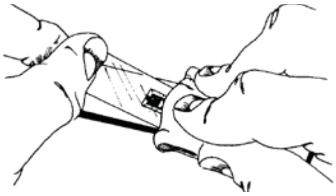
Lift one end of the tape at a shallow angle to surface (about 45 degrees) until gage and terminal are free of specimen surface. Tuck the loose end of the tape under and press to the surface so the gage lies flat with the bonding side exposed. In some cases this may be difficult because of space limitations. If this situation occurs, leave enough slack in the tape to allow a finger to be slipped behind the gage to support it while applying the adhesive.

Step 7



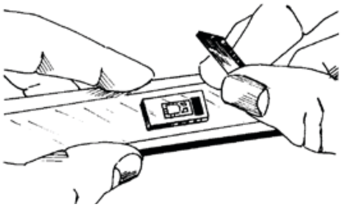
Coat the specimen, back of the gage, and terminal strip with the prepared adhesive. The mixing rod can be used to apply a thin layer of adhesive over each surface. Be careful not to pick up any unmixed components of the adhesive. To ensure this, it is advisable to wipe the mixing rod clean and then pick up a very small amount of the adhesive from the center area of the adhesive jar. Immediately after coating the gage and specimen with adhesive, proceed without delay to Step 8. This will limit the absorption of moisture by the uncured adhesive, and the gage installation tape will serve as a temporary moisture barrier during curing.

Step 8



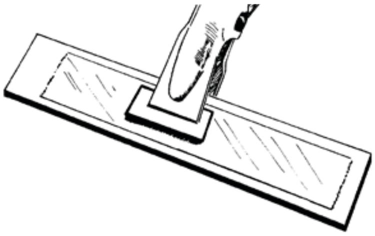
Lift the tucked-over end of tape and bridge it over the adhesive at approximately a 30-degree angle. With a piece of gauze, slowly make a single wiping stroke over the gage/tape assembly, bringing the gage back down over the alignment marks on the specimen. Use firm pressure with your fingers when wiping over the gage, since the adhesive is quite viscous. A very thin layer of adhesive is desired for optimum bond performance.

Step 9



Place a silicone gum pad and backup plate (GT-14) over the gage installation. The silicone gum should be soft (Durometer A40-60) and at least 3/32 in [2.5 mm] thick. This will allow the clamping force to be exerted evenly over the gage. The area of the silicone gum pad should be used to compute the final clamping pressure.

Step 10



Apply force by spring clamp or dead weight until a clamping pressure of 5 to 20 psi [35 to 135 kN/m2] is attained.

Strain Gage Applications with M-Bond AE-10, AE-15 and GA-2 Adhesive Systems

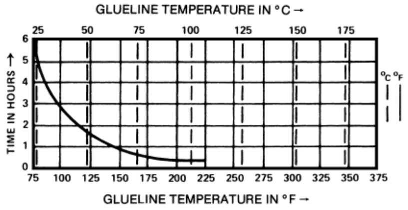
Take special care in making sure the clamping pressure is equal over the entire gage. Unequal clamping pressure may result in an irregular glueline. Take steps to ensure that the clamps will not slide out of position during cure. A few strips of tape to assist in holding the clamps or backup plate in place during cure may be helpful. Cure the installation in accordance with the recommended cure schedule below.

Step 11

The gage and terminal strip are now solidly bonded in place. To remove the tape, pull it back directly over itself, peeling it slowly and steadily off the surfaces. This technique will prevent possible lifting of the foil on open-faced gages or otherwise damaging the installation. It is not necessary to remove this tape immediately after gage installation. The tape will offer mechanical protection for the grid surface, and may be left in place until it is removed for gage wiring.

Recommended Cure Schedules

M-Bond AE-10 and GA-2

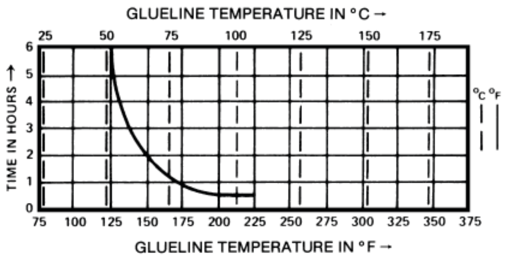


Caution: These systems may not cure properly below +70°F [+20°C]. Postcuring the installation for two hours at least +25°F [+15°C] above the maximum operating temperature with the clamping fixture removed will provide essentially creep-free performance.

M-Bond AE-15

Caution: To ensure proper polymerization, the cure cycle should start within 1.5 hours after mixing.

Note: Do not exceed +225°F [+105°C] cure temperature.



Final Installation Procedure

1. Select appropriate solder and attach leadwires. Remove solder flux with RSK Rosin Solvent. See Micro-Measurements Strain Gage Accessories Data Book for these materials.

2. Select and apply protective coating. See Micro-Measurements Strain Gage Accessories Data Book.

3. Micro-Measurements gages have been treated for optimum bonding conditions and require no precleaning before use unless contaminated during handling. If contaminated, the back of any gage may be cleaned with a cotton applicator slightly moistened with Neutralizer 5A.

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Strain Gage Soldering Techniques

Strain Gage Soldering Techniques

Introduction

The most common method of making electrical connections in strain gage circuits is by means of soft solders, in wire form. Other methods, such as spot welding, brazing, compression bonding, paste solders, and conductive epoxies, are also available, but find only limited application. Solders have many advantages for strain gage use — they are low in cost, readily available in various alloy compositions to provide a range of melting temperatures, and are easily obtained in the form of either solid wire or wire with a core of flux. They are convenient to use, and offer an excellent combination of electrical and mechanical properties.

Although soldering is basically a simple procedure, it must be done with appropriate tools, supplies, and techniques to assure accurate strain measurement. This is particularly true when test requirements are severe in the sense of approaching the limits of the strain gage circuit capabilities; e.g., long-term stability, high-elongation measurements, fatigue endurance, etc. Use of improper materials or techniques can significantly degrade strain gage performance.

The purpose of this Tech Tip is to outline recommended procedures and materials for attaching leadwires to strain gage solder tabs or to bonded printed-circuit terminals. These reliable, experience-proven methods are based on the use of a professional quality soldering station, in conjunction with Micro-Measurements solders and installation accessories.

Soldering Station and Pencil

For precision soldering of strain gages, it is always necessary to use a temperature- or power-controlled soldering station that provides low voltage and adjustable temperature to the soldering iron tip. An unregulated soldering iron, connected directly to the power line, is not ordinarily suitable for strain gage use because the tip temperature is apt to be far too high. This tends to oxidize the tip, and to instantly vaporize the flux, making soldering much more difficult. In addition, the unnecessarily high temperature may damage the strain gage, the bonding adhesive, or even the test specimen. For these reasons, the soldering station should incorporate provision for adjusting the soldering temperature to suit varying installation conditions and requirements. The temperature must be adjusted, of course, to accommodate the melting points of the different solders commonly used for strain gage connections, but also to allow for environmental conditions such as drafts or outdoor soldering in cold weather. Moreover, the temperature controller should be carefully designed to ensure that it does not generate electrical noise that could adversely affect nearby measuring instruments when both are in use.

Design of the soldering pencil also requires special consideration. It should be light in weight, with a very flexible power cord, and with the gripping area thermally insulated from the heating element. These characteristics contribute to the comfort, ease, and precision of soldering, and minimize operator fatigue during long periods of use. The soldering tip itself should be of the flat, chisel, or screwdriver type. Pointed tips should not be used, because they tend to draw solder away from the work area, and thus make it more difficult to achieve a proper joint. In contrast, flat tips act to confine the solder, while offering greater surface area for better heat transfer and more effective soldering, generally.

Micro-Measurements soldering units incorporate all of the above features and a number of others, designed to help the user easily make consistent, reliable solder joints. These soldering units are widely used by professional strain gage installers everywhere, in both stress analysis laboratories and in transducer manufacture.

Solder Selection

The Micro-Measurements Division stocks a broad range of solder types to meet various installation and test requirements. While solders are sometimes selected to provide specific electrical or mechanical properties, the most common basis for selection is simply the melting-temperature range. Low-melting-point solders, for example, are generally used for strain gage installations on nonmetallic test parts to avoid damaging the gage, bonding adhesive, or

Strain Gage Soldering Techniques

test material due to overheating. In contrast, high-temperature solders are normally selected only when necessary to satisfy elevated-temperature testing requirements. These solders are somewhat more difficult to handle because the higher working temperature rapidly vaporizes the flux, and oxidizes the soldering tip, both of which tend to impede the soldering process. Specially designed soldering tips are recommended for high-temperature use.

For routine applications, where test conditions do not dictate the use of either a low- or high-temperature solder, an alloy with an intermediate melting temperature is the normal selection. The 63/37 tin-lead alloy (Type 361A-20R) is an excellent choice for general-purpose strain gage soldering. As an eutectic alloy, it has a sharply defined melting temperature — a characteristic that largely eliminates "cold" solder joints. The addition of a trace of antimony provides superior performance when the soldered connections will be exposed to very low (cryogenic) temperatures for long periods of time.

The general-purpose solders are supplied with a core of activated rosin flux. This makes soldering much more convenient, and is particularly useful in field applications where accessory liquid rosin flux (M-Flux AR-2) may not be available. Solid-wire solder, with externally applied acid flux (M-Flux SS), is recommended for making soldered connections to Micro-Measurements K- and D-alloy (modified Karma and isoelastic) strain gages. Rosin-core solders should not be used in conjunction with acid flux.

Silver solder (Type 1240-FPA) is available for applications where leadwire connections will be exposed to temperatures above about +550°F (+290°C). This solder, in paste form, is not suitable for attaching wires directly to strain gage solder tabs or to bondable terminals, but is intended for connecting instrument leads to preattached strain gage leads, as with WK-Series gages using a special resistance soldering unit. Techniques for making leadwire connections with silver solder are described in Micro-Measurements Tech Tip TT-602, Silver Soldering Technique for Attachment of Leads to Strain Gages.

Soldering Flux

The function of a soldering flux is to remove oxidation from the members being joined (solder tabs, terminals, leadwires), and to prevent further oxidation during soldering. For making leadwire splices, or soldering directly to constantan foil or copper terminals, the flux contained in a rosin-core solder is usually sufficient. With higher temperature solders, however, it may be necessary to supply additional flux. A liquid activated-rosin flux such as M-Flux AR-2 is recommended for this purpose.

Acid fluxes should never be used on constantan strain gages or copper terminals, or for splicing copper leadwires; and paste fluxes, containing chlorides, should not be used under any circumstances for strain gage soldering. When tinning bare (without soldering options) solder tabs of Micro-Measurements K- and D-alloy strain gages, a liquid acid flux (M-Flux SS) is recommended. After the tinning operation, the residual flux must be completely neutralized within one to two minutes; and then the leadwire joint can be completed using the same solder and M-Flux AR-2 rosin flux or a rosin-cored solder.

Preparation of the Soldering Tip

New soldering tips should always be tinned with solder prior to initial use. This is easily accomplished by wrapping one to two in (25 to 50 mm) of solder wire around the working portion of the tip while the soldering iron is cold, before applying power to the soldering station. If rosin-core solder is used, no external flux is required. With solid-wire solder, however, the wrapped tip should be dipped into liquid rosin flux (M-Flux AR-2) to provide sufficient flux for initial tinning. Set the control on the soldering station to the appropriate temperature range for the solder, and apply power to the unit. Allow the soldering pencil to heat until the solder wrapped around the tip melts completely. Remove excess melted solder from the tip with a dry gauze sponge. Never

Strain Gage Soldering Techniques

knock the heated soldering pencil against any object to remove excess solder, since this may result in personal injury or damage to the soldering pencil.

Note: Cross-alloying of solders can change the electrical, chemical, thermal and mechanical properties of the solder being used. To prevent cross-alloying, it is recommended that only one type of solder be used with each soldering tip. Of course, if one type of solder is incorporated in a gage with solder dots and another type is added, a mixture is produced. This mixture cannot be expected to have melting and strength properties any better than those of the lower temperature component.

Oxidation of the soldering tip seriously hinders the soldering operation. The tendency for oxidation can be minimized by ensuring that excess melted solder remains on the tip at all times when it is not actually in use. Negligent maintenance practices, or wiping the hot tip with materials that char on the surface, will produce a buildup of oxide that prevents proper soldering. If the tip does become oxidized, the following procedure is effective for cleaning and re-tinning:

1. Set the soldering station to the appropriate temperature range for the solder in use.
2. Place several drops of M-Flux SS on a glass plate. Retin the soldering surface by holding the heated tip in the SS flux while feeding solder onto the tip. A generous amount of solder is essential for proper tinning.
3. Wipe the excess solder from the tinned tip with a dry gauze sponge. For severely oxidized tips, it may be necessary to repeat this operation several times to obtain a properly tinned surface. The soldering tip should never be filed or sanded, since this may remove the plating on the tip, accelerating the oxidation and leading to the early deterioration of the tip. After the cleaning operation, remove excess solder, re-tin and clean the tip several times, using rosin-core solder, or solid-wire solder with M-Flux AR-2.

Tinning Solder Tabs and Bondable Terminals

All strain gage solder tabs, terminals, and leadwires must be properly tinned before making soldered connections. This helps ensure active surface wetting and good heat transfer during the soldering operation. Tinning stranded leadwires to produce a formable solid conductor will also greatly simplify the leadwire attachment procedure.

Before tinning the solder tabs on open-face (unencapsulated) strain gages, the measuring grid should be protected with PDT drafting tape. The drafting tape is positioned to cover the entire grid and the upper portion of the solder tabs, as shown in Figure 1. This not only shields the grid from soldering flux and inadvertent solder splash, but also restricts the flow of solder on the tabs. The tinned area on the solder tabs should be only large enough to easily accommodate the leadwire size in use. The latter consideration is particularly important when making installations for dynamic applications or large-strain measurement.

The tinning procedure for strain gage tabs and terminals consists of first cleaning and reapplying a small amount of solder to the hot soldering iron tip. Next, apply a drop of M-Flux AR-2 to the tab or terminal (this step can be omitted if a rosin-core solder is used). When soldering directly to

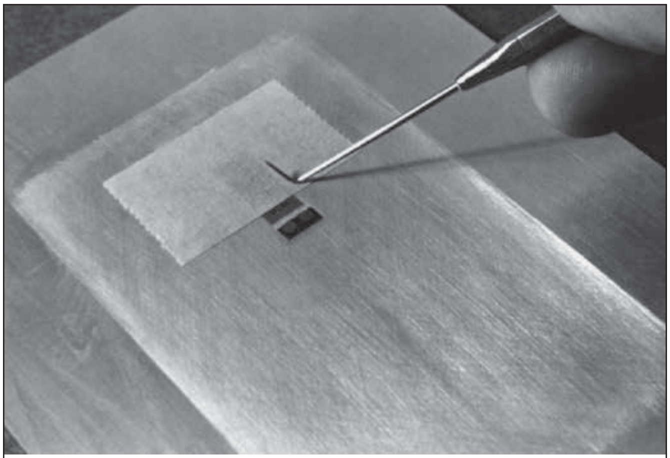

Figure 1 – Gage grid and upper portion of solder tabs masked with drafting tape.

Strain Gage
Soldering Techniques

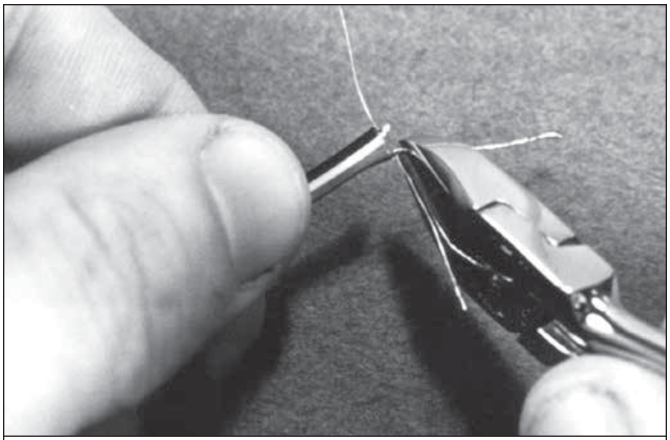
Figure 2 – Trimming leadwire ends before taping in place.

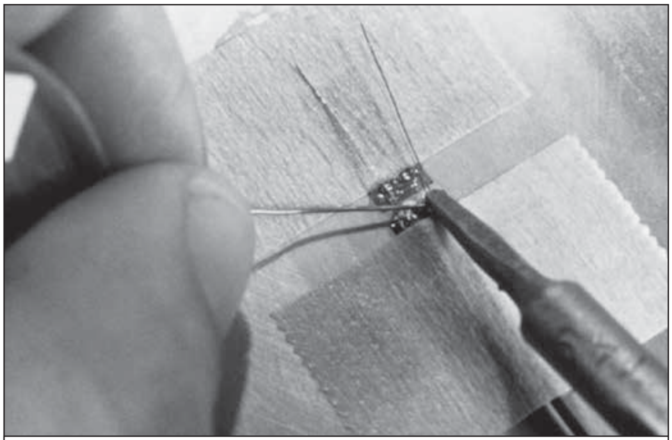
Figure 3 – Leadwire end taped to surface in preparation for soldering.

bare Karma or isoelastic foil, use M-Flux SS on the gage tabs only. Hold the soldering pencil in a nearly horizontal position (<30°), with the flat surface of the tip parallel to the solder tab or terminal. Place the solder wire flat on the gage tab, and press firmly with the tinned hot soldering tip for about one to two seconds, while adding approximately 1/8 in (3 mm) of fresh solder at the edge of the tip. This procedure assures that there is sufficient solder and flux for effective tinning. Simultaneously lift both the soldering pencil and solder wire from the tab area.

NOTE: Lifting the soldering iron before lifting the solder may result in the end of the solder wire becoming attached to the tab; lifting them in the reverse order can leave a jagged (spike) solder deposit on the tab. When the operation is performed properly, it will produce a small, smoothly tinned area on the tab or terminal.

If M-Flux AR-2 or a rosin-core solder is used in the tinning, it is not necessary to remove the residual soldering flux at this time. However, when M-Flux SS is employed to tin the bare solder tabs of K- or D-alloy gages, the acidic flux residue must be removed immediately following the tinning operation. To remove the residue, apply M-Prep Conditioner A liberally, and wash the area with a soft brush; then blot dry with a clean gauze sponge. Next, wash again with freely applied M-Prep Neutralizer 5A, and blot dry with a clean gauze sponge.

NOTE: Special procedures for tinning and wiring strain gages supplied with preattached solder dots are described in Micro-Measurements Tech Tip TT-606, Soldering Techniques for Lead Attachment to Strain Gages with Solder Dots.

Tinning and Attaching Leadwires

Of course, leadwire ends must be stripped of insulation before tinning, and this should be done with a thermal wire stripper to avoid the damage to the wire that often occurs when mechanical wire strippers are used. After the wires are stripped, the ends of stranded conductors should be twisted tightly together before tinning. The bare leadwire ends can then be tinned easily with the following procedure:

1. Remove excess solder from the soldering tip, using a dry gauze sponge. Then melt fresh solder on the hot tip to form a hemisphere of molten solder about twice the diameter of the wire to be tinned.
2. If rosin-core solder is used, slowly draw the bare wire through the molten solder while continuously adding fresh solder to the interface of the wire and soldering

Strain Gage
Soldering Techniques

tip. With solid-wire solder, apply M-Flux AR-2 to the wire end before starting to tin, and proceed in the same manner. This will produce a smooth, shiny coating of solder over the bare wire.

For applications employing bondable terminal strips and stranded instrumentation wire, it may be convenient to use a single strand of the wire as a jumper between the terminal and the strain gage solder tab. In such cases, the single wire strand should be separated out before twisting and tinning the remaining strands (see Micro-Measurements Tech Tip TT-603, The Proper Use of Bondable Terminals in Strain Gage Applications).

Leadwires should be formed and routed to the strain gage or terminal strip, then firmly anchored to the test-part surface with drafting tape before making the soldered connection. Attempting to route the leadwires after completing the solder joint will often result in damage to the gage or terminals. Routing into the connection area should be along a minimum strain direction (such as the ''Poisson'' direction in a uniaxial stress field) particularly for high elongation or dynamic tests. The tinned leadwire end should be trimmed short enough so that it will not protrude through the connection area, and cannot inadvertently make electrical contact with the test-part surface or adjacent solder connections. Figure 2 illustrates this stage in the procedure. In the final preparatory step, bend the leadwire end slightly to form a spring-like loop, and tape the wire firmly in place over the connection area, using PDT drafting tape. The tape should be within about 1/8 in (3 mm) of the connection area, as shown in Figure 3.

Clean and re-tin the soldering iron tip with fresh solder. The temperature of the iron should be adjusted so that the solder is easily melted, without rapidly vaporizing the flux. If the iron temperature is either too low or too high, it may cause poor solder connections, or it may damage the strain gage, terminal, or bonding adhesive. Apply a small amount of M-Flux AR-2 to the joint area and, holding the soldering pencil nearly horizontal, firmly press the flat surface of the tip on the junction for about one second; then lift the tip from the soldered joint. If needed, additional flux can be provided during the joining operation by feeding a little fresh solder into the joint from a spool of rosin-core solder. This procedure should result in a smooth, hemispherical solder joint, without any peaks or jagged areas. If the solder joints are not smooth and uniform in size, repeat the soldering procedure, using additional flux and/or solder as necessary.

Cleanup and Inspection of Soldered Joints

After completing the soldering operation, it is imperative that all traces of residual flux be completely removed with RSK Rosin Solvent. The same solvent is used to soften the mastic of the drafting tape, permitting its easy removal. Do not try to pull away the tape with tweezers or other tools, because this may result in damage to the soldered connections or the strain gage grid. Thoroughly clean the entire installation area with generously applied rosin solvent and a soft-bristled brush. Clean the solder connection area until no visible signs of residual flux remain, and blot the area dry with a clean gauze sponge. Any traces of residual flux can cause gage instability and drift, and will inhibit bonding of the installation's protective coating. Incompletely removed soldering flux is the most common cause of degraded performance in strain gage installations. Residual flux mixed with a protective coating application can completely destroy the coating objective.

Visually inspect the soldered joints for any gritty or jagged joint surfaces, and for traces of flux. Solder connections should be smooth, shiny, and uniform in appearance. Any soldered joints that look questionable should be re-soldered, and flux removed. Check the resistance-to-ground of the completed gage installation, using the Model 1300 Gage Installation Tester. Low or marginal resistance readings suggest a leakage path between the soldered connections and the test-part surface. This condition usually results from residual soldering flux, or from bare leadwire conductors

Strain Gage Soldering Techniques

partially shorting the gage tabs or terminals to the test part. Soldered joints should not be tested by pulling on the leadwire, or by probing at the joint area. These practices frequently cause lifting or tearing of the solder tab from the gage backing material.

Summary

The ability to make consistently good soldered joints is essential for precision strain gage measurements. The techniques described here are straightforward and easily mastered, but they are most effective when used with professional soldering equipment which is specially designed for making soldered connections in strain gage circuits. The soldering pencil should be lightweight, with a flat chisel or screwdriver tip, and it should be connected to the soldering station with a very flexible power cord. Requirements for the soldering station include low-voltage operation of the soldering pencil, and provision for temperature adjustment to suit the type of solder and the application conditions. The equipment should not generate electrical interference that could affect sensitive measuring instrumentation. Solder selection is based primarily on the expected operating temperature range of the strain gage installation; and all solder tabs, bondable terminals, and leadwire ends should be tinned before soldering the joints. Soldered joints should always be smooth and shiny, with no jagged or irregular edges, and all traces of residual flux must be thoroughly removed prior to the application of protective coating. Use of the recommended materials and techniques, with careful attention to detail, will result in consistently proper and reliable soldered connections.

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The Three-Wire Quarter-Bridge Circuit

The Three-Wire Quarter-Bridge Circuit

Introduction

Since the invention of the electrical resistance strain gage more than a half century ago, the Wheatstone bridge has become the sensing circuit of choice in most commercially available strain gage instrumentation. This is due in large measure to its inherent ability to:

1. detect the small resistance changes produced in the strain gage as it follows even minute dimensional changes on the surface of a test part under load,
2. produce a zero output voltage when the test part is at rest, and
3. provide for compensation of temperature-induced resistance changes in the strain gage circuit.

To varying degrees, each of these factors is essential for accurate strain gage measurements.

In the majority of strain gage applications for the determination of the state of stress on a test-part surface, individual strain gage elements, whether from uniaxial or rosette strain gage configurations, are connected independently to the Wheatstone bridge in a quarter-bridge arrangement. As discussed in the following sections, the wiring scheme chosen to connect the strain gage to the bridge circuit has a significant effect on the accuracy of measured strain data.

The Wheatstone Bridge

The Wheatstone bridge circuit in its simplest form (Figure 1) consists of four resistive elements, or bridge arms (R1, R2, R3, R4), connected in a series-parallel arrangement, with an excitation voltage source (E). The connection points formed by (adjacent) pairs of bridge arms and the leadwires from the excitation voltage source are input corners of the bridge; and those formed by pairs of bridge arms and the signal (eo) measurement leads are output corners. It is worth noting for this discussion that each input corner is adjacent to each output corner, and each bridge arm is connected between two adjacent corners.

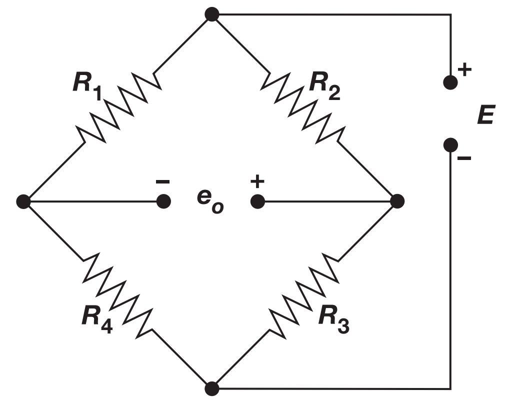

Figure 1. Basic Wheatstone Bridge Circuit.

Also, if the bridge circuit is resistively symmetrical about an imaginary line drawn through both output corners, the output voltage eo will be exactly zero, regardless of the excitation voltage level, and the bridge will be “balanced”.

Two-Wire Circuit

For an initially balanced bridge, if one of the resistors in Figure 1 is replaced with a strain gage of precisely the same resistance value and connected with two leadwires having negligible resistance, the bridge circuit remains at balance. But in practice the leadwires will have some measurable resistance RL as shown in Figure 2 on the next page. And because both leadwires are in series with the strain gage between adjacent corners of the bridge circuit, the bridge arm resistance becomes RG+RL1+RL2, causing a significant lack of symmetry and an unbalanced condition in the bridge, resulting in a non-zero output voltage at eo.

If the initial imbalance is modest, it may be mathematically subtracted from subsequent measured strain readings; but large imbalances may cause a more serious problem. As an example, a 20-ft (6 m) length of two-conductor AWG26 (0.4 mm dia.) copper leadwire has a room-temperature resistance value of about 1.7 ohms. Wired in a two-wire

The Three-Wire Quarter-Bridge Circuit

connection with a 120-ohm strain gage, and connected to a measuring instrument with a gage factor setting of 2.0, this would produce an initial bridge imbalance corresponding to about 7000 με. This offset may significantly limit the available measurement range of the instrumentation, and also should be considered when correcting for Wheatstone bridge nonlinearity (see Tech Note TN-507).

Further, the leadwires are a parasitic resistance in the gage arm of the bridge, and effectively reduce or desensitize the gage factor of the strain gage, resulting in a reduced signal output. For modest values of leadwire resistance, the desensitization is approximately equal to the ratio of leadwire resistance to strain gage resistance. In the example given here, this results in about a 1.5% loss in sensitivity.

And finally, a more serious problem may result if the temperature of the leadwires changes during the measurement process. Copper leadwires change in resistance approximately 22% of their room-temperature resistance value for a 100°F (55°C) temperature change. For the 120-ohm gage circuit in Figure 2, this would result in an error equivalent to approximately 156 microstrain, or about 4700 psi (0.03 GPa) in steel, for a 10°F (5.5°C)temperature change in the leadwire system.

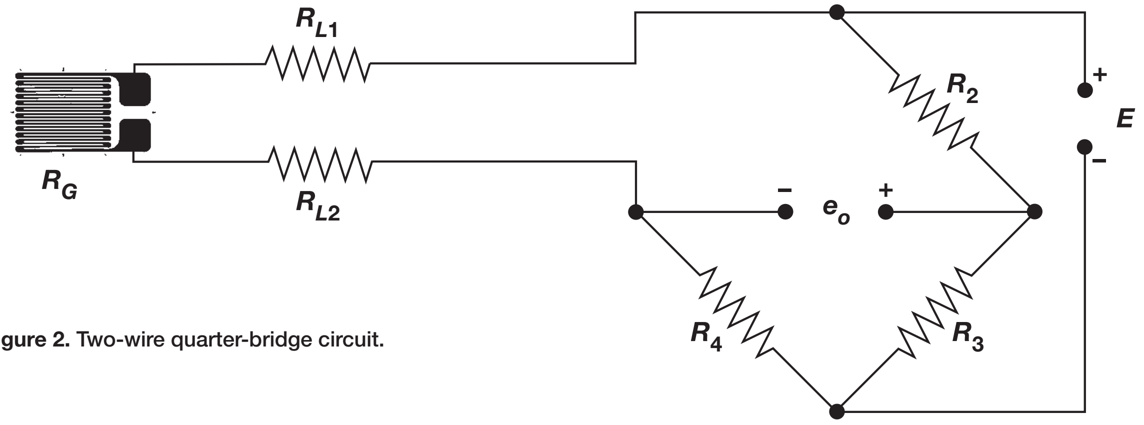

Figure 2. Two-wire quarter-bridge circuit.

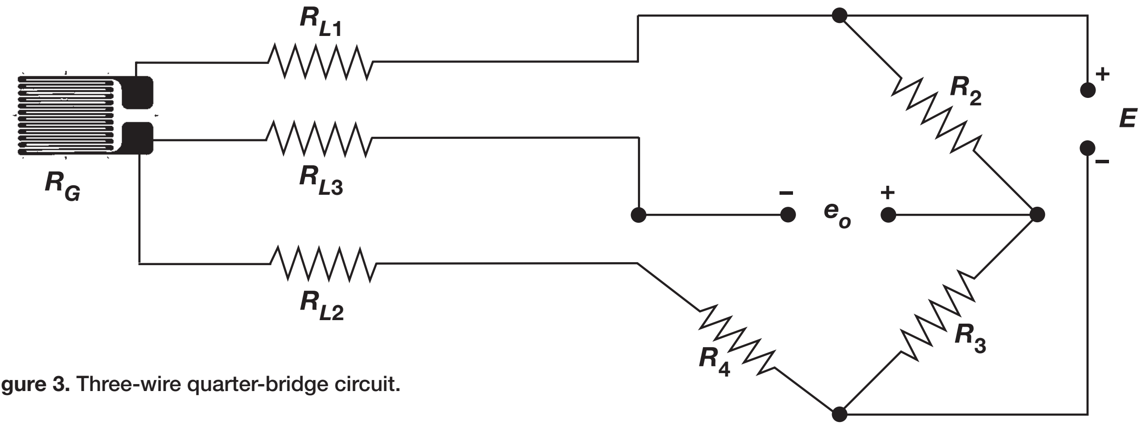

Figure 3. Three-wire quarter-bridge circuit.

The Three-Wire Quarter-Bridge Circuit

All three of these effects increase in severity with increased leadwire resistance. It is worth noting that use of a 350-ohm strain gage circuit will reduce each of these effects, but cannot eliminate completely the associated measurement errors. But the three-wire circuit described in the following section will reduce the loss in sensitivity, and essentially eliminate the initial imbalance problem and the error that results from temperature changes in the leadwire system.

Three-Wire Circuit

With the three-wire circuit shown in Figure 3, the negative output bridge corner is electrically moved from the top of R4, to the bottom strain gage tab at the end of RL3. In this configuration, leadwire RL1 and strain gage RG comprise one arm of the bridge, and RL2 with resistor R4 the adjacent arm. For an equal-arm bridge, if leadwires RL1 and RL2 are initially the same type and length, their resistances will be equal, and the two respective bridge arms will therefore be equal in resistance. The bridge is resistively symmetrical about a line through the bridge output corners, and the bridge is balanced. And regardless of leadwire temperature changes, so long as the two leadwires are at the same respective temperature, the bridge remains in balance. Additionally, because only one leadwire is in series with the strain gage, leadwire desensitization is reduced about 50% compared to the two-wire configuration. The third wire (RL3) in Figure 3 is a voltage-sensing wire only, it is not in series with any of the bridge arms, therefore it has no effect on bridge balance or temperature stability.

While the three-wire circuit offers several advantages over the two-wire circuit, in some special applications involving, for example, slip rings or feed-through connectors, not enough connections may be available for a continuous three-wire system from the gage site to the instrument terminals. In these cases, use of a two-wire lead system between the strain gage and the connector, and a three-wire circuit between the connector and the measuring instrument, is recommended to minimize the total length of the two-wire system.

The foregoing discussion applies primarily to measurement of static strains using a measuring instrument with dc-coupling between the bridge circuit and the amplifier input terminals. For measurement of purely dynamic strains when only the peak-to-peak amplitude of a time-varying signal is of interest, the two-wire system may sometimes be used effectively by selecting a signal-conditioning amplifier that provides for ac-coupling of the input signal, and blocks the effects of temperature-induced changes in leadwire resistance.

In summary, benefits of the three-wire circuit include intrinsic bridge balance, automatic compensation for the effects of leadwire temperature changes on bridge balance, and increased measurement sensitivity compared to the two-wire configuration. The three-wire hookup is the recommended configuration for quarter-bridge strain gage circuits for static strain measurement. The two-wire circuit can sometimes be used effectively for special situations such as dynamic-only measurements with ac-coupled instrumentation, or in static strain applications where the length of the two-wire system can be kept very short.

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Installation Verification

Installation Verification

Zero-shift and zero-drift in the resistance of strain gages can arise from a number of sources, including the gage installation itself. This application note describes the necessary steps for the verification of strain gage installations to ensure stability.

After Bonding

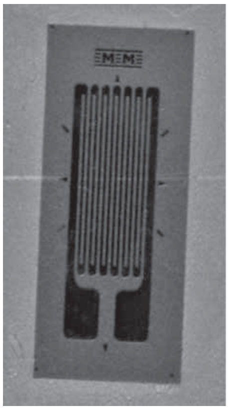
A recommended checklist follows for inspection of installations prior to both leadwire attachment and application of protective coatings. These, by necessity, are limited to visual inspections. Magnification is helpful when dealing with small gages.

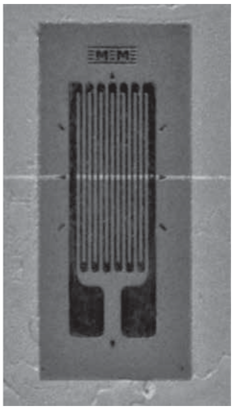
Adhesive Uncured

Use a DPR-1 dental probe to check the exposed adhesive on the specimen surface beside the gage backing after bonding. If adhesive is soft or rubber-like, either complete the cure (if possible) or replace the installation.

Gage Misaligned

Visually inspect to ensure that the alignment marks on the gage are in the desired orientation. Resulting errors are discussed in Micro-Measurements Tech Note TN-511, Errors Due to Misalignment of Strain Gages.


Misaligned


Aligned

Backing Unbonded

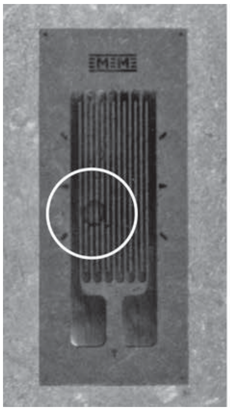
If visibly obvious, gage should be replaced. If in doubt, recheck electrically for zero-return and stability under load after leadwire connections have been made.

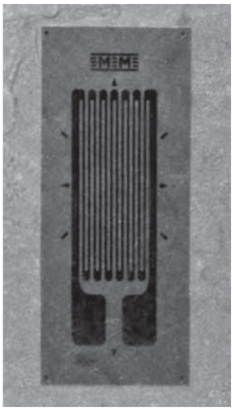
Grid Wrinkled or Creased

Installer must judge whether caused by normal undulation of adhesive or by mishandling during bonding. If obviously wrinkled or creased, the installation should be replaced.

Bubbles

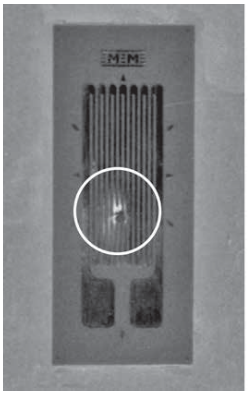
Usually a concern only when directly under gage grid. If bubble area is small in comparison to grid, check for zero-return and stability under load when electrical connections have been made.


Unacceptable


Bubble-free

Bumps

Usually caused by entrapped foreign matter, undissolved crystals of adhesive resin, or filler. May reduce fatigue en-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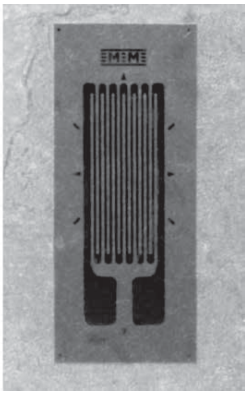

Bump-free

Installation Verification

durance. Usually a concern only when directly under gage grid. If particle is small in comparison to grid, check for zero-return when electrically connected.

Residual Tape

Adhesive tapes (and their mastics) used during installation will interfere with environmental protection if not removed. Rosin Solvent may be helpful in removing residual pieces from the gage and specimen.

Adhesive Layer Uneven

Usually caused by uneven clamping pressure, uneven "gluelines" have a varying color density when viewed through the gage backing. May affect strain transmission, thermal output, and magnitude of errors due to the location of the grid above the specimen surface during bending. Regaging is recommended when pronounced.

Adhesive Flow

The adhesive must be present under the entire grid but should not flow between the top surface of the gage and the transfer tape and/or pressure pad. Check for adhesive on solder tabs and terminals that will interfere with soldering.

Discoloration

Unusual darkening of backing or solder tabs may indicate excessive curing temperatures. If soldering is difficult, clean tabs with a soft (usually pink) pencil eraser. (After protecting the gage grid with drafting tape, stroke the tabs away from the tape. Avoid side-to-side or back-and-forth motions.) Check thermal output and zero-return after electrical connections are made.

Gage Identification

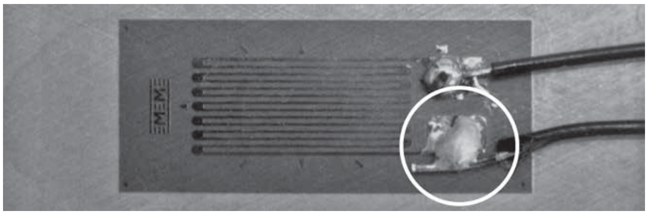
Good practice requires that each gage be identified for reference to the engineering data supplied with the gage. Serialize at the gage site, or prepare a diagram showing gage locations and identification.

After Leadwire Attachment

The following checklist gives the recommended inspections immediately after the completion of leadwire attachment, but prior to the application of a protective coating.

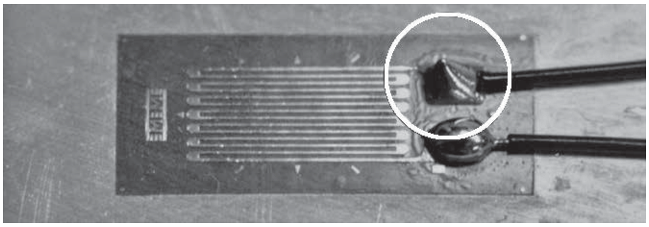
Cold Solder Joints

Caused by failure of the entire solder joint to reach the proper soldering temperature, leadwire movement during soldering, or insufficient flux. Solder may not "wet" the leadwire and solder tabs on the strain gage or terminal strip. Cold joints are characterized by an uneven, "flaky" appearance and poor solder flow.


Cold Solder Joint

Solder Peaks

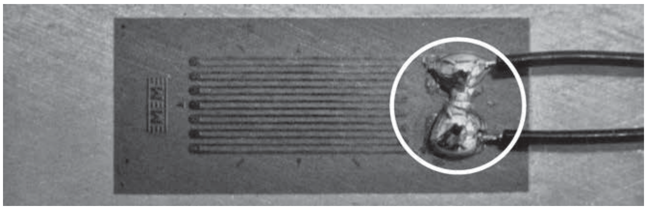
Sharp peaks of solder are usually the result of insufficient flux (use of solder without flux, loss of flux due to excessive soldering temperature, or failure to remove rosin-core solder wire and soldering iron tip from the solder joint simultaneously). Peaks may interfere with flux removal and environmental protection. Large solder masses of any shape are undesirable in tests involving high acceleration or deceleration.


Solder Peak

Solder Bridges

Solder tabs are often closely spaced. Care must be taken to ensure that solder joints or excessively long leadwire

Installation Verification



Solder Bridge

strands do not form an electrical connection between tabs. A visual inspection is usually adequate, however, an electrical resistance check is recommended if any doubt exists.

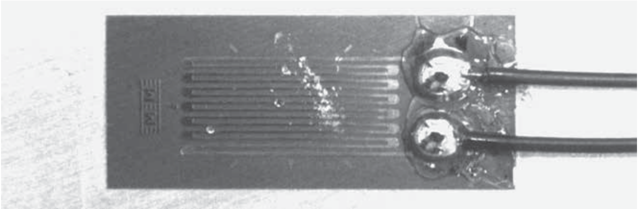
Wiring Errors

Be certain that all leadwires are connected to their intended circuit locations. Wire markers and color coding are helpful. Electrical verification of connections is recommended for installations with long runs or large bundles of leads.

Installed Resistance

A properly installed strain gage will usually retain a nominal grid resistance within the tolerance shown on the Engineering Data Sheet supplied with it. (Gages installed on a small radius or with a heat-curing adhesive may exceed these limits.) The Model 1300 gage installation tester is an ideal instrument for verifying the deviation of installed resistance (sum of gage grid and leadwire resistances) from the nominal value.

Residual Flux



Residual Flux

Visually inspect for flux residue after cleaning with rosin solvent. When cleaning solvents have evaporated, the insulation resistance (leakage) between the gage grid and specimen (if electrically conductive) should be at least 10,000 megohms. Caution: Always use a megohm meter, like that incorporated into the Model 1300, that applies a test voltage of less than 100 VDC.

Residual Moisture

Condensation and other forms of moisture may also affect insulation resistance. Dry the installation with warm air and recheck resistance as previously described just prior to the application of any environmental protection.

Zero Return

Connect the installation to a strain indicator and zero-balance. If possible, load the specimen to produce a strain of about the same magnitude expected in the test and unload immediately. The reading should return to within ±5 microstrain of zero. If loading is impractical, protect the gage grid with drafting tape and gently press the grid with a soft (usually pink) rubber eraser. Poor zero return may indicate bubbles, inclusions, or unbonded areas in the adhesive layer under the grid.

Stability

A strain gage subjected to a static strain over a period of time should yield an indicated strain that is stable within a few microstrain. Unexplained changes in indicated strain while the test specimen is under a static load may also be due to bubbles, inclusions, or unbonded areas.

After Environmental Protection

Circuit Resistance

A repeat check of the resistance of the gage grid and leadwires will ensure that no short circuit, open circuit, or unintentional grounding has developed during installation of the protection system.

Insulation Resistance

Any moisture or residual flux trapped under the environmental protection may affect the insulation resistance (leakage) between the gage grid and specimen (if electrically conduc-

Installation Verification

tive). Inappropriate or incorrectly installed coatings may also produce similar undesirable effects. A megohm meter should be used to ensure that the leakage resistance is at least 10,000 megohms (and preferably 20,000 megohms or more). For this test, always use a megohm meter, like that incorporated into the Model 1300 gage installation tester, that applies a test voltage of less than 100 VDC to avoid damage to the installed gage.

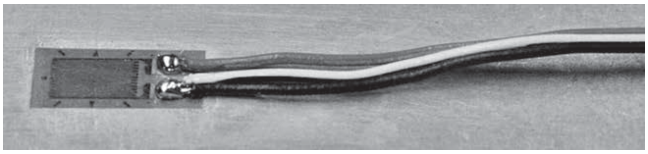
If the insulation resistance is low, the protective coating should be removed and the installation carefully cleaned and dried. Check the resistance again before replacing the coating. If the coating system requires a supplementary insulation over unencapsulated grids and leadwire connections, be sure it is in place. Some coatings contain solvents which must evaporate before an acceptable insulation resistance is obtained.

Visual Checks

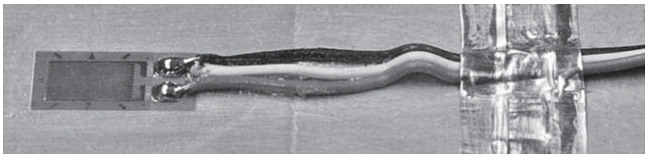
Use STW-1 tweezers or a DPR-1 dental probe to locate any unbonded areas between the specimen surface and the environmental protection. Make certain that any holes or voids in the coating are not deep enough to compromise the environmental protection system. Look for uncured areas which may indicate incomplete mixing or curing. Remove coating and apply again if any doubt exists regarding the integrity of the protection system.

Leadwire Anchoring

Leadwires should be held firmly in place for those coatings which harden or cure. Any motion during these processes may produce “tunnels” between the coating and leadwire through which moisture and contaminates can invade the gage installation. (This is particularly true for M-Coat W-1 microcrystalline wax.) Visual inspection of the leadwire entry into the protective coating will reveal the presence of any separation between them.



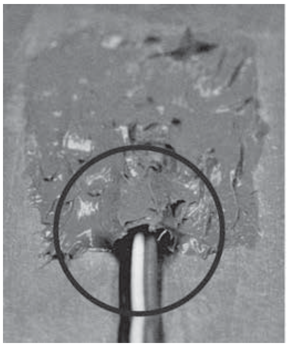
Unanchored Cable



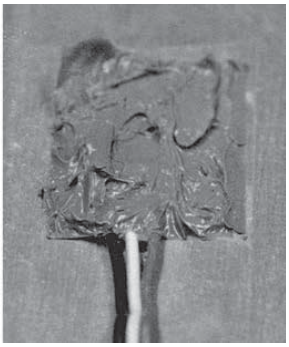
Anchored Cable

Reinforcing Effects

The extent of reinforcement produced by the protective coating depends upon the dimensions and mechanical properties of the specimen, as well as the protection system itself. While the stiffening effect is often negligible, specimens having thin sections or those made of low-modulus materials warrant special attention. The relative magnitude of the effect on measurement data often can be determined by applying a small preload to the specimen both before and after installation of the environmental protection. If preloads are not permitted, a similarly sized specimen of the same material can be used to make an estimation of the extent of reduction in indicated strain under similar loading conditions.



Tunnel



No Tunnel

Viscoelastic Effects

Most coatings behave in a viscoelastic manner under load

Installation Verification

and produce reinforcing effects that, in time, approach zero. Conversely, when long-standing loads are removed, reinforcements that are opposite in sign but equal in magnitude to the initial effects are produced. These, too, will diminish with time. If either of these coating-related, viscoelastic effects on the indicated strains are unacceptable in a particular application, an alternate method of environmental protection must be sought.

With the exception of encapsulated gages used in immediate, short-term indoor tests, every strain gage installation should be protected by an appropriate environmental protection system. Properly selected and applied, Micro-Measurements protective coating systems will enhance the quality of your strain measurements by protecting gage installations against chemical attack, mechanical abuse, and electrical malfunctions.

Most gage installations will exhibit none of these faults if the installation techniques outlined in Micro-Measurements instructional materials and training programs are followed. However, field applications made in harsh environments, or even laboratory installations with difficult gage locations on the test specimen, warrant special attention. If you have any questions concerning your particular applications, our Applications Engineering Department will be pleased to assist you in establishing a program for verifying the integrity of strain gage installations.

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Instrumentation

67............... Static/Quasi Static Instruments
68............... Signal Conditioning Systems
69............... StudentDAQ – Mobile and Easy to Use
70............... Dynamic/Quasi Dynamic Instruments

Static/Quasi Static Instruments

Constant load monitoring applications

Models: StudentDAQ, P3, and D4

	StudentDAQ	D4	P3
Measurement Range	±16,000 @ GF=2.0	±31,000 @ GF=2.0	±31,000 @ GF=2.0
Connection	RJ45 (1)	RJ45 (4)	Terminal Block or TIO
Input Type	Strain Gage Bridge	Strain Gage Bridge	Strain Gage Bridge
Bridge Types	QB, HB, FB	QB, HB, FB	QB, HB, FB
Bridge Completion	120 Ω, 350 Ω, 1000 Ω, internal HB 1 KΩ(2)	120 Ω, 350 Ω, 1000 Ω, internal HB 1 KΩ(2)	120 Ω, 350 Ω, 1000 Ω, internal HB 1 KΩ(2)
A/D Converter	24 bit Delta-Sigma	24 bit Delta-Sigma	24 bit Delta-Sigma
Max Input	±8 mV/V @ GF = 2.0	±15.5mV/V @ GF=2.0	±15.5mV/V @ GF=2.0
Resolution	1ue @ GF=2.0	1ue @ GF=2.0	1ue @ GF=2.0
Accuracy	1% of reading @GF=2.0	0.1% of reading ± 3 counts	0.1% of reading ± 3 counts
Excitation	2.5 Volts (nominal,fixed)	1.5 Volts (nominal, pulsed)	1.5 Volts (nominal, pulsed)
Power Source	USB only	USB only	USB, battery, or AC/DC
Data Rate	80 S/s	8 S/s	1 S/s
Max Storage	PC dependent	PC dependent	2GB card or PC
Max Channels	1	24	24
Software	Windows based	Windows based	Windows based
Drivers	Labview, .NET interface	Labview, .NET interface	Labview, .NET interface

Signal Conditioning Systems

Low-level signal amplification and filtering

Models: 2100, 2200, and 2300

	210	220	2300
Bandpass(-3dB)	DC-15kHz (50kHz)	DC-100kHz	DC-125kHz
Output (Vdc)	±10V	±10V	±10V
Filters	None	1-10kHz	1-10kHz
AC Coupling	No	Yes	Yes
Gain	1-2100	1-3300	1-11000
Strain Gage Excitation	0.5-12Vdc	0.5-15Vdc 0.5-30mA	0.2-15Vdc
Excitation	Constant Voltage only	Constant Current and Voltage	Constant Voltage only
Power Supply	AC/DC	AC	AC
Balance	Manual	Auto	Auto
Setup	Manual	Manual	Manual
Saved Setups	1	1	1
Output Display	Optional	Optional	Optional
Thermocouple Input	Not allowed	Not allowed	Not allowed
Low Level Input	Yes	Yes	Yes
Channels	2-10	1-10	1-10
Max. Channels	Unlimited	Unlimited	Unlimited

StudentDAQ – Mobile and Easy to Use

Compact USB Data Acquisition for Educators

Models: MM01-120, MM01-350, MM01-1K

Capabilities

- Collects single or multi channel strain gage data
- Supports full bridge and half bridge inputs
- Quarter bridge circuits supported include 120,
- 350, or 1000 ohms depending on MM01 model
- Support 3 wire quarter bridge inputs
- Wheatstone bridge completed internally
- Loadcell connectivity allowed
- Excitation provided by the PC
- Collects data at 80 samples/sec
- USB connection provides power to the bridge
- Measurement range of +/- 16, 000 microstrain
- Turnkey software included via web download
- Connectivity type to the StudentDAQ is RJ-45

Promotes

- Engineering Education
- Strain Measurement for Novices
- Material Properties Determination
- Strain Gage Connectivity testing
- Rosette Measurements

Dynamic/Quasi Dynamic Instruments

Quickly varying load applications

Models: 7000, 8000, and 9000

	7100	8000	9000
Measurement Range (ue)	25,000 - 310,000 @ GF = 2.0	25,000-310,000 @ GF=2.0	25,000-310,000 @ GF=2.0
Input Type	(SG,HL,LVDT, and TC)	(SG,HL, and TC)	(SG, TC*,HL*,Piezo*)
Bridge Types	QB, HB, FB	QB, HB, FB	QB, HB, FB
Bridge Completion	120 Ω, 350 Ω, 1000 Ω, internal HB 1 KΩ(2)	120 Ω, 350 Ω, 1000 Ω, internal HB 1 KΩ(2)	120 Ω, 350 Ω, 1000 Ω, internal HB 1 KΩ(2)
A/D Converter	24 bit Delta-Sigma	24 bit Delta-Sigma	24 bit Delta-Sigma
Max Input	±50 mV/V @ GF = 2.0	±155mV/V @ GF=2.0	±155mV/V @ GF=2.0
Resolution	0.5 ue @ GF=2.0	0.5 ue @ GF=2.0	0.5 ue @ GF=2.0
SG Excitation	0-10Vdc (SW selectable)	0-10Vdc (SW selectable)	0-10Vdc (SW selectable)
HL Excitation	0-11.997 VDC	0-11.997 VDC	0-11.997 VDC
Power Source	11-32VDC, 30A max	10-32VDC, 5A max	11-32VDC, 10A max
Data Rate	Up to 2000 S/s	Up to 1000 S/s	5000 - 50,000 S/s
Max Storage	PC Dependent	PC dependent	>16GB (2GB file max size)
Analog Output	No (provides Digital I/O)	No	Optional SM-AO only
Max Channels	1000	128	48
Software	Windows based	Windows based	Windows based
Drivers	.NET interface	Labview, .NET interface	.NET interface
Self calibrate	Yes – with Vcal	Yes – with Vcal option	Yes – with Vcal option

* Optional Cards

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Appendix

Strain Gage Installation Checklists

72............... Steel
76............... Concrete
80............... Aluminum
84............... Composite/Plastic Materials

Strain Measurements on Steel

Strain gage applications on steel can be exposed to a wide variety of environments and temperature conditions, so attention to the variables related to these two conditions is important. This guide will lead you through the selection process for the strain gage, adhesive, wire and solder, and protective coatings to ensure the most successful results when measuring strain on steel.

Step 1
Define the Test Conditions

Conditions to Consider	Your Test Conditions
Static measurement One sample per second or less, steady loading	
Dynamic measurement Cyclical or impact loading, high frequency Event duration Anticipated frequency	
Installation longevity Short Term: Hours, days, weeks Long Term: Months, years	
Environment Maximum temperature Minimum temperature Exposure (outdoors, oil, chemicals)	

Step 2
Ensure Appropriate Surface Preparation Materials Are On Hand

Use the recommended surface preparation materials for steel:

CSM degreaser
GSP-1 gauze sponge
220-grit SCP-1 silicon carbide paper
320-grit SCP-2 silicon carbide paper
CSP-1 cotton-tipped applicator

M-Prep Neutralizer 5A
M-Prep Conditioner A
PCT-3M gage installation tape
PDT-3 drafting tape

Reference **Instruction Bulletin B-129**: SEARCH our website using the document number **11129**.

Step 3
Select the Strain Sensor

Consult the Micro-Measurements team and/or review our **Tech Note TN-505**, “Strain Gage Selection – Criteria, Procedures, Recommendations” for detailed information about the strain gage selection process.

Step 3A: **Select the Gage Series for the Temperature Range**

Consider the temperature range that will be encountered during the strain measurements and select a **Gage Series** that meets your requirements.

Gage Series	Temperature Range	Features
CEA	–100°F to +350°F (–75°C to +175°C)	Universal, general-purpose strain gages. Large, easily soldered tabs. Precabled (Option P2) available. Weldable gages are also available.
C4A	–60° to +180°F (–50° to +80°C)	Precabled, general-purpose strain gages.
EA	–100° to +350°F (–75° to +175°C)	Widest range of available patterns, sizes and optional features.
WK	–452° to +550°F (–269° to 290°C)	Widest temperature range and most extreme environmental capability of any general-purpose gage when self-temperature compensation is required. High fatigue-endurance leadwires. Weldable gages are also available.
WD	–320° to +500°F (–195° to 260°C)	Highest fatigue life, for dynamic applications only. High endurance leadwires and wide temperature range.

Step 3B: **Choose the STC for Your Material**

When temperature changes will occur during the course of strain measurements, **self-temperature-compensation (STC) 06** is specified for mild and carbon steel alloys.

Step 3C: **Consider the Geometry**

If your specialized measurement requires a unique strain gage, Micro-Measurements has hundreds of strain gage geometries available. Check **Super Stock** for gages that are available to ship promptly.

Strain Gage Pattern	Stress State	Where Directions of Principal Stresses Are
Linear	Uniaxial	Known
0° to 90° (T-Rosette)	Biaxial	Known
Triaxial (Rectangular or Delta Rosette)	Unknown	Both the principal stresses need to be determined along with their direction
Dual-Shear	Typically used when a measurement of shear strain is required	

Step 3D: **Other Considerations**

Consider the available area to fit the strain gage, strain gradient and gage length required. Refer to the matrix dimensions, given in the strain gage datasheet, which define the “footprint” of the strain gage.

There are some advantages to higher resistance, but many of the smallest strain gages are available only in lower resistance. The most common general-purpose strain gage resistances are 120 Ω, 350 Ω, and 1000 Ω.

Consider compatibility with instrumentation as well.

Step 4
Select the Adhesive

Adhesive	Conditions to Consider
M-Bond 200 Kit	The most frequently used adhesive for short-term room temperature testing, with fast installation
M-Bond AE-10	Long-term testing where room temperature cure is required
M-Bond 600 or **M-Bond 610**	Wide temperature range testing; elevated temperature cure required

Follow the instructions included with the adhesive for application and cure requirements.

Application Kits contain specific adhesives, surface preparation materials, and in some cases wire and coatings necessary for a successful strain gage installation on steel.

- **BAK-200 Kit**
  Contains M-Bond 200 adhesive and basic materials for surface preparation (does not include GC-6 Alcohol). Excellent for use with pre-cabled gages.
- **GAK-2-200, GAK-2-AE-10, and GAK-2-610 Kits**
  Contain all materials needed to install strain gages on steel, including solder and cable.

Step 5
Select Cable and Solder Terminals

Micro-Measurements offers a variety of **cable types** for gage installation on steel. For ease of installation, consider pre-cabled gages (**C4A-Series**, **Option P2, Option P, Option SP35**); no additional cable is required unless length needs to be extended.

Cable	Conditions to Consider
Vinyl Insulated	Room temperature testing
Teflon Insulated	Wide temperature range testing, high moisture or water immersion, and chemical resistance

Solder Terminals	Conditions to Consider
Bondable Terminals	For use with small gages or those with short preattached wires, such as WK- and WD-Series gages.

Step 6
Select a Solder

Micro-Measurements has a wide selection of **solder** for strain gage applications. Solder melt point should be at least 50°F (28°C) above the maximum operating temperature. Solder is not needed when using pre-cabled gages.

Step 7
Select a Protective Coating

Consider the environmental conditions that the coating will need to resist and any application issues, such as:

Environmental Conditions	Application Issues
• Temperature range • Humidity • Chemical exposure • Localized reinforcement concerns	• Vertical surface • Horizontal surface • Component sensitivity

For room temperature testing in a laboratory environment, the most popular coating is **M-Coat A**. For field testing, **M-Coat JA**, **M-Coat F**, and **Barrier E** are rugged and waterproof.

For testing in other environments and temperatures, refer to the **Protective Coating Selection Guide** to select the proper coating.

Step 8
Select the Measurement Instrumentation

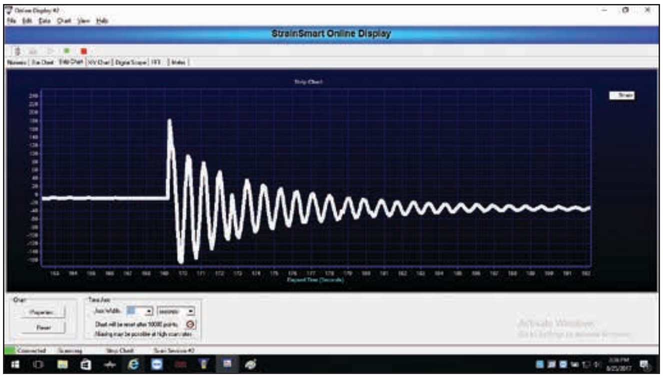
Micro-Measurements offers a wide variety of **instrumentation** specifically designed and optimized for strain measurement. Simple Strain Indicators are available for high-accuracy static measurements. Signal Conditioning Amplifiers accept direct strain gage input and provide a conditioned signal output in the ±10 V range. Data Systems accept direct strain gage input and provide reduced data, already in engineering units of strain and/or stress.

P3
Strain Indicator

StudentDAQ

D4 Data Acquisition
Conditioner

System 8000 Data Acquisition



StrainSmart® Data Acquisition Software

System 9000 Data Acquisition

Pacific Instruments
Series 6000 Data Acquisition System

Strain Gage Installation Checklist
Concrete

Strain Measurements on Concrete

Concrete is a porous material and generally will have a surface that is too rough to form a very thin and void-free adhesive layer between the strain gage and the concrete. For these reasons, concrete must first be sealed with an epoxy such as M-Bond AE-10. Long gage length strain gages are typically required on the surface of concrete in order to correctly strain-average over the aggregate and mortar mixture. Since concrete is a poor conductor of heat, precabled gages or gages with preattached leadwires are highly recommended.

Step 1
Define the Test Conditions

Conditions to Consider	Your Test Conditions
Static measurement One sample per second or less, steady loading	
Dynamic measurement Cyclical or impact loading, high frequency Event duration Anticipated frequency	
Installation longevity Short Term: Hours, days, weeks Long Term: Months, years	
Environment Maximum temperature Minimum temperature Exposure (outdoors, moisture, chemicals)	

Step 2
Ensure Appropriate Surface Preparation Materials Are On Hand

Use the recommended surface preparation materials for concrete:

GC-6 alcohol
GSP-1 gauze sponge
400-grit SCP-3 silicon carbide paper
CSP-1 cotton-tipped applicator
M-Prep Neutralizer 5A
M-Prep Conditioner A
PCT-3M gage installation tape
PDT-3 drafting tape

Reference **Related Documents**: SEARCH our website using the document number.
11129 – Instruction Bulletin B-129; **11091** – Tech Tip TT-611

Step 3
Select the Strain Sensor

Consult the Micro-Measurements team and/or review our **Tech Note TN-505**, “Strain Gage Selection – Criteria, Procedures, Recommendations” for detailed information about the strain gage selection process.

Step 3A: **Select the Gage Series for the Temperature Range**

Consider the temperature range that will be encountered during the strain measurements and select a **Gage Series** that meets your requirements.

Gage Series	Temperature Range	Features
CEA	–100°F to +350°F (–75°C to +175°C)	Universal, general-purpose strain gages. Large, easily soldered tabs. Precabled (Option P2) available.
C4A	–60°F to +180°F (–50°C to +80°C)	Precabled, general-purpose strain gages.
EA	–100°F to +350°F (–75°C to +175°C)	Widest range of available patterns, sizes and optional features.
EGP	+25°F to +125°F (–5°C to +50°C)	For direct embedment in concrete
LEA	–40°F to +180°F (–40°C to +83°C)	Sealed weldable strain gage for rebar

Step 3B: **Choose the STC for Your Material**

When temperature changes will occur during the course of strain measurements, **self-temperature-compensation (STC) 06** is often selected for concrete.

Step 3C: **Consider the Geometry**

The strain gages below are popular for strain measurements on concrete. Check **Super Stock** for gages that are available to ship promptly. Our C4A-06-20CLW-350 is an excellent choice for aggregate ≤0.5" (13 mm) diameter.

Type	Gage Designation	Geometry/Construction
SUPER STOCK Strain Gages with Long Gage Lengths	**C2A-06-20CLW-120** **C2A-06-20CLW-350**	Linear pattern, 2-in long gage length, precabled
	EA-06-40CBY-350	Linear pattern, 4-in long gage length
Concrete Embedment Gages	**EGP-5-120** **EGP-5-350**	Linear embedment gage, precabled
Weldable Gages for Rebar	**CEA-06-W250A-120** **CEA-06-W250A-350**	Linear pattern
Sealed Weldable Gages for Rebar	**LEA-06-W125E-350/10L** **LEA-06-W125E-350/3R**	Linear pattern, precabled

Step 4
Select the Adhesive

Adhesive	Conditions to Consider
M-Bond 200 Kit	For short-term applications involving bonding a strain gage to a sealed surface
M-Bond AE-10	Room-temperature curing epoxy used as a surface sealer and leveler. The prefered adhesive for bonding strain gages to a sealed surface for long-term structural monitoring

Follow the instructions included with the adhesive for application and cure requirements.

Application Kits contain specific adhesives, surface preparation materials, and in some cases wire and coatings necessary for a successful strain gage installation on concrete.

- **BAK-200 Kit**
  Contains M-Bond 200 adhesive and basic materials for surface preparation (does not include GC-6 Alcohol). Excellent for use with pre-cabled gages.
- **GAK-2-AE-10 Kit**
  Contain all materials needed to install strain gages on concrete, including solder and cable.

Step 5
Select Cable and Solder Terminals

Micro-Measurements offers a variety of **cable types** for gage installation on steel. For ease of installation, consider pre-cabled gages; no additional cable is required unless length needs to be extended.

Cable	Conditions to Consider
Vinyl Insulated	Room temperature testing
Teflon Insulated	Wide temperature range testing, high moisture or water immersion, and chemical resistance

Solder Terminals	Conditions to Consider
Bondable Terminals	Bonded to the test structure, these can be used as transition or anchor point for cable.

Step 6
Select a Solder

Micro-Measurements has a wide selection of **solder** for strain gage applications. Solder melt point should be at least 50°F (10°C) above the maximum operating temperature. Solder is not needed when using pre-cabled gages.

Step 7
Select a Protective Coating

Consider the environmental conditions that the coating will need to resist and any application issues, such as:

Environmental Conditions	Application Issues
• Temperature range • Humidity • Chemical exposure • Localized reinforcement concerns	• Vertical surface • Horizontal surface • Component sensitivity

For a wide range of applications on concrete, **M-Coat JA** is often selected. A single tube can coat up to three strain gage installations. M-Coat JA has a pot life of about 2 hours after mixing.

- **M-Coat JA Kit**, one tube
- **M-Coat JA-3 Kit**, three tube

For harsh environments and extreme temperatures, refer to the **Protective Coating Selection Guide** to select the proper coating.

Step 8
Select the Measurement Instrumentation

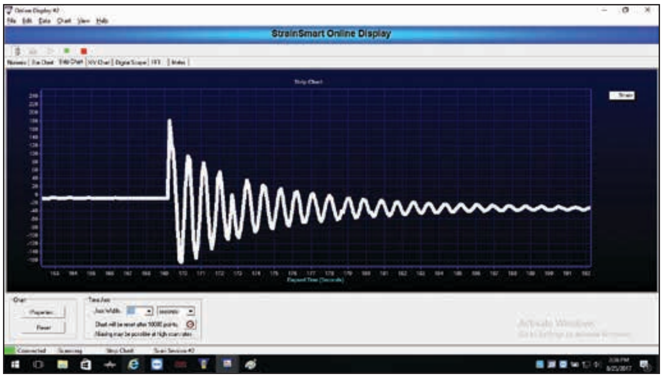
Micro-Measurements offers a wide variety of **instrumentation** specifically designed and optimized for strain measurement. Simple Strain Indicators are available for high-accuracy static measurements. Signal Conditioning Amplifiers accept direct strain gage input and provide a conditioned signal output in the ±10 V range. Data Systems accept direct strain gage input and provide reduced data, already in engineering units of strain and/or stress.

P3
Strain Indicator

StudentDAQ

D4 Data Acquisition
Conditioner

System 8000 Data Acquisition



StrainSmart® Data Acquisition Software

System 9000 Data Acquisition

Pacific Instruments
Series 6000 Data Acquisition System

Strain Measurements on Aluminum

Since Aluminum is an isotropic and homogeneous material, selecting the strain gage, adhesive, cable, and protective coating is a very straightforward procedure. Following is a guide to step you through the process of selecting strain gages and materials for measurements on aluminum.

Step 1
Define the Test Conditions

Conditions to Consider	Your Test Conditions
Static measurement One sample per second or less, steady loading	
Dynamic measurement Cyclical or impact loading, high frequency Event duration Anticipated frequency	
Installation longevity Short Term: Hours, days, weeks Long Term: Months, years	
Environment Maximum temperature Minimum temperature Exposure (outdoors, oil, chemicals)	

Step 2
Ensure Appropriate Surface Preparation Materials Are On Hand

Use the recommended surface preparation materials for aluminum:

CSM degreaser
GSP-1 gauze sponge
320-grit SCP-2 silicon carbide paper
400-grit SCP-3 silicon carbide paper
CSP-1 cotton-tipped applicator

M-Prep Neutralizer 5A
M-Prep Conditioner A
PCT-3M gage installation tape
PDT-3 drafting tape

Reference **Instruction Bulletin B-129**: SEARCH our website using the document number **11129**.

Strain Gage Installation Checklist
Aluminum

☑ Step 3
Select the Strain Sensor

Consult the Micro-Measurements team and/or review our **Tech Note TN-505**, “Strain Gage Selection – Criteria, Procedures, Recommendations” for detailed information about the strain gage selection process.

Step 3A: **Select the Gage Series for the Temperature Range**

Consider the temperature range that will be encountered during the strain measurements and select a **Gage Series** that meets your requirements.

Gage Series	Temperature Range	Features
CEA	–100°F to +350°F (–75°C to +175°C)	Universal, general-purpose strain gages. Large, easily soldered tabs. Precabled (Option P2) available.
C4A	–60° to +180°F (–50° to +80°C)	Precabled, general-purpose strain gages.
EA	–100° to +350°F (–75° to +175°C)	Widest range of available patterns, sizes and optional features.
WK	–452° to +550°F (–269° to 290°C)	Widest temperature range and most extreme environmental capability of any general-purpose gage when self-temperature compensation is required. High fatigue-endurance leadwires.
WD	–320° to +500°F (–195° to 260°C)	Highest fatigue life, for dynamic applications only. High endurance leadwires and wide temperature range.

Step 3B: **Choose the STC for Your Material**

When temperature changes will occur during the course of strain measurements, **self-temperature-compensation (STC) 13** is specified for aluminum alloys.

Step 3C: **Consider the Geometry**

If your specialized measurement requires a unique strain gage, Micro-Measurements has hundreds of strain gage geometries available. Check **Super Stock** for gages that are available to ship promptly.

Strain Gage Pattern	Stress State	Where Directions of Principal Stresses Are
Linear	Uniaxial	Known
0° to 90° (T-Rosette)	Biaxial	Known
Triaxial (Rectangular or Delta Rosettes)	Unknown	Both the principal stresses need to be determined along with their direction
Dual-Shear	Typically used when a measurement of shear strain is required	

Step 3D: **Other Considerations**

Consider the available area to fit the strain gage, strain gradient and gage length required. Refer to the matrix dimensions, given in the strain gage datasheet, which define the “footprint” of the strain gage.

There are some advantages to higher resistance, but many of the smallest strain gages are available only in lower resistance. The most common general-purpose strain gage resistances are 120 Ω, 350 Ω, and 1000 Ω.

Consider compatibility with instrumentation as well.

Step 4
Select the Adhesive

Adhesive	Conditions to Consider
M-Bond 200 Kit	The most frequently used adhesive for short-term room temperature testing, with fast installation
M-Bond AE-10	Long-term testing where room temperature cure is required
M-Bond 600 or **M-Bond 610**	Wide temperature range testing; elevated temperature cure required

Follow the instructions included with the adhesive for application and cure requirements.

Application Kits contain specific adhesives, surface preparation materials, and in some cases wire and coatings necessary for a successful strain gage installation on aluminum.

- **BAK-200 Kit**
  Contains M-Bond 200 adhesive and basic materials for surface preparation (does not include GC-6 Alcohol). Excellent for use with pre-cabled gages.
- **GAK-2-200, GAK-2-AE-10, and GAK-2-610 Kits**
  Contain all materials needed to install strain gages on aluminum, including solder and cable.

Step 5
Select Cable and Solder Terminals

Micro-Measurements offers a variety of **cable types** for gage installations on aluminum. For ease of installation, consider pre-cabled gages (**C4A-Series**, **Option P2, Option P, Option SP35**); no additional cable is required unless length needs to be extended.

Cable	Conditions to Consider
Vinyl Insulated	Room temperature testing
Teflon Insulated	Wide temperature range testing, high moisture or water immersion, and chemical resistance

Solder Terminals	Conditions to Consider
Bondable Terminals	For use with small gages or those with short preattached wires, such as WK- and WD-Series gages.

Step 6
Select a Solder

Micro-Measurements has a wide selection of **solder** for strain gage applications. Solder melt point should be at least 50°F (28 °C) above the maximum operating temperature. Solder is not needed when using pre-cabled gages.

Step 7
Select a Protective Coating

Consider the environmental conditions that the coating will need to resist and any application issues, such as:

Environmental Conditions	Application Issues
• Temperature range • Humidity • Chemical exposure • Localized reinforcement concerns	• Vertical surface • Horizontal surface • Component sensitivity

For room temperature testing in a laboratory environment, the most popular coating is **M-Coat A**. For field testing, **M-Coat JA**, **M-Coat F**, and **Barrier E** are rugged and waterproof.

For testing in other environments and temperatures, refer to the **Protective Coating Selection Guide** to select the proper coating.

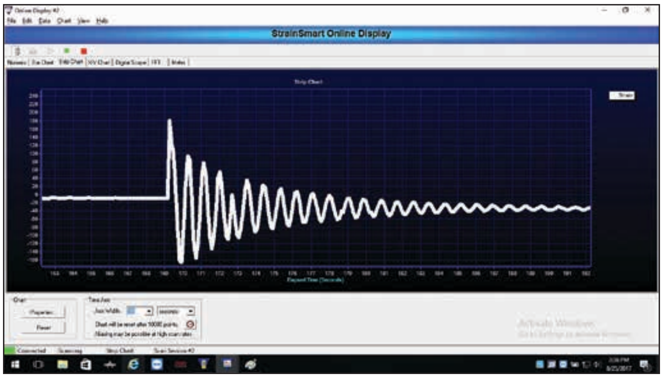
Step 8
Select the Measurement Instrumentation

Micro-Measurements offers a wide variety of **instrumentation** specifically designed and optimized for strain measurement. Simple Strain Indicators are available for high-accuracy static measurements. Signal Conditioning Amplifiers accept direct strain gage input and provide a conditioned signal output in the ±10 V range. Data Systems accept direct strain gage input and provide reduced data, already in engineering units of strain and/or stress.


P3
Strain Indicator


StudentDAQ


D4 Data Acquisition
Conditioner



StrainSmart® Data Acquisition Software


System 8000 Data Acquisition

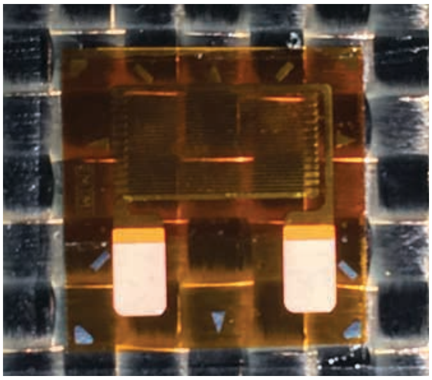

System 9000 Data Acquisition


Pacific Instruments
Series 6000 Data Acquisition System

Strain Gage Installation Checklist

Composite and Plastic Materials

Strain Measurements for Plastics and Composites



Composites typically have one of two surface conditions. The tooling side is usually smooth requiring slight roughening to give the adhesive something to bite into. The non-tooling side is usually rough due to the layup of either woven or filament wound or random orientation carbon fiber filaments. This kind of surface typically needs to be as filled to make it smooth enough for bonding. The gage length is dictated by the desired averaging. With woven composites, that would typically be 3-5 cycles of the weave. Since composites are typically poor conductors of heat, pre-cabled gages or gages with preattached leadwires are highly recommended. For long-term dynamic loading conditions, strain gages with maximum fatigue life may be required.

Step 1
Define the Test Conditions

Conditions to Consider	Your Test Conditions
Static measurement One sample per second or less, steady loading	
Dynamic measurement Cyclical or impact loading, high frequency Event duration Anticipated frequency	
Installation longevity Short Term: Hours, days, weeks Long Term: Months, years	
Environment Maximum temperature Minimum temperature Exposure (outdoors, oil, chemicals)	

Step 2
Ensure Appropriate Surface Preparation Materials Are On Hand

Use the recommended surface preparation materials for composite materials:

GC-6 alcohol
GSP-1 gauze sponge
400-grit SCP-3 silicon carbide paper
CSP-1 cotton-tipped applicator

M-Prep Neutralizer 5A
M-Prep Conditioner A
PCT-3M gage installation tape
PDT-3 drafting tape

Reference **Related Documents**: SEARCH our website using the document number.
11129 – Instruction Bulletin B-129; **11183** – Application Note VMM-19

Step 3
Select the Strain Sensor

Consult the Micro-Measurements team and/or review our **Tech Note TN-505**, “Strain Gage Selection – Criteria, Procedures, Recommendations” for detailed information about the strain gage selection process.

Step 3A: **Select the Gage Series for the Temperature Range**

Consider the temperature range that will be encountered during the strain measurements and select a **Gage Series** that meets your requirements.

Gage Series	Temperature Range	Features
CEA	–100°F to +350°F (–75°C to +175°C)	Universal, general-purpose strain gages. Large, easily soldered tabs. Precabled (Option P2) available.
C4A	–60° to +180°F (–50° to +80°C)	Precabled, general-purpose strain gages.
WK	–452° to +550°F (–269° to 290°C)	Widest temperature range and most extreme environmental capability of any general-purpose gage when self-temperature compensation is required. High fatigue-endurance leadwires.
WD	–320° to +500°F (–195° to 260°C)	Highest fatigue life, for dynamic applications only. High endurance leadwires and wide temperature range.

Step 3B: **Choose the STC for Your Material**

Self-Temperature-Compensation (STC) numbers of **00, 03, and 06** are often selected for composite materials when the measurements involve changes in temperature. For constant-temperature measurements where thermal output is not a concern, 06 is often selected due to higher stock availability. Since composites and plastics offer poor heat sink conditions, strain gages with 350 Ω resistance or higher are often selected.

Step 3C: **Consider the Geometry**

The strain gages below are popular for strain measurements on composites. Check **Super Stock** for gages that are available to ship promptly.

Type	Gage Designation	Geometry/Construction	Super Stock
For Static and Low-Fatigue Dynamic Measurements	**C4A-06-125SL-350-39P**	Linear pattern, precabled	Yes
	C4A-06-250SL-350-39P	Linear pattern, precabled	Yes
	CEA-06-125UNA-350	Linear pattern	Yes
	CEA-06-250UWA-350	Linear pattern	Yes
	CEA-03-250UWA-350	Linear pattern	Yes
	CEA-06-125UTA-350	0-90 degree tee rosette	Yes
	CEA-06-125UB-350	Linear pattern, solder tabs on side	No
	CEA-06-250UB-350	Linear pattern, solder tabs on side	No
	CEA-06-250UTA-350	0-90 degree tee rosette	Yes
	CEA-06-500UWA-350	Linear pattern, long gage length	Yes
For Dynamic Measurements (High Fatigue)	**WK-06-250BG-350**	Linear pattern, wide temperature	No
	WD-DY-250BG-350	Linear pattern, highest fatigue life	No
	WK-06-120WT-350	0-90 degree tee rosette, wide temperature	No
	WD-DY-120WT-350	0-90 degree tee rosette, highest fatigue life	No

Step 4

Select the Adhesive

Adhesive	Conditions to Consider	
M-Bond 200 Kit	Most frequently used adhesive for short-term room temperature testing, with fast installation	
M-Bond AE-10	Long term testing where room temperature cure is required	Used as a filler for rough surfaces prior to gage bonding, as well as for the strain gage adhesive
M-Bond GA-61 or **EPY-500**	Elevated temperature testing	

Follow the instructions included with the adhesive for application and cure requirements.

Application Kits contain specific adhesives, surface preparation materials, and in some cases wire and coatings necessary for a successful strain gage installation on plastics and composites.

- **BAK-200 Kit**
  Contains M-Bond 200 adhesive and basic materials for surface preparation (does not include GC-6 Alcohol). Excellent for use with pre-cabled gages.
- **GAK-2-AE-10 Kit**
  Contain all materials needed to install strain gages on plastics and composites, including solder and cable.

Step 5

Select Cable and Solder Terminals

Micro-Measurements offers a variety of **cable types** for gage installation on plastics and composites. For ease of installation, consider pre-cabled gages; no additional cable is required unless length needs to be extended.

Cable	Conditions to Consider
Vinyl Insulated	Room temperature testing
Teflon Insulated	Wide temperature range testing, high moisture or water immersion, and chemical resistance

Solder Terminals	Conditions to Consider
Bondable Terminals	Bonded to the test structure, these can be used as transition or anchor point for cable.

Step 6

Select a Solder

Micro-Measurements has a wide selection of **solder** for strain gage applications. Solder melt point should be at least 50°F (28°C) above the maximum operating temperature. Solder is not needed when using pre-cabled gages.

Step 7

Select a Protective Coating

Consider the environmental conditions that the coating will need to resist and any application issues, such as:

Environmental Conditions	Application Issues
• Temperature range • Humidity • Chemical exposure • Localized reinforcement concerns	• Vertical surface • Horizontal surface • Component sensitivity

For room temperature testing in a laboratory environment, the most popular coating is **M-Coat A**. For field testing, **M-Coat JA**, **M-Coat F**, and **Barrier E** are rugged and waterproof.

For testing in other environments and temperatures, refer to the **Protective Coating Selection Guide** to select the proper coating.

☑ Step 8
Select the Measurement Instrumentation

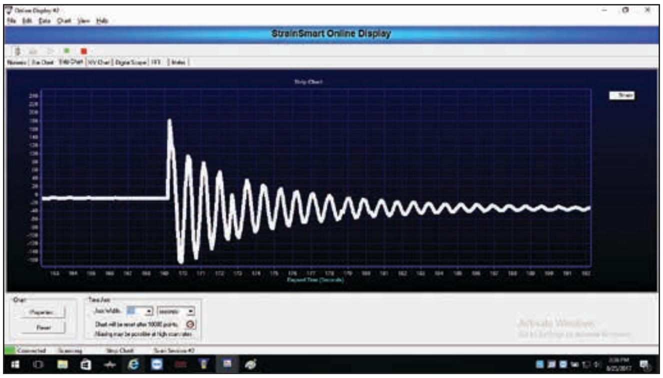
Micro-Measurements offers a wide variety of **instrumentation** specifically designed and optimized for strain measurement. Simple Strain Indicators are available for high-accuracy static measurements. Signal Conditioning Amplifiers accept direct strain gage input and provide a conditioned signal output in the ±10 V range. Data Systems accept direct strain gage input and provide reduced data, already in engineering units of strain and/or stress.

P3
Strain Indicator

StudentDAQ

D4 Data Acquisition
Conditioner

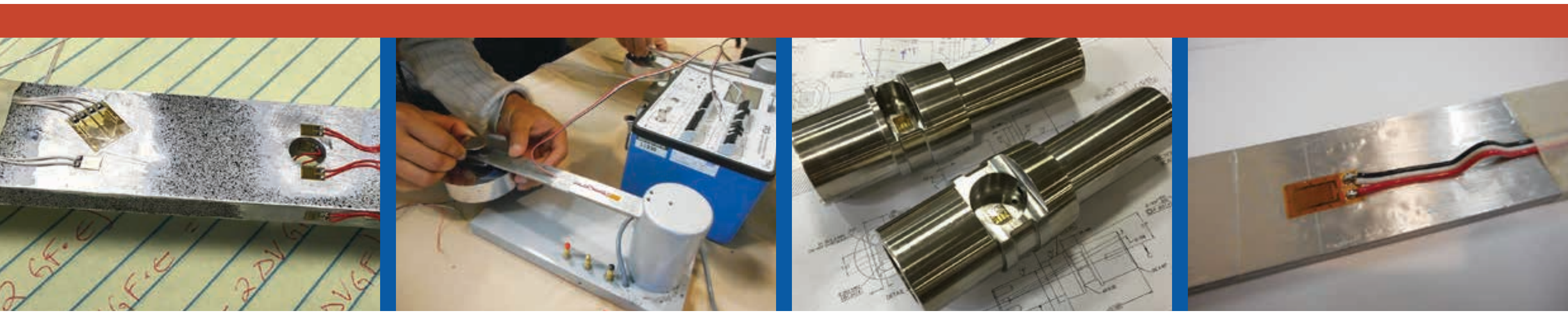
System 8000 Data Acquisition



StrainSmart® Data Acquisition Software

System 9000 Data Acquisition

Pacific Instruments
Series 6000 Data Acquisition System



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