Introduction to Strain Gage Technology

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 the 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-the-art strain gages and strain gage instrumentation, Vishay Measurements Group 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 Vishay Measurements Group 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 strain 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 by professional stress analysts in preparing the test specimen and making gage installations with both 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 the later sections, the hardware of strain gage technology is described:

- **Description of Strain Gages and Accessories:** Partial listings of Micro-Measurements strain gages show the range of modern foil strain gage sizes and geometries. Included are linear patterns, three-element rosettes, pressure diaphragm gages, shear patterns, and others. Also included is a description of the accessory materials and equipment necessary for making good, sound installations.

- **Description of Strain Gage Instrumentation:** The range of instrumentation — including static, dynamic, and computer-controlled stress analysis systems — is shown. A selection chart is provided as a guide in determining the type of instrumentation best suited to a specific measurement application.

- **Reading List:** Additionally, a reading list of recommended references is provided for supplemental study.

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 materials (carrier)
- gage length
- gage pattern
- self-temperature-compensation number
- grid resistance
- 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 Vishay Measurements Group Transducer Applications 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 — see diagram on page 11) 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, integral 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$\mu\epsilon$) 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$\mu\epsilon$/°F *(145$\mu\epsilon$/°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.

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$\mu\epsilon$.

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.

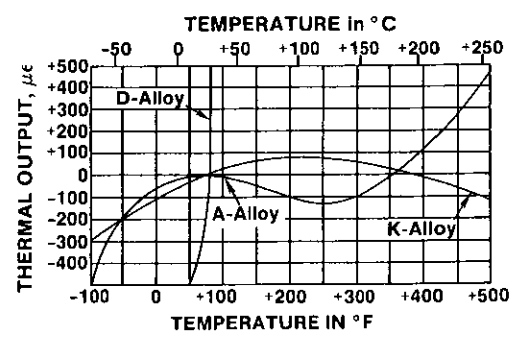
Among its other advantages, K alloy offers a much flatter thermal output curve than A alloy, and thus permits more accu-

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 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 (supplied with each package of strain gages) 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.



rate 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 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 table on page 5. 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.

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 here, in condensed form, in two tables.

The table on page 4 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 strain gages of 0.125 in *(3 mm)* or longer gage length.

The table on page 5 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 table on page 4, is used in conjunction with Catalog 500, *Micro-Measurements Precision Strain Gages* to arrive at the complete gage selection. The selection procedure for accomplishing this is described in ***Section 3.0***.

Standard Strain Gage Series Selection Chart

GAGE SERIES	DESCRIPTION AND PRIMARY APPLICATION	TEMPERATURE RANGE	STRAIN RANGE	FATIGUE LIFE Strain level in $\mu\epsilon$	FATIGUE LIFE 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 Catalog 500.	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*
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
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.	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 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.

Strain Gage Series and Adhesive Selection Reference Table

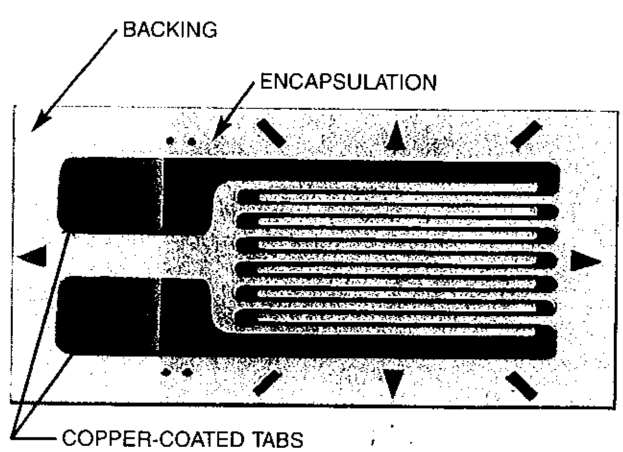
TYPE OF TEST OR APPLICATION	OPERATING TEMPERATURE RANGE	TEST DURATION IN HOURS	ACCURACY REQUIRED**	CYCLIC ENDURANCE REQ'D		TYPICAL SELECTION	
				Maximum Strain, $\mu\epsilon$	Number of Cycles	Gage Series	M-Bond Adhesive
GENERAL STATIC OR STATIC-DYNAMIC STRESS ANALYSIS*	–50° to +150°F *(–45° to +65°C)*	$<10^4$	Moderate	±1300	$<10^6$	CEA, EA	200 or AE-10
		$>10^4$	Moderate	±1300	$<10^6$	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	$<10^5$	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.

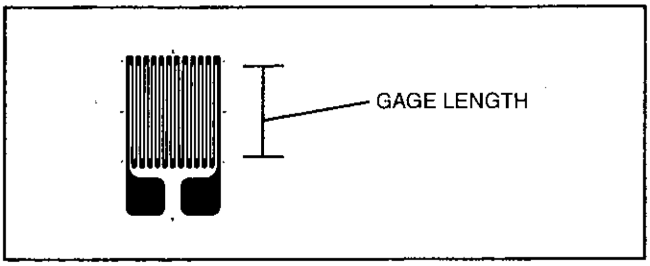
When a test profile is encountered that is beyond the ranges specified in the above table, it can usually be assumed that the test requirements approach or exceed the performance limitations of available gages. Under these conditions, the interactions between gage performance characteristics become too 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.

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 (see illustration). 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.

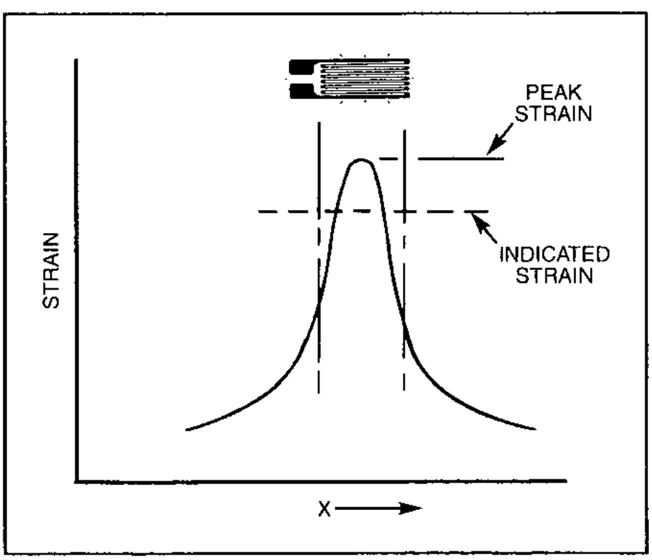


2.4 Gage Length

The gage length of a strain gage is the active or strain-sensitive length of the grid, as shown below. The endloops 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 gages are available in 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 which is too low. The sketch below illustrates a representative strain distribution in the vicinity of a stress concentration, and 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 nonhomogeneous 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 Catalog 500. 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:

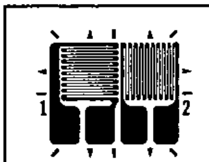
Solder tabs — These should, of course, be compatible in size and orientation with the space available at the gage installation site. It is also important that the tab arrangement be such as to not excessively tax the proficiency of the installer in making proper leadwire connections.

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.

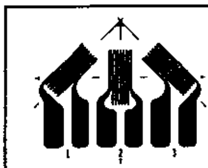
In experimental stress analysis, a single-grid gage would normally be used only when the stress state at the point of measurement is known to be uniaxial and the directions of the principal axes are known with reasonable accuracy (±5°).

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.



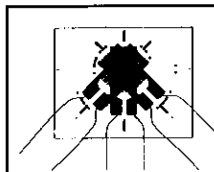
90-degree rosette

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


60-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.


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 selection of optional features for its strain gages and special 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
- Increased reliability of applications
- 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 Catalog 500.

Shown below is a summary of the optional features offered.

Standard Catalog Options

Option	Brief Description
W	Integral Terminals and Encapsulation
E	Encapsulation with Exposed Tabs
SE	Solder Dots and Encapsulation
L	Preattached Leads
LE	Preattached Leads and Encapsulation

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:** +400°F *(+200°C)* for E-backed gages, +500°F *(+260°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 ±1000$\mu\epsilon$. **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.

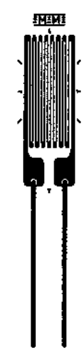
Option SE

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)* 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.

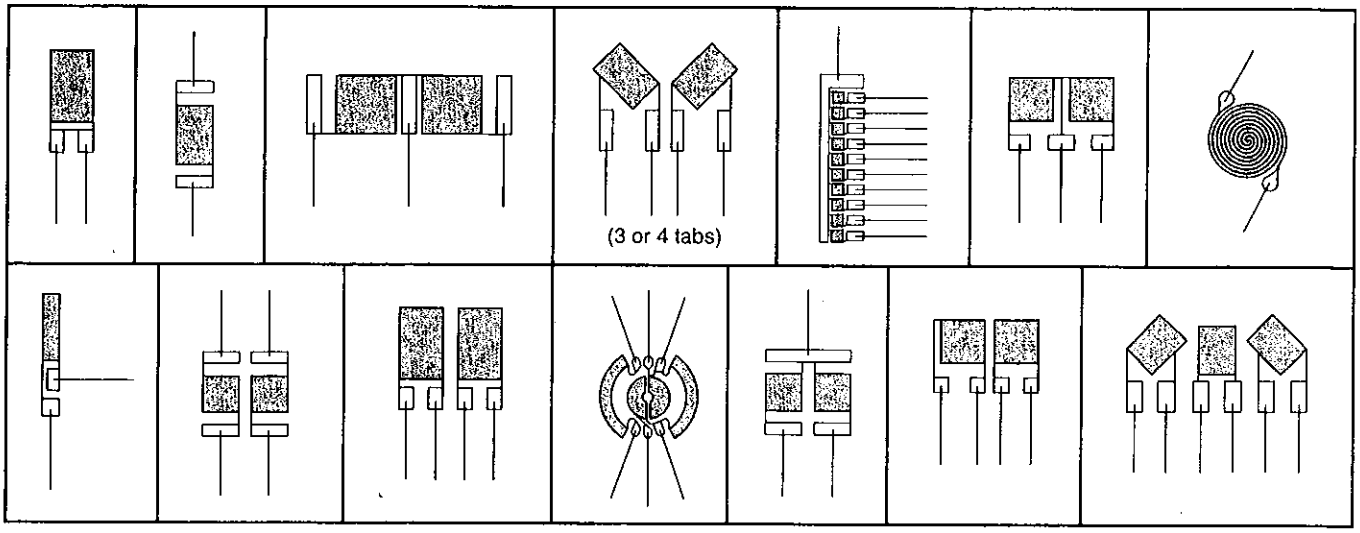
Option LE

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.

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.



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 below 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.

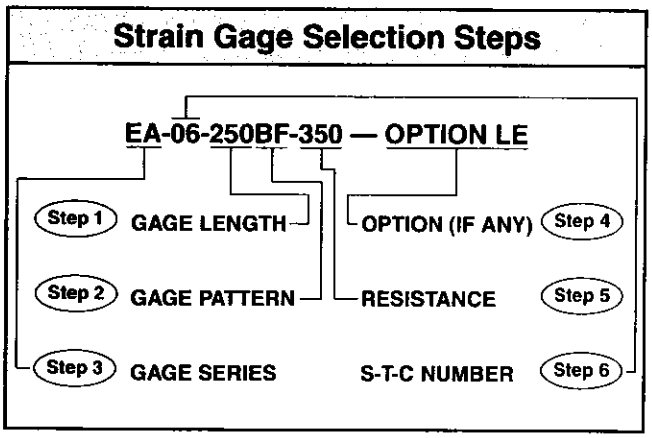
In the table below, the respective performance parameters for an open-faced EA-Series gage without options are arbitrarily assigned a value of 5. Numbers greater than 5 indicate a particular parameter is improved by addition of the option, while smaller numbers indicate a reduction in performance.

Installation Attribute Or Performance Parameter	Standard Options					CEA Series
	W	E	SE	L	LE	
Overall Ease of Gage Installation	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 Indurance	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

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 diagram below 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.

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.



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 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 Catalog 500, *Micro-Measurements Precision Strain Gages* 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 Super Stock section of the catalog 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 chart on page 5, 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 Catalog 500 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 Super Stock Listings to eliminate the likelihood of extended delivery time or a minimum order requirement.

As noted under the gage pattern discussion on page 6, 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 on page 4 of Catalog 500.

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.

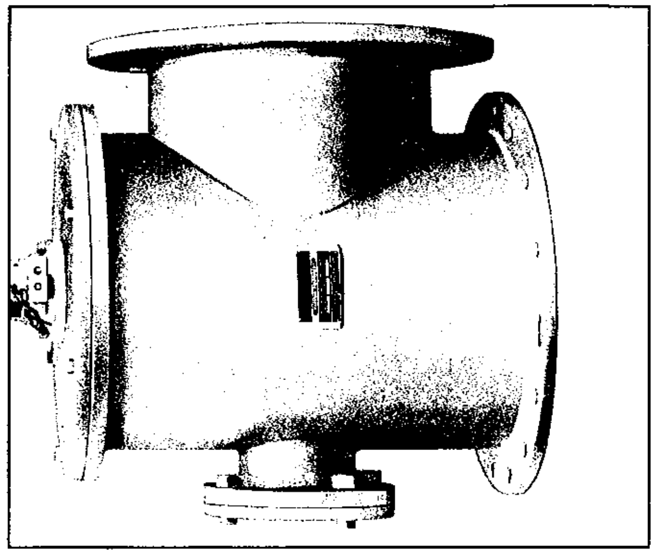
	CONSIDERATIONS FOR PARAMETER SELECTION
Selection Step: **1** *Parameter:* **Gage Length**	☐ strain gradients ☐ area of maximum strain ☐ accuracy required ☐ static strain stability ☐ maximum elongation ☐ cyclic endurance ☐ heat dissipation ☐ space for installation ☐ ease of installation
Selection Step: **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

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 Catalog 500 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.

   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.

3. *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.

4. *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.

5. *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.

6. *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. 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:

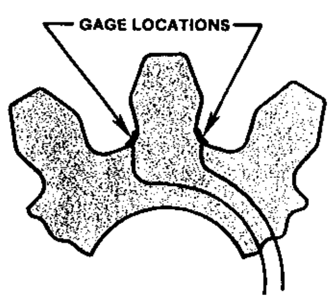
From the above steps, the strain gages to be used are:

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

See page 15 for a description of the strain gage types mentioned in this section.

B. Dynamic Stress Analysis Study of a Spur Gear in a 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 Catalog 500 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 leadwires after gage bonding, and prevents the use of preattached leads.

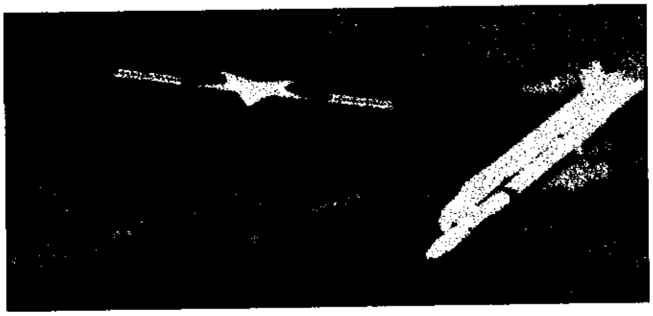
5. *Resistance* — In the ED-Series version of the 031CF gage pattern, Catalog 500 lists the resistance as 350 ohms. The higher resistance should usually be selected whenever the choice exists, and will be advantageous in this instance in improving the signal-to-noise ratio when slip rings are used.

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 Catalog 500, 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 6A1-4V type, with a thermal expansion coefficient of 4.9 x 10^{-6} per °F *(8.8 x 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

Strain gages referenced on pages 12–14.

GAGE PATTERN Actual size shown. Enlarged when necessary for definition.

ES = Each Section
S = Section (S1 = Sec 1)
CP = Complete Pattern
M = Matrix

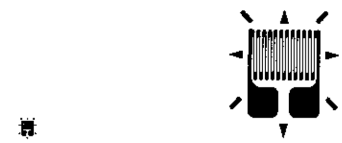
inches
millimetres

GAGE PATTERN Actual size shown. Enlarged when necessary for definition.

ES = Each Section
S = Section (S1 = Sec 1)
CP = Complete Pattern
M = Matrix

inches
millimetres

031CF



1X 6X

GAGE LENGTH	OVERALL LENGTH	GRID WIDTH	OVERALL WIDTH
0.031	0.076	0.062	0.062
0.79	*1.93*	*1.57*	*1.57*
Matrix Size	0.19L x 0.14W		*4.8L x 3.5W*

062AP

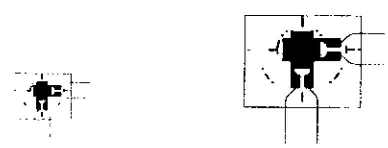
1X 2X

GAGE LENGTH	OVERALL LENGTH	GRID WIDTH	OVERALL WIDTH
0.062	0.114	0.062	0.062
1.57	*2.90*	*1.57*	*1.57*
Matrix Size	0.26L x 0.16W		*6.6L x 4.1W*

250BF

GAGE LENGTH	OVERALL LENGTH	GRID WIDTH	OVERALL WIDTH
0.250	0.375	0.125	0.125
6.35	*9.53*	*3.18*	*3.18*
Matrix Size	0.52L x 0.22W		*13.2L x 5.6W*

060WT



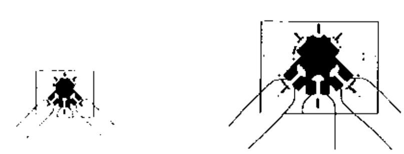
1X 2X

GAGE LENGTH	OVERALL LENGTH	GRID WIDTH	OVERALL WIDTH
0.060 ES	0.24 M	0.060 ES	0.30 M
1.52 ES	*6.1 M*	*1.52 ES*	*7.6 M*
Matrix Size	0.24L x 0.30W		*6.1L x 7.6W*

250RD

GAGE LENGTH	OVERALL LENGTH	GRID WIDTH	OVERALL WIDTH
0.250 ES	0.550 CP	0.125 ES	0.847 CP
6.35 ES	*13.97 CP*	*3.18 ES*	*21.51 CP*
Matrix Size	0.78L x 0.93W		*19.8L x 23.6W*

060WR



1X 2X

GAGE LENGTH	OVERALL LENGTH	GRID WIDTH	OVERALL WIDTH
0.060 ES	0.24 M	0.060 ES	0.30 M
1.52 ES	*6.1 M*	*1.52 ES*	*7.6 M*
Matrix Size	0.24L x 0.30W		*6.1L x 7.6W*

Notes

Installation of Micro-Measurements Strain Gage with M-Bond 200 and AE-10 Adhesive Systems

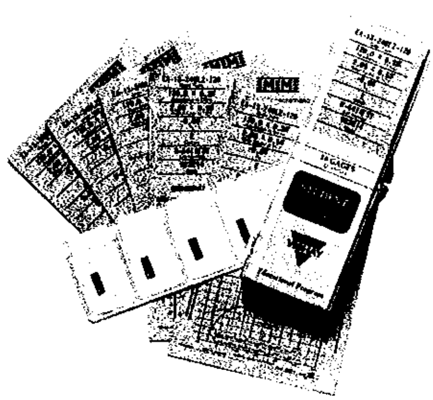
1.0 INTRODUCTION

Because the strain gage is an extremely sensitive device capable of registering the smallest effects of an imperfect bond, considerable attention to detail must be taken to assure stable, creep-free installations. However, the techniques involved are very simple, and readily mastered.

This manual gives explicit step-by-step instructions for making consistently successful strain gage installations with M-Bond 200 and M-Bond AE-10 Adhesives. These directions should be followed precisely. More detailed information may be found in the Vishay Measurements Group VideoTech® Library and in the following publications:

- Instruction Bulletin B-129, *Surface Preparation for Strain Gage Bonding.*
- Instruction Bulletin B-127, *Strain Gage Installations with M-Bond 200 Adhesive..*
- Instruction Bulletin B-137, *Strain Gage Installations with M-Bond AE-10, AE-15, and GA-2 Adhesive Systems.*

All operations described in this manual can be performed with the use of the Student Strain Gage Application Kit. The procedures outlined here are ideally suited to the classroom or teaching laboratory. For most teaching/learning activities involving strain gage technology, the specially priced, first-quality *Student Gages* manufactured by Micro-Measurements Division of Vishay Measurements Group may be used with excellent results.

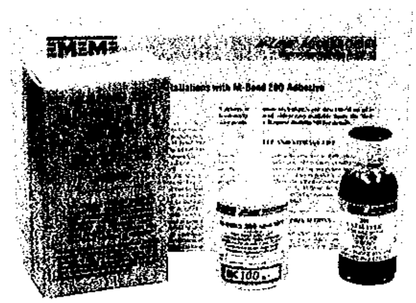


2.0 STRAIN GAGE ADHESIVES

Because consistently successful installation of strain gages requires the use of an adhesive certified for strain gage use, Micro-Measurements *M-LINE* adhesives undergo extensive laboratory testing to ensure reliability and consistency of those properties required in strain gage bonding. To assure accurate and reliable strain gage measurements, it is strongly recommended that a certified adhesive such as M-Bond 200 methyl-2-cyanoacrylate or M-Bond AE-10 epoxy adhesive be selected for most general laboratory installations.

2.1 M-Bond 200

Micro-Measurements certified M-Bond 200 is an excellent general-purpose laboratory adhesive because of its fast room-temperature cure and ease of application. It is compatible with all Micro-Measurements strain gages and all common structural materials. When properly handled and used with the appropriate strain gage, M-Bond 200 Adhesive can be used for high-elongation tests (+60 000$\mu\epsilon$), for fatigue studies, and for one-cycle proof tests within a normal operating temperature range of –25° to +150°F *(–30° to +65°C)*.



The catalyst supplied with M-Bond 200 is specially formulated to control the reactivity rate. For best results, the catalyst should be used sparingly. Since M-Bond 200 bonds are weakened by exposure to high humidity, adequate protective coatings are essential. Because this adhesive will become harder and more brittle with time, M-Bond 200 is not generally recommended for permanent installations over one or two years in duration.

HANDLING PRECAUTIONS

M-Bond 200 is a 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 Material Safety Data Sheet which is available upon request.

M-Bond 200 Adhesive has a shelf life of three months at +75°F *(+24°C)* 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.

2.2 M-Bond AE-10

Micro-Measurements certified M-Bond AE-10 is a 100% solids epoxy system for use with strain gages. It offers the advantages of high elongation (10%) and wider operating temperature range [−320° to +200°F *(−195° to +95°C)*]. Because it is highly resistant to moisture and most chemicals, M-Bond AE-10 is recommended for permanent installations over one year in duration.

M-Bond AE-10 Adhesive is supplied in kit form with preweighed resin and sufficient curing agent for six separate mixes of adhesive. Allow the materials to attain room temperature before opening the containers. Each of the individual units of resin can be separately activated by filling one of the calibrated droppers with curing agent *exactly* to the number 10 and dispensing the contents into the center of the jar of resin. *Immediately cap the bottle of curing agent to avoid moisture absorption.* Mix the resin and curing agent for five minutes, using one of the plastic stirring rods. The pot life or working time after mixing is 15 to 20 minutes at +75°F *(+24°C)*. The pot life can be somewhat extended by occasionally stirring the mixture, by cooling the jar, or by spreading the adhesive on a chemically clean aluminum plate. Discard the dropper and stirring rod after use.

HANDLING PRECAUTIONS

While M-Bond AE-10 is considered relatively safe to handle, *contact with skin and inhalation of its vapors should be avoided.* Immediately washing with ordinary soap and water is effective in cleansing should skin contact occur. For eye contact, rinse thoroughly with copious amounts of water and consult a physician. For additional health and safety information, consult the Material Safety Data Sheet which is available upon request.

The shelf life of unmixed components is one year at room temperature. During storage, crystals may form in the resin. 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. Because excess heat will shorten pot life, allow the resin to return to room temperature before adding the curing agent.

3.0 SURFACE PREPARATION

Strain gages can be bonded satisfactorily to almost any solid material if the material surface is properly prepared. While there are many surface preparation techniques available, the specific procedures and techniques described here are a carefully developed and thoroughly proven system. They are ideal for both M-Bond 200 and M-Bond AE-10 Strain Gage Adhesives.

The purpose of surface preparation is to develop a chemically clean surface having a roughness appropriate to the gage installation requirements, a surface alkalinity of the correct pH, and visible gage layout lines for locating and orienting the strain gage. The Micro-Measurements system of surface preparation will accomplish these objectives for aluminum alloys and steels in five basic operations:

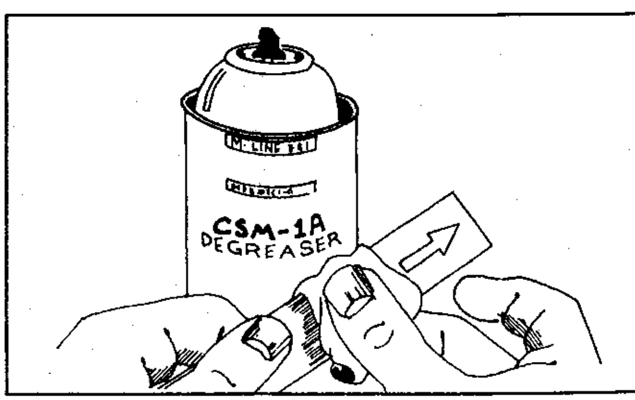
- Solvent degreasing
- Surface abrading
- Application of gage layout lines
- Surface conditioning
- Neutralizing

To ensure maximum cleanliness and best results, the following should be avoided in all steps:

- Touching the surface with the fingers
- Wiping back and forth or reusing swabs or sponges
- Dragging contaminants into the cleaned area from the uncleaned boundary of that area
- Allowing a cleaning solution to evaporate on the surface
- Allowing partially prepared surface to sit between steps in the preparation process or a prepared surface to sit before bonding

Consult Instruction Bulletin B-129 for other test materials and for special precautions and considerations for surface preparation.

3.1 Solvent Degreasing

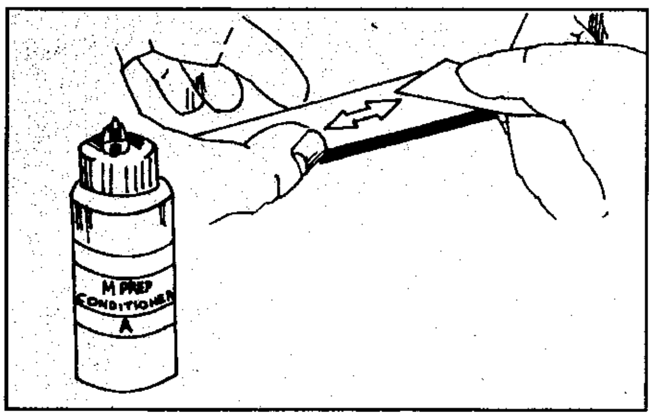


Degreasing is performed to remove oils, greases, organic contaminants, and soluble chemical residues. Degreasing should *always* be the first operation.

Degreasing can be accomplished using solvents such as CSM-1A Degreaser or GC-6 Isopropyl Alcohol. CSM-1A 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. Spray applicators are preferred to avoid back-contamination of the parent solvent. Use a clean gauze sponge to clean the entire specimen, if possible, or an area covering 4 to 6 in *(100 to 150 mm)* on all sides of the gage location.

3.2 Surface Abrading

The surface is abraded to remove any loosely bonded adherents (scale, rust, paint, coatings, oxides, etc.), and to develop a surface texture suitable for bonding. For rough or coarse surfaces it may be necessary to start with a grinder, disc sander, or file; but, for most specimens a suitable surface can be produced with only silicon-carbide paper of the appropriate grit.



Place a liberal mount of *M-PREP* Conditioner A in the gaging area and wet-lap with clean 320-grit silicon-carbide paper for aluminum, or 220-grit for steel. Add Conditioner A as necessary to keep the surface wet during the lapping process.

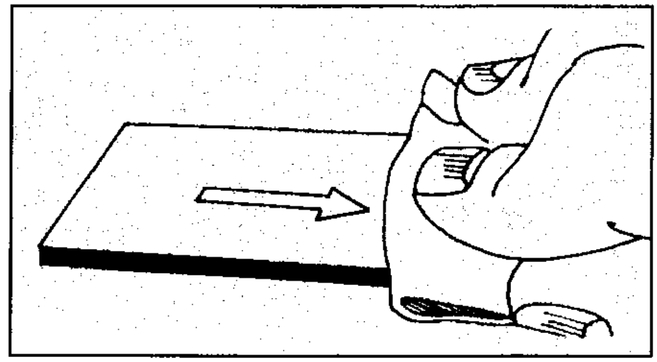
When a bright surface is produced, wipe the surface dry with a clean gauze sponge. A clean surface of the gauze should be used with each wiping stroke. A sufficiently large area should be cleaned to ensure that contaminants will not be dragged back into the gaging area during the steps to follow.

Repeat the above step, using 400-grit silicon-carbide paper for aluminum, or 320-grit for steel.

3.3 Layout Lines

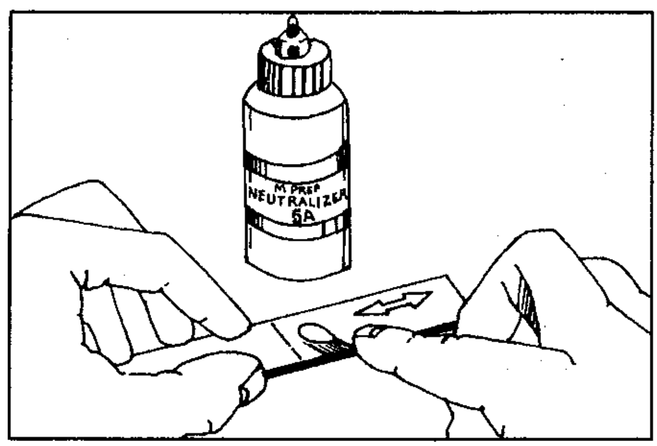
The desired location and orientation of the strain gage on the test surface should be marked with a pair of crossed, perpendicular reference lines. The reference or layout lines should be *burnished*, rather than scored or scribed, on the surface. For aluminum, a medium-hard drafting pencil is satisfactory. For most steels, a ball-point pen or a tapered brass rod may be used. All residue from the burnishing operations should be removed in the following step.

3.4 Surface Conditioning



After the layout lines are marked, Conditioner A should be applied repeatedly, and the surface scrubbed with cotton-tipped applicators until a clean tip is no longer discolored by scrubbing. The surface should be kept constantly wet with Conditioner A until the cleaning is completed. When clean, the surface should be dried by wiping through the cleaned area with a *single* slow stroke of a gauze sponge. The stroke should begin inside the cleaned area to avoid dragging contaminants in from the surrounding area. Throw the used gauze away and, with a fresh gauze, make a *single* slow stroke in the opposite direction. Throw the second gauze away.

3.5 Neutralizing



To provide optimum alkalinity for Micro-Measurements strain gage adhesives, the cleaned surfaces must be neutralized. This can be done by applying *M-PREP* Neutralizer 5A liberally to the cleaned surface, and scrubbing the surface with a clean cotton-tipped applicator. The cleaned surface should be kept completely wet with Neutralizer 5A throughout this operation. When neutralized, the surface should be dried by wiping through the cleaned area with a *single* slow stroke of a clean gauze sponge. Throw the gauze away and with another fresh gauze sponge, make a *single* stroke in the opposite direction. Always begin within the cleaned area to avoid recontamination from the uncleaned boundary.

If the foregoing instructions have been followed precisely, the surface is now properly prepared for gage bonding. The gages should be installed within 30 minutes on aluminum or 45 minutes on steel.

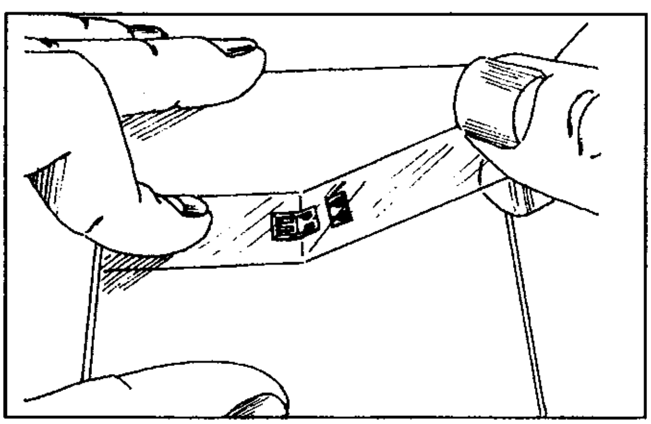
4.0 STRAIN GAGE BONDING

The electrical resistance strain gage is capable of making accurate and sensitive indications of strains on the surface of the test part. Its performance is absolutely dependent on the bond between itself and the test part. The procedures outlined below will help ensure satisfactory bonds when using M-Bond 200 and AE-10 Adhesives. While the steps may appear unduly elaborate, these techniques have been used repeatedly in strain gage installations which have yielded consistent and accurate results. The steps shown assume that a terminal strip will be used. When CEA-Series gages are used, no strip is required.

4.1 Handling and Preparation

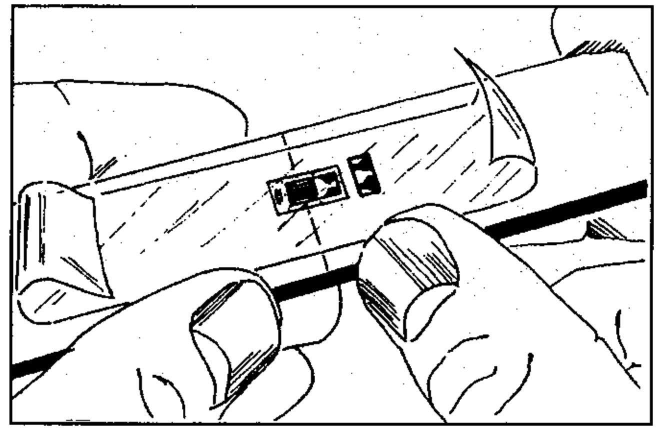
Micro-Measurements strain gages are specially treated for optimum bond formation with all appropriate gage adhesives. No further cleaning is necessary if contamination of the prepared bonding surface is avoided during handling. (Should contamination occur, clean with a cotton swab moistened with a low residue solvent such as *M-LINE* Neutralizer 5A or GC-6 Isopropyl Alcohol. Allow the gage to dry for several minutes before bonding.) Gages should never be touched with the hands.

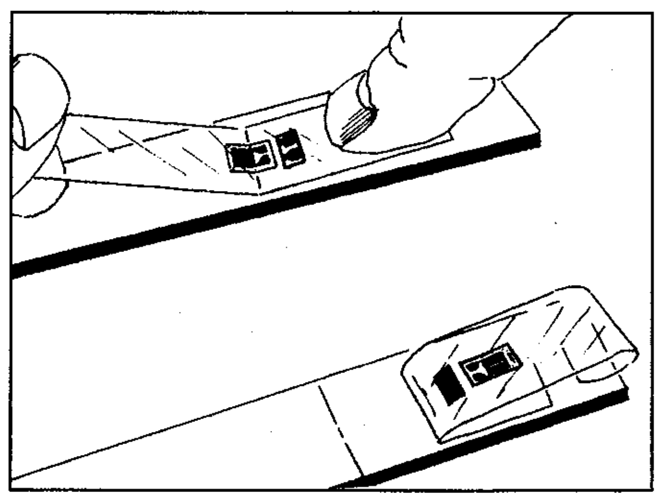
Remove the strain gage from its transparent envelope by grasping the edge of the gage backing with tweezers, and place on a chemically clean glass plate (or empty gage box) with the bonding side of the gage down. Place the appropriate terminals (if any) next to the strain gage solder tabs, leaving a space of approximately 1/16 in *(1.5 mm)* between the gage backing and terminal.



Using a 4-to-6-in *(100-to-150-mm)* length of *M-LINE* PCT-2A cellophane tape, anchor one end of the tape to the glass plate behind the gage and terminals. Pick the gage and terminals up by carefully lifting the tape at a shallow angle (30 to 45 degrees to the glass plate) until the tape comes free with the gage and terminal attached. (The shallow angle is important to avoid over-stressing the gage and causing permanent resistance changes.) **Caution: Some tapes may contaminate the bonding surface or react with the bonding adhesive. Use only tapes certified for strain gage installations.**

The strain gage is now prepared for positioning on the test specimen. 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 is misaligned, lift the tape again at a shallow angle until the assembly is free of the specimen. Reposition and wipe the assembly again with a shallow angle.

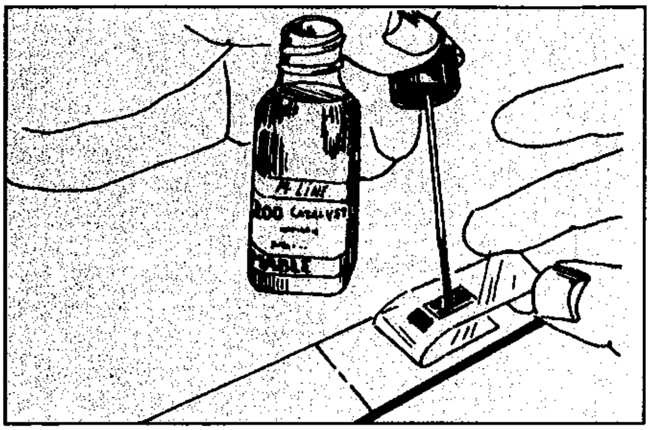




In preparation for applying the adhesive, lift the end of the tape opposite the solder tabs at a shallow angle until the gage and terminal are free of the specimen. Tack the loose end of the tape under and press to the surface so the gage lies flat with the bonding side exposed.

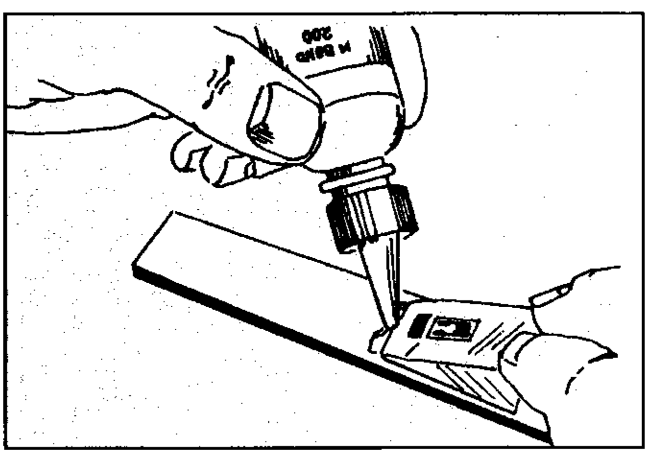
The appropriate adhesive may now be applied. The procedures for M-Bond 200 and M-Bond AE-10 are described in the two sections which follow.

4.2 Bonding with M-Bond 200



M-Bond 200 Catalyst should be applied sparingly in a thin uniform coat. Wipe the brush against the lip of the bottle approximately ten times to remove most of the catalyst. Set the brush down on the gage and swab the gage backing by sliding — not brushing in the painting style — the brush over the entire gage surface. Move the brush to an adjacent tape area prior to lifting from the surface. Allow the catalyst to dry at least one minute under normal ambient laboratory conditions.

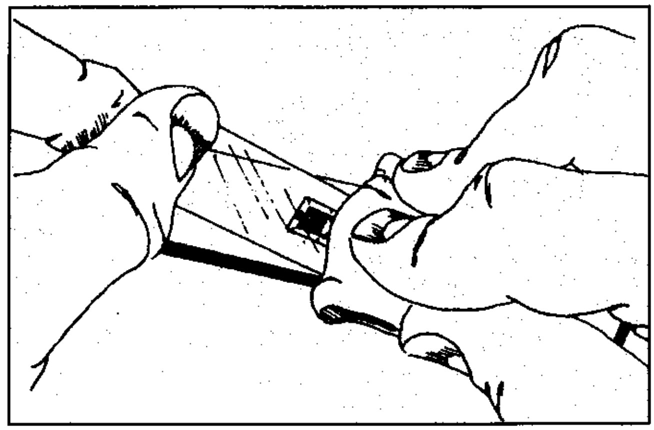
The next three steps must be completed in sequence within three to five seconds. Read these steps before proceeding.



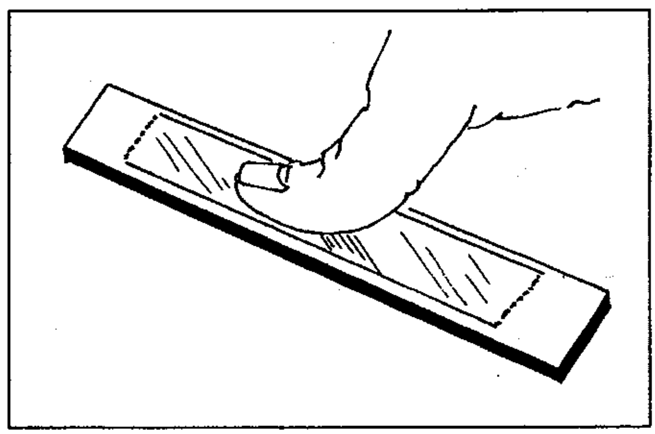
Lift the tucked-under tape. Holding the gage/tape assembly in a fixed position, apply one or two drops of M-Bond 200 Adhesive at the junction of the tape and specimen surface, about 1/2 in *(13 mm)* outside the actual gage installation area.

Immediately rotate the tape to approximately a 30-degree angle so that the gage is bridged over the installation area.

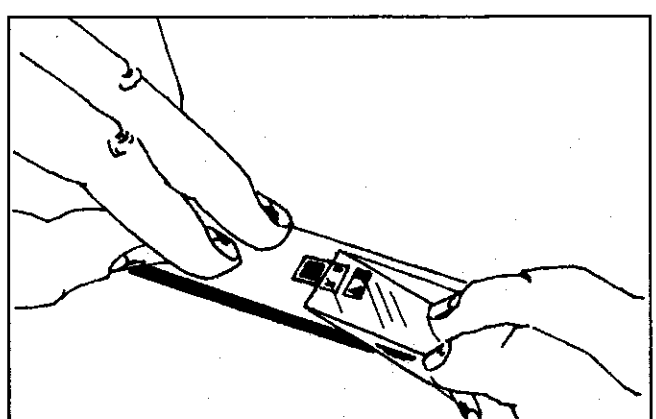
Holding the tape slightly taut and beginning from the tab end of the gage, slowly and *firmly* make a single wiping stroke over the gage/tape assembly with a clean gauze sponge to bring the gage back down over the alignment marks on the specimen. Release the tape.



Immediately upon completion of the above step, *discard the gauze* and apply firm thumb pressure to the gage and terminal area. This pressure should be held for at least one minute. Wait two minutes before the next step (tape removal).

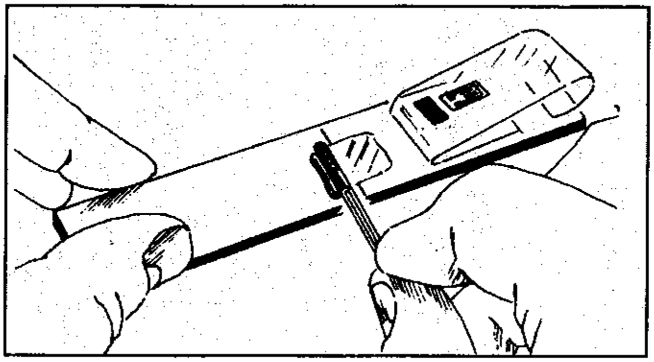


The gage and terminals should now be bonded to the specimen. To remove the tape, pull it back directly over itself, *peeling* it slowly and steadily off the surface.

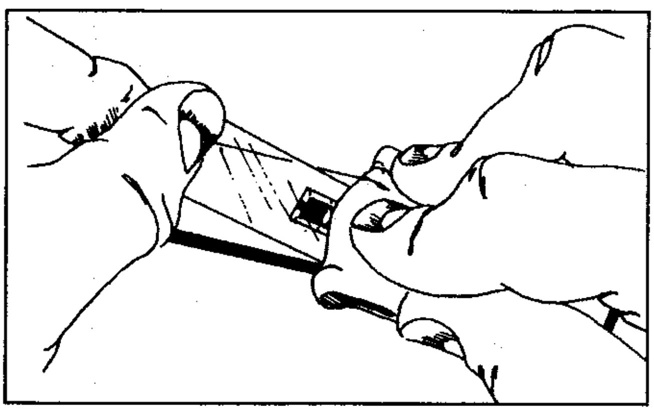


4.3 Bonding with M-Bond AE-10

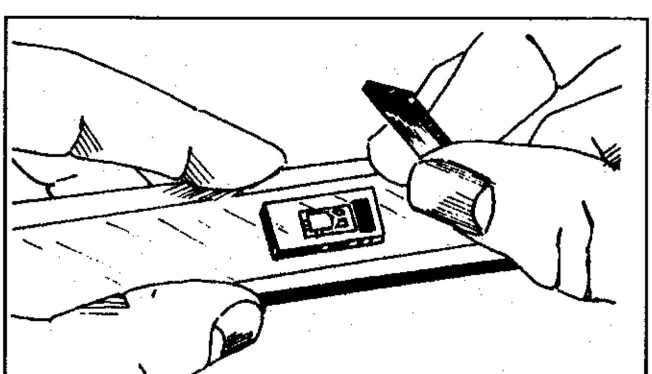
(This section follows 4.1 when using M-Bond AE-10 Adhesive.) Mix the Resin AE with Curing Agent Type 10 per the instructions in Instruction Bulletin B-137 supplied with the adhesive.



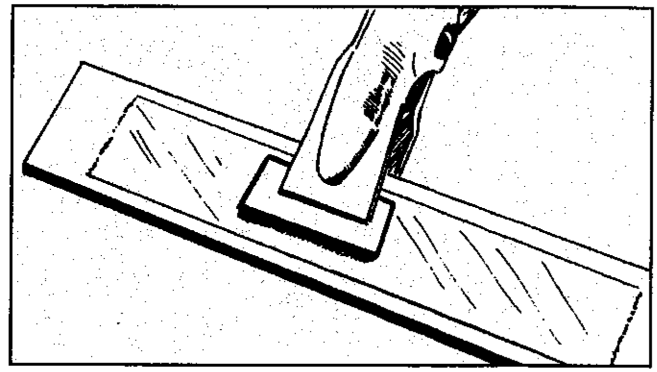
Coat the specimen, back of the gage, and terminal strip with the prepared M-Bond AE-10 Adhesive. The mixing rod may be used to apply a thin layer of adhesive over each surface. *Be careful not to pick up any unmixed components of the adhesive.* To ensure this, wipe the mixing rod clean and then pick up a very small amount of adhesive from the central area of the adhesive jar. After applying the adhesive, proceed immediately to the next step.



Lift the tucked-over end of the tape and bridge over the specimen installation area at approximately a 30-degree angle. Beginning from the tab end of the gage and using a clean gauze sponge, slowly and firmly make a single wiping stroke over the gage/tape assembly to bring the gage back down over the alignment marks on the specimen.

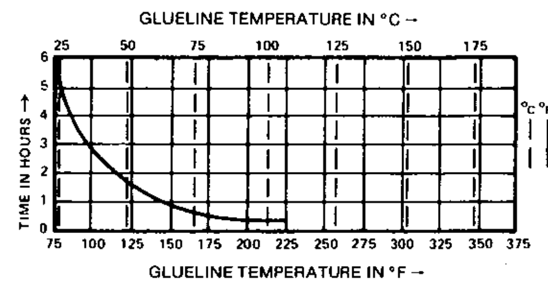


Place a silicone rubber pad and a back-up plate over the gage installation. Apply force by dead weight or spring clamp until a pressure of 5 to 20 psi *(35 to 135 kN/M²)* is attained. Take care to ensure the pressure is equal over the entire gage surface.



The M-Bond AE-10 Adhesive will develop adequate bonding strength in six hours at room temperature [+70°F *(+20°C)*]. This time may be reduced by increasing the temperature of the glueline per the schedule below. **Warning: For curing temperature above +150°F *(+66°C)* a special mylar tape must be used for gage handling, and a Teflon® strip should be placed between the gage and the silicone rubber pad.**

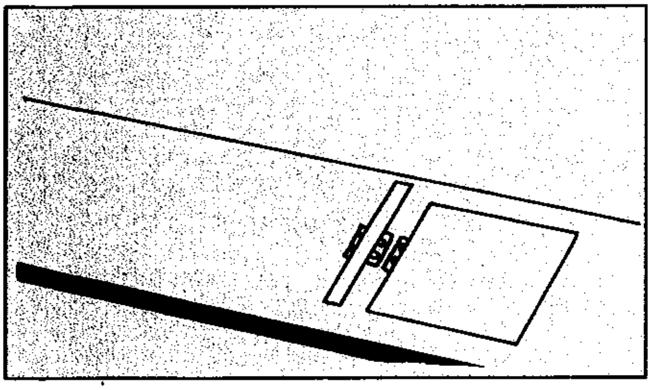
RECOMMENDED CURE SCHEDULE



After the adhesive is cured, remove the clamps or weights, the silicone pads and Teflon strip (if used). To remove the tape, pull it back directly over itself, *peeling* it slowly and steadily off the surface.

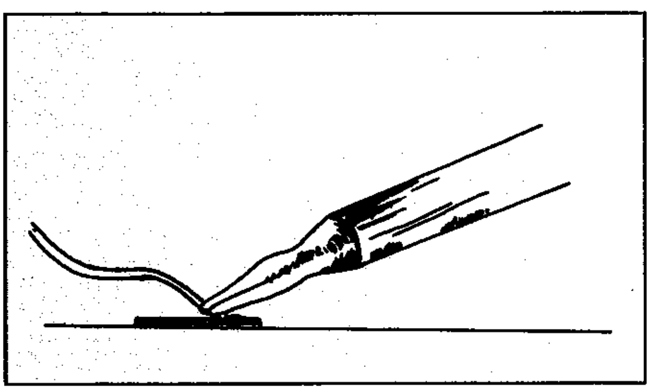
®Registered trademark of DuPont.

5.0 SOLDERING TECHNIQUES



If the strain gage is without encapsulation or preattached lead ribbons, mask the gage grid area with drafting tape, leaving only the tabs exposed.

After the soldering iron has reached operating temperature, clean the tip with a gauze sponge and tin it with fresh solder. Tin the gage tabs and terminal tabs (if used). Melt a small amount of solder on the tip of the soldering iron, lay the rosin-core solder wire across the gage tab or copper terminal. Firmly apply the iron tip for one second, then *simultaneously* lift both solder and tip. A bright, shiny, even mound of solder should have been deposited on the tab. If not, repeat the process. If spikes are formed rather than smooth beads, it is a sign of inadequate flux, dwelling too long with the iron, and/or an improper iron temperature. Feeding the cored solder into the tab area during heat application will increase the amount of flux available.

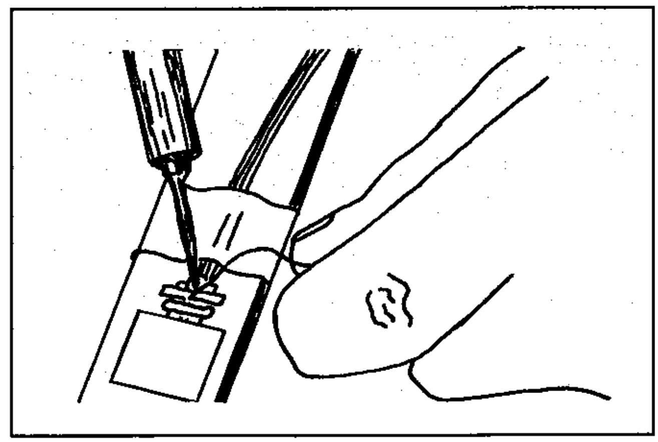


For a three-conductor lead-in wire, separate the individual leads for 3/4 in *(20 mm)*. Strip away 1/2 in *(13 mm)* of insulation by using the soldering tip to melt the insulation on both sides of each end of the wire 1/2 in *(13 mm)* from the ends and quickly pulling off the insulation. **Warning: Do not use a knife or other blade to cut the insulation.** When the main leadwire is stranded and terminal strips are used, it is often convenient to cut all strands but one to fit the size of the copper pad. The long strand can then be used as the jumper wire. Soldering is made considerably easier by this method. This is unnecessary when the leadwires are bonded directly to the solder tabs on CEA-Series strain gages.

Holding the tip of a finger on the tip of the tinned wire for safety, cut each wire with diagonal wire cutters leaving 1/8 in *(3 mm)* of exposed, tinned wire.

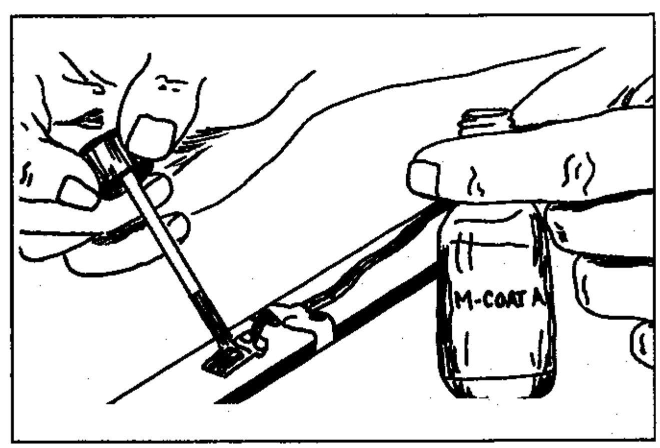
Tack the lead-in wires to the specimen with drafting tape so the tinned end of the wire is spring-loaded in contact with the solder bead. Complete the solder connection as before by applying solder and iron tip for one second and removing simultaneously.

Apply rosin solvent liberally to the solder joints. Drafting tape may be removed by loosening the mastic with rosin solvent. Remove all solvent with a gauze sponge, using a dabbing action. Repeat.



Tape or otherwise secure the lead-in wires to the specimen to prevent the wires from being accidentally pulled from the tabs. A stress relief "loop" should be placed between the tape and the solder connections.

Apply a protective coating over the entire gage and terminal area. For most laboratory uses, M-Coat A will provide adequate long-term protection. The coating should be continuous up to and over at least the first 1/8 in *(3 mm)* of leadwire insulation.



The properly installed strain gage will have a resistance to ground of at least 10 000 to 20 000 megohms. Checking leakage resistance with the Model 1300 Gage Installation Tester is highly recommended.

6.0 TWO-AND THREE-WIRE CIRCUITS

6.1 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 popularity is due in large measure to its inherent ability to 1) detect the small resistance changes produced in the strain gage when 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.

In particular, use of a two-wire connection is generally not recommended because it may introduce a significant resistance offset in the strain gage circuit; temperature changes in the leadwire system will introduce errors into measured strain data; and the leadwire system will reduce the sensitivity of the strain gage circuit. Configuring the strain gage input as a three-wire circuit provides for intrinsic "bridge balance" and automatic compensation for the effects of leadwire temperature changes on measured strain data, and reduces the loss in sensitivity present in the two-wire configuration. Consequently, the three-wire connection is the recommended hookup for quarter-bridge strain gage circuits for static strain measurement.

6.2 The Wheatstone Bridge

The Wheatstone bridge circuit in its simplest form (Fig. 1) consists of four resistive elements, or bridge arms (R_1, R_2, R_3, R_4), connected in a series-parallel arrangement, and an excitation voltage source (E). The electrical connections where pairs of bridge arms are joined to the leadwires from the excitation voltage source are referred to as input corners of the bridge. A differential output voltage (e_o) is measured at the two remaining bridge corners, referred to as output or signal corners.

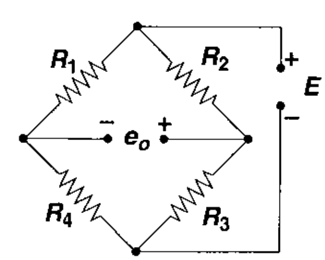


Fig. 1 — Basic Wheatstone Bridge Circuit.

While a mathematical proof is beyond the scope of this manual, it can be shown that if the arm resistances are chosen such that the bridge is resistively symmetrical about an imaginary line drawn through the bridge output corners (as is the case with most commercially available strain gage instrumentation and as assumed here) the differential output voltage (e_o) will be identically zero regardless of the value of the excitation supply voltage. In this condition, the bridge is said to be resistively balanced. If the bridge is not in balance, a differential voltage will be present at the output corners of the bridge, and the magnitude of this output voltage will be proportional to the amount of unbalance.

6.3 Two-Wire Circuit

For an initially balanced bridge, if one of the bridge arms is replaced with a strain gage of precisely the same resistance value and connected with two leadwires having negligible resistance, the bridge remains at balance. But in practice the leadwires will have some measurable resistance (R_L) as shown in Fig. 2, which may result in a significant lack of symmetry in the bridge. This occurs because both leadwires are in series with the strain gage between, for example, the positive (+) input corner and the negative (–) output corner, adding to the gage arm resistance. That is, the gage arm resistance becomes $R_G + 2R_L$.

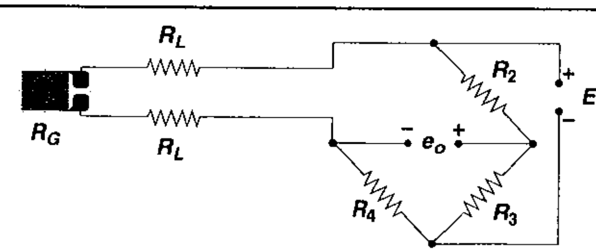


Fig. 2 — Two-wire quarter-bridge circuit.

As a measure of the magnitude of this effect, consider a 120-ohm strain gage installed at a distance of 20 ft *(6 m)* from the instrument, and connected to the instrument with a pair of AWG26 *(0.4 mm dia.)* copper leadwires. At room temperature, the total resistance in series with the strain gage is about 1.7 ohms. For an instrument gage factor setting of 2.0, this produces an initial imbalance in the bridge corresponding to approximately 7000$\mu\epsilon$. 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 when the test part is subjected to test loads. For modest values of leadwire resistance, the percentage of loss in signal 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.

The initial imbalance may be offset using a strain indicator that has a sufficient balance range, or may be (mathematically) subtracted from measured strain readings. However, a more serious problem may result if the temperature of the leadwires changes during the measurement process, causing a corresponding change in resistance of the interconnecting leadwires. 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 above, this would result in an error equivalent to approximately 156$\mu\epsilon$ for a 10°F *(5.5°C)* temperature change in the leadwire system.

The errors and problems specifically caused by the two-wire circuit are due to the pair of leadwires in series with the strain gage. All three of the effects discussed here increase in severity with increased leadwire resistance; and the two-wire circuit offers no intrinsic compensation. 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 a straightforward method exists to reduce the loss in sensitivity, and essentially eliminate the initial imbalance problem and the error that results from temperature changes in the leadwire system. This method involves simply adding a third leadwire to the strain gage circuit as shown in Fig. 3.

6.4 Three-Wire Circuit

The preferred circuit for use with a single strain gage in a quarter-bridge configuration is the three-wire circuit shown in Fig. 3. In the two-wire circuit, both leadwires are in series with the strain gage in one arm of the Wheatstone bridge. In the three-wire circuit, the first leadwire remains in series with the strain gage, but the second leadwire is now in series with dummy resistor R_4 between the negative input and output corners of the bridge. Referring to Fig. 3, if these two leadwires are the same type and length and exposed to the same temperature, their resistances will be equal. The two respective bridge arms will therefore be equal in resistance, the bridge is again resistively symmetrical about a horizontal line through the bridge output corners, and the bridge remains balanced regardless of leadwire temperature changes, so long as the two leadwires are at the same respective temperature. And 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 in Fig. 3 is a voltage-sensing wire only and it is not in series with any of the bridge arms, therefore it does not affect bridge balance or temperature stability.

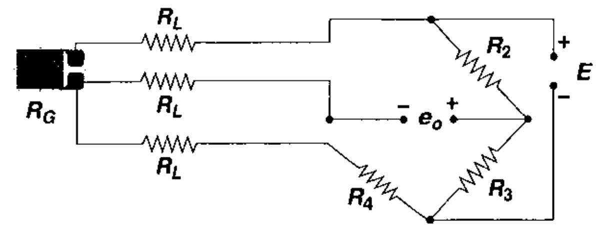


Fig. 3 — Three-wire quarter-bridge circuit.

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.

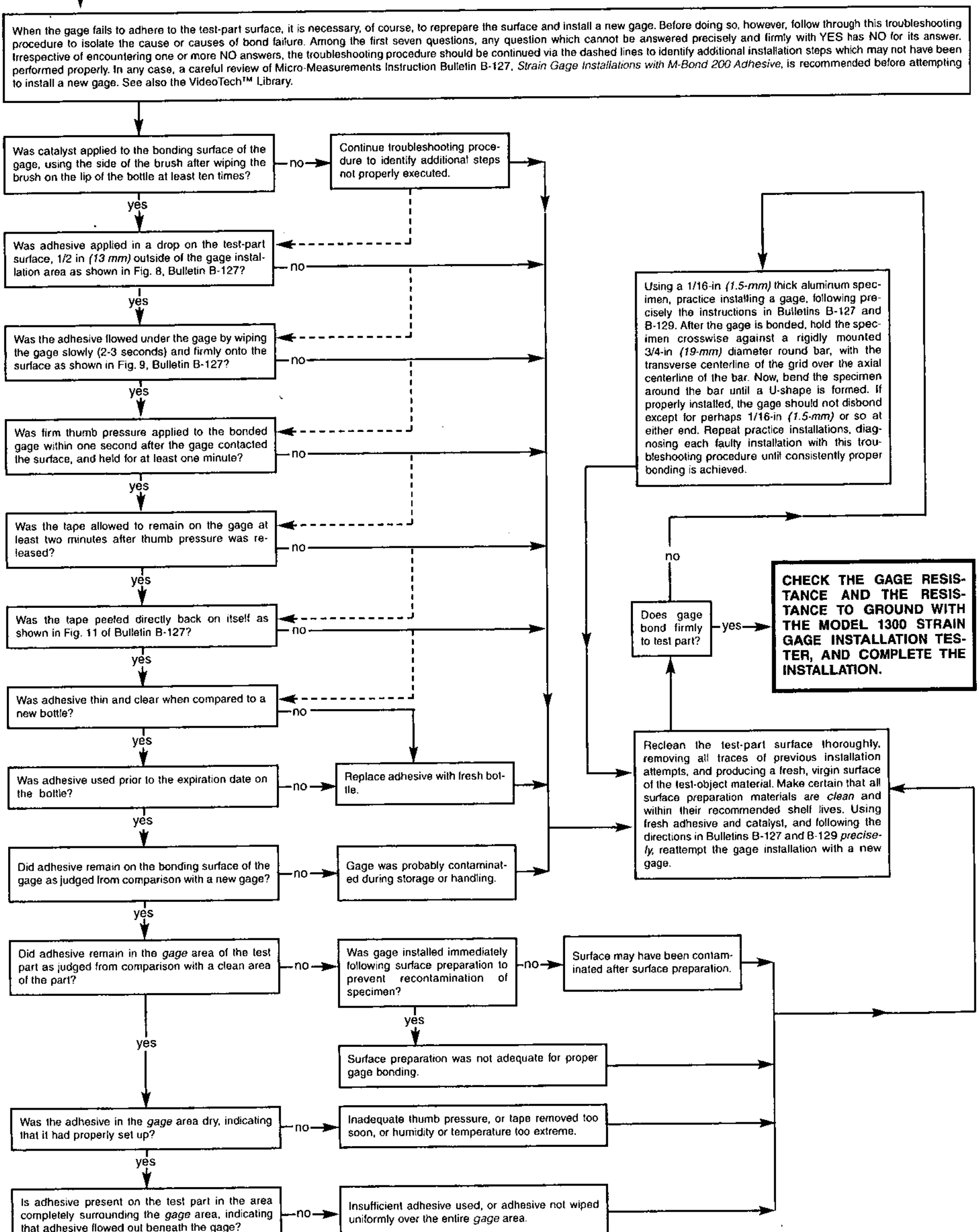
The foregoing discussion applies primarily to measurement of static strains with a measuring instrument that provides dc-coupling between the bridge circuit and the amplifier input terminals. For measurement of purely dynamic strains when only the peak-to-peak amplitude of a time-varying strain signal 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, to "block" the effects of temperature-induced changes in leadwire resistance on the strain signal.

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.

7.0 TROUBLESHOOTING PROCEDURE

M-Bond 200 Gage Installation

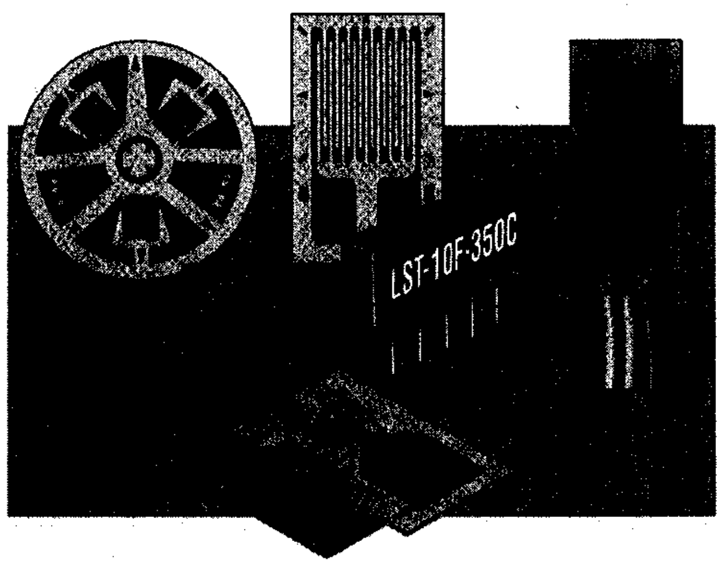
I attempted to install a strain gage with M-Bond 200 Adhesive, but the gage unbonded from the test surface when I removed the handling tape. What should I do?



An Introduction to . . .

Micro-Measurements

- **Strain Gages**
- **Special Sensors**
- **Installation Accessories**



VISHAY

The Broadest Range of Strain Gages and Accessories Available

Micro-Measurements has been a trusted name in the field of Strain Gage Technology for many years. We are proud of our worldwide reputation as a premier supplier of high-quality precision strain gages and strain gage accessories, and are fully committed to maintaining our position as the leader in this field. This short-form catalog of Micro-Measurements strain gages and related products is intended to provide a condensed overview of the sensors, supplies, and tools commonly needed for strain gage applications.

Micro-Measurements was independently founded and operated in the early 1960's. A few years later it became a part of Vishay Intertechnology, Inc. and, in late 1973, was incorporated with the Instruments and Photolastic Divisions of Vishay into a single entity — Vishay Measurements Group. All divisions of Vishay Measurements Group are located in our world headquarters facility near Raleigh, North Carolina.

Customer Support Services

The common denominator in all Micro-Measurements products and services is our dedication to helping you achieve consistently accurate and reliable strain measurements. And we've made some significant commitments to help ensure your success:

We publish the widest range of technical reference literature in the strain gage field — available through the Vishay Measurements Group's Technical Data Mailing Program.

We respond quickly to requests for "specials" to suit individual requirements.

An experienced Applications Engineering staff is readily available by phone, letter or facsimile.

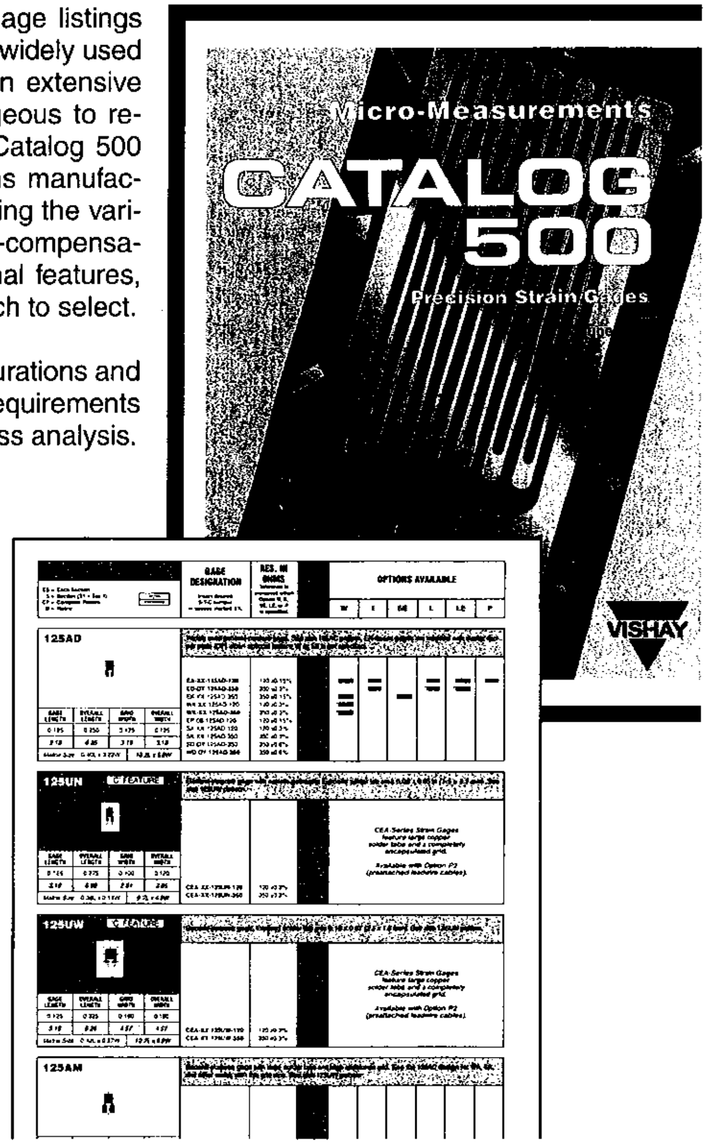
We offer a variety of comprehensive technical training programs from beginner to advanced levels in strain gage technology. Vishay Measurements Group regularly conducts workshops and technical seminars in our Technical Training Center near Raleigh, North Carolina and at locations throughout the U.S. and the world.

***Your* Success is *Our* Goal.**

Micro-Measurements Strain Gage Catalog 500

This introductory catalog contains abridged strain gage listings which are representative of the types and sizes most widely used in stress analysis applications. For those involved in extensive stress/strain measurement programs, it is advantageous to request a copy of Catalog 500. The gage listings in Catalog 500 include all standard types and pattern configurations manufactured by the Micro-Measurements Division. Considering the variations in pattern design, grid alloys, self-temperature-compensation (S-T-C) numbers, backing materials, and optional features, there are over 250,000 possible gage types from which to select.

Catalog 500 contains a broad range of pattern configurations and sizes, designed to meet the many and varied test requirements encountered throughout the field of experimental stress analysis.



A special group of strain gages — *Transducer-Class*® — has been developed specifically for transducer applications. *Transducer-Class* strain gages, described in separate Vishay Measurements Group literature, are a select group of standard and special gage patterns designed for optimum cost/performance ratio (in transducer service) in high-volume production quantities.

Gage Listings

A sample Catalog 500 listing for a single, representative gage pattern is reproduced below. The listing includes a tabulation of all gage series in which the pattern is available, as well as optional features applicable to each series. Complete descriptions of the gage series, options, etc., are provided in Catalog 500.

ES = Each Section
S = Section (S1 = Sec 1)
CP = Complete Pattern
M = Matrix

inches / millimetres

GAGE DESIGNATION Insert desired S-T-C number in spaces marked XX.	RES. IN OHMS Tolerance is increased when Option W, E, SE, LE, or P is specified.	OPTIONS AVAILABLE: W	E	SE	L	LE	P
EA-XX-125AD-120	120 ±0.15%	■	■		■	■	■
ED-DY-125AD-350	350 ±0.3%		■		*■	*■	
EK-XX-125AD-350	350 ±0.15%	■		■			
WA-XX-125AD-120	120 ±0.3%	*■					
WK-XX-125AD-350	350 ±0.3%	*■					
EP-08-125AD-120	120 ±0.15%						
SA-XX-125AD-120	120 ±0.3%						
SK-XX-125AD-350	350 ±0.3%						
SD-DY-125AD-350	350 ±0.6%						
WD-DY-125AD-350	350 ±0.6%						

125AD

Widely used general-purpose gage. See also 125AC pattern. EK-Series gages are supplied with duplex copper pads (DP) when optional feature W or SE is not specified.

GAGE LENGTH	OVERALL LENGTH	GRID WIDTH	OVERALL WIDTH
0.125	0.250	0.125	0.125
3.18	*6.35*	*3.18*	*3.18*
Matrix Size 0.40L x 0.22W		*10.2L x 5.6W*	

Strain Gage Designation System and Selection Chart

In selecting the most suitable strain gage for each application, consideration must be given to the variations in pattern design, grid alloy, self-temperature-compensation (S-T-C), backing material, and optional features. The gage designation system and standard strain gage selection chart shown on this page present a partial summary of the many combinations of these factors available in Micro-Measurements strain gages. For brevity, this summary is limited to those gage series and optional features listed in this catalog only. When selecting or ordering a strain gage from this catalog, these charts will provide a key to choosing the appropriate gage for your application.

A complete, detailed designation system and selection chart are included in Catalog 500.

When test conditions are severe, or when there are unusually stringent demands on accuracy and stability, selection of the optimum gage parameters to satisfy the test specifications can involve a number of subtle considerations. As an aid in systematically arriving at the most appropriate gage type, given a specific measurement task, Tech Note TN-505, *Strain Gage Selection Criteria, Procedures, Recommendations*, available on request from the Vishay Measurements Group Applications Engineering Department, will provide a valuable reference for use in conjunction with these selection criteria and charts.

Self-Temperature-Compensation

Foil Alloy

Carrier Matrix (Backing)

Active Gage Length in Mils
[0.001 in *(0.0254 mm)*]

Grid and Tab Geometry

Resistance in Ohms

Optional Feature

E A - 0 6 - 2 5 0 B G - 1 2 0 Option E

E: Open-faced cast polyimide backing.
W: Fully encapsulated; glass-fiber-reinforced epoxy-phenolic resin. High-endurance leadwires.
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.

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 standard compensations are available:

A and K alloy: 06, 13.
P alloy: 08

The D alloy is 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.

GAGE SERIES	DESCRIPTION AND PRIMARY APPLICATION	TEMPERATURE RANGE	STRAIN RANGE	FATIGUE LIFE	
				Strain Level in $\mu\epsilon$	Number of Cycles
EA	General-purpose static and dynamic stress analysis. Wide range of options available.	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 & 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 & over	±1500 ±1500	10^5 10^6
ED	Excellent for dynamic measurements. High gage factor and extended fatigue life.	Dynamic: –320° to +400°F *(–195° to +205°C)*	±2% Nonlinear at strain levels over ±0.5%	±2500 ±2200	10^6 10^7
WA	Stress analysis and transducer applications. Wide temperature range and extreme environmental capability. High-endurance leadwires.	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
WK	Widest temperature range and most extreme environmental capability. High-endurance leadwires.	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
EP	High-elongation measurements (post yield). Only available in 08 S-T-C value.	–100° to +400°F *(–75° to +205°C)*	±10% for gage lengths under 1/8 in *(3.2 mm)* ±20% for 1/8 in & over	±1000 EP gages show zero shift under high-cyclic strains.	10^4
WD	For wide-range dynamic strain measurements in severe environments. High-endurance leadwires.	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

Micro-Measurements
Super Stock Gage Listings Section

The gages listed on this and the following page represent the most widely used types for general-purpose experimental stress analysis. Gage lengths range from 0.015 to 0.500 in *(0.4 to 13 mm)* in a wide range of pattern configurations. In addition to single-element gages in a variety of sizes and aspect ratios, the list includes two- and three-element rosettes for use in biaxial stress fields. There are also twin-element chevron patterns for measuring shear strain or torque. Grid resistances of 120, 350, and 1000 ohms are available.

Selection of gages from this list will generally lead to the best delivery and, in many cases, to a price advantage as well. The "C"-feature, or CEA-Series, strain gages are normally the first choice because of the ease of installation. These gages have rugged, copper-coated solder tabs, permitting direct leadwire attachment.

All gage's in this list are classified as *Super Stock.* This means that Vishay Measurements Group guarantees to maintain stock for off-the-shelf delivery of at least 10 packages of any type listed in 06 and 13 self-temperature-compensation numbers (except 08 S-T-C for P alloy and DY for isoelastic). There is no Minimum Order Requirement for gages selected under the above conditions.

If your application requires a gage that is not listed here, refer to Micro-Measurements Catalog 500, which includes all standard, general-purpose Micro-Measurements strain gages. All gage patterns are shown at actual size except where enlargement is necessary for geometry definition.

GAGE DESIGNATION AND PATTERN

CEA-XX-**015UW**-120

Micro-miniature pattern with large exposed solder tabs for high-strain-gradient applications. Exposed tab area is 0.06 x 0.04 in *(1.5 x 1.0 mm).*

4X

CEA-XX-**032UW**-120

Short-gage-length pattern with large exposed solder tabs for high-strain-gradient applications. Exposed tab area is 0.07 x 0.04 in *(1.8 x 1.0 mm).*

2X

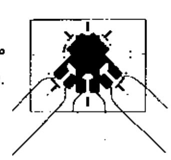
EA-XX-**031DE**-120

Miniature pattern for positioning adjacent to high stress concentrations, e.g., holes, fillets, etc.

4X

WA-XX-**060WR**-120

Small three-element 45° rectangular stacked rosette.



2X

EA-XX-**062AK**-120

Small general-purpose pattern with elongated solder tabs.

2X

GAGE DESIGNATION AND PATTERN

EA-XX-**062AP**-120
WK-XX-**062AP**-350

Compact, small, general-purpose pattern. Select WK gage for wide-temperature-range applications.

2X

EA-XX-**062AQ**-350

Same size as 062AP pattern but with high-resistance grid in EA Series.

2X

CEA-XX-**062UW**-120
CEA-XX-**062UW**-350

Small general-purpose gage with large exposed solder tabs. Exposed tab area is 0.07 x 0.04 in *(1.8 x 1.0 mm).*

2X

EA-XX-**062TV**-350

Small two-element 90° torque gage.

2X

EA-XX-**062TT**-120

Small general-purpose 90° tee rosette. Sections are electrically independent.

2X

GAGE DESIGNATION AND PATTERN

EA-XX-**125AC**-350

Widely used general-purpose pattern with high-resistance grid.

EA-XX-**125AD**-120
ED-DY-**125AD**-350
WD-DY-**125AD**-350
WK-XX-**125AD**-350

Widely used general-purpose pattern. Select ED- or WD-DY gages for fatigue applications; WK for wide-temperature-range static or dynamic measurements.

CEA-XX-**125UN**-120
CEA-XX-**125UN**-350

Narrow general-purpose gage pattern. Exposed tab area is 0.06 x 0.05 in *(1.5 x 1.1 mm).*

CEA-XX-**125UW**-120
CEA-XX-**125UW**-350

Most widely used general-purpose gage in CEA Series. Exposed tab area is 0.10 x 0.07 in *(2.5 x 1.8 mm).*

EA-XX-**125BB**-120

Narrow general-purpose pattern with elongated tabs.

Micro-Measurements
Super Stock Gage Listings Section

GAGE DESIGNATION AND PATTERN

EA-XX-**125BT**-120

General-purpose pattern with narrow grid and compact geometry.

2X

EA-XX-**125BZ**-350

Narrow high-resistance pattern with compact geometry.

2X

EA-XX-**125RA**-120

General-purpose three-element 45° rectangular rosette. Compact geometry.

CEA-XX-**125UR**-120
CEA-XX-**125UR**-350

General-purpose 45° single-plane rosette. Compact geometry. Exposed tab area is 0.08 x 0.06 in *(2.0 x 1.5 mm)*.

EA-XX-**125TM**-120

General-purpose two-element 90° tee rosette. Sections are electrically independent.

CEA-XX-**125UT**-120
CEA-XX-**125UT**-350

Two-element 90° tee rosette for general-purpose use. Exposed tab area is 0.10 x 0.07 in *(2.5 x 1.8 mm)*.

EA-XX-**125TK**-350

High-resistance two-element 90° gage for torque applications.

GAGE DESIGNATION AND PATTERN

CEA-XX-**187UV**-120
CEA-XX-**187UV**-350

Two-element 90° rosette for torque and shear-strain measurements. Sections have a common electrical connection. Exposed tab area is 0.13 x 0.08 in *(3.3 x 2.0 mm)*.

EA-XX-**250AE**-350

Large general-purpose gage. Used when high power dissipation is required.

EA-XX-**250AF**-120

Large general-purpose gage. Used when high power dissipation is required.

EA-XX-**250BG**-120
EP-08-**250BG**-120
WA-XX-**250BG**-120
WK-XX-**250BG**-350

Widely used general-purpose pattern. EP Series capable of elongations >20%.

EA-XX-**250BF**-350

General-purpose pattern with high-resistance grid. Compact geometry. Similar to 250BG pattern except for resistance.

CEA-XX-**250UN**-120
CEA-XX-**250UN**-350

Narrow general-purpose gage pattern. Exposed tab area is 0.08 x 0.05 in *(2.0 x 1.1 mm)*.

CEA-XX-**250UW**-120
CEA-XX-**250UW**-350

Larger grid and tabs than 250UN pattern. Exposed tab area is 0.10 x 0.07 in *(2.5 x 1.8 mm)*.

GAGE DESIGNATION AND PATTERN

EA-XX-**250BK**-10C

Very high-resistance (1000Ω) pattern. Recommended for high bridge voltage or for use on plastics.

CEA-06-**W250A**-120
CEA-06-**W250A**-350

Lowest cost, most flexible and conformable linear, weldable gage pattern. See page 8 for more details.

CEA-XX-**250UR**-120
CEA-XX-**250UR**-350

Large three-element 45° single-plane rosette. Exposed tab area is 0.13 x 0.08 in *(3.3 x 2.0 mm)*.

EA-XX-**500BH**-120

Long general-purpose gage in a compact geometry.

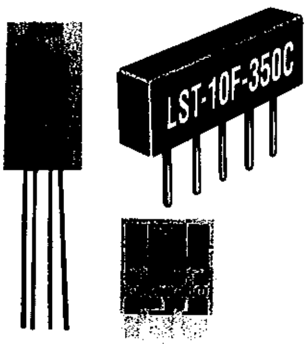
CEA-XX-**500UW**-120

Widely used, long gage pattern. Exposed tab area is 0.10 x 0.07 in *(2.5 x 1.8 mm)*.

Special-Purpose Gages, Sensors, and Equipment

In addition to providing the stress analyst with a vast selection of standard strain gage types, Micro-Measurements offers a variety of products designed to meet special needs and perform special functions in experimental stress analysis. Although space in this introductory catalog permits neither a full listing of these products, nor complete descriptions, a few types of special sensors are briefly noted.

Full information on any of these products, along with detailed technical specifications, can be obtained by requesting Catalog 500, or by contacting our Applications Engineering Department.



Temperature Sensors

TG Temperature Sensors, with a grid of ultra-pure nickel foil, are recommended for general-purpose temperature measurement from –320° to 500°F *(–195 to +260°C)*. For application at extremely low temperatures, two alloys — nickel and manganin — are combined to produce the CLTS-2B (cryogenic linear temperature sensor). The duplex construction of this sensor results in an essentially linear change of overall resistance with temperature, from –452° to +100°F *(–269° to +40°C)*.

Reusable LST matching networks are available for half-bridge connection of temperature sensors to strain indicators. With these accessories, the strain indicator registers temperature directly, at a scale factor of 10 or 100 microstrain per °F or °C.

Crack Detection

CD-Series Crack Detection Gages are designed to provide a convenient, economical method of indicating the presence of a crack, or indicating when a crack has progressed to a predetermined location on a test part or structure. By employing several CD gages, it is also possible to monitor the rate of crack growth. Crack Detection Gages are available with various strand lengths; from 0.4 to 2.0 in *(10 to 50 mm)*.

Crack Propagation

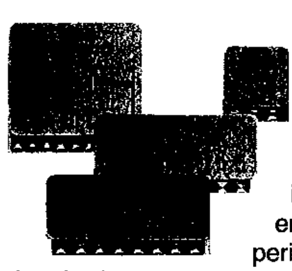
Crack Propagation Gages accurately indicate rate of crack propagation in a specimen material over a very small distance. These sensors are often used adjacent to notches, fillets, or other types of discontinuities in structures. Several sizes and geometries are available.

Strain Gages for Residual Stress Determination

EA Series

CEA Series

The most widely used practical technique for measuring residual stresses is the hole-drilling strain gage method described in ASTM Standard Method E837. With this method, a specially configured electrical resistance strain gage rosette is bonded to the surface of the test object, and a small, shallow hole is introduced through the center of the gage using a precision drilling apparatus such as the Vishay Measurements Group's RS-200 Milling Guide. After drilling, the strain in the immediate vicinity of the hole is measured, and the relaxed residual stresses are computed from these measurements. *For further details, request Bulletin 304.*



Bridge Completion Modules

Bridge Completion Modules are designed for completing the bridge circuit at the strain gage site. This provides for a symmetrical, balanced leadwire system between the strain gage circuit and the instrumentation, which can reduce effects of noise pickup in the leadwire system in some environments. Where switch contacts, slip rings, or other mechanical connections are employed between the strain gages and measuring instrumentation, or when leadwires will be periodically disconnected from the measuring instrument, accuracy can be improved by completing the bridge at the measurement site. Bridge completion modules can be designed to meet special circuit requirements. Contact our Applications Engineering Department for a detailed discussion of your special needs.

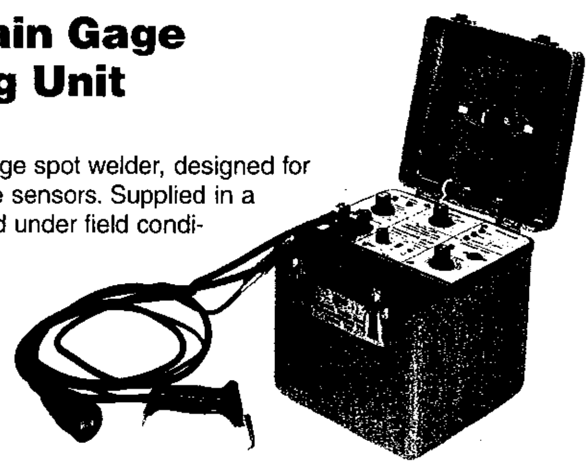
Weldable Strain Gages and Temperature Sensors

Weldable gages are precision foil sensors bonded to a metal carrier for spot welding to structures and components. These sensors are easy to install and require minimal surface preparation. Installation is accomplished without adhesives, eliminating heat-curing problems on massive structures. They are also well suited to laboratory test programs requiring elevated-temperature testing and minimal installation time.

Sensor Descriptions		
CEA-Series Weldable Strain Gage: Constantan alloy sensing grid completely encapsulated in polyimide. Very flexible. In most cases can be contoured to radii as small as 1/2 in *(13 mm)*. Rugged, copper-coated tabs for convenient leadwire attachment.	*LWK-Series Weldable Strain Gage:* Nickel-chromium alloy sensing grid completely encapsulated in a fiberglass-reinforced epoxy-phenolic matrix. Integral three-wire lead system consists of 10 in *(250 mm)* flexible etched Teflon®-insulated leadwires. Installation radius generally limited to 2 in *(50 mm)* or larger in the direction of the grid axis.	*WWT-Series Weldable Temperature Sensor:* High-purity nickel sensing grid completely encapsulated in a fiberglass-reinforced epoxy-phenolic matrix. Integral three-tab printed circuit terminals for convenient leadwire attachment.
 W250A	 W250B	 W200B

®Registered Trademark of DuPont

Model 700 Portable Strain Gage Welding and Soldering Unit

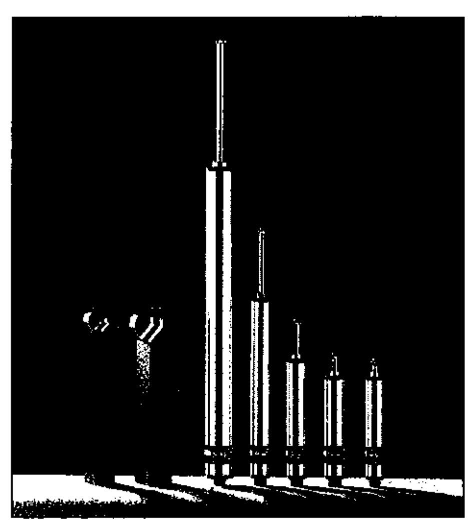


The Model 700 is a completely portable, capacitance-discharge spot welder, designed for efficient installation of weldable strain gages and temperature sensors. Supplied in a rugged, gasketed case, the battery-powered unit can be used under field conditions where no power lines are available.

A temperature-controlled soldering pencil, operated from the main battery supply, is an integral part of the Model 700. The lightweight pencil can be adjusted to a wide range of tip temperatures for both gage soldering and leadwire splicing.

For further details, request Bulletin 302.

Linear Displacement Sensors



Micro-Measurements Linear Displacement Sensors use a fully active 350-ohm strain-gage bridge to sense spindle displacement, giving infinite resolution and excellent linearity. They are compatible with all standard strain-gage instrumentation with bridge excitation from 2 to 10 volts. With a selection of models having full-scale ranges from 1/4 in *(5 mm)* to 4 in *(100 mm)*, Micro-Measurements Linear Displacement Sensors feature a unique design that produces maximum operating forces of less than 1 lb *(4.4 N)*. Available with specially designed mounting fixtures, these versatile sensors are ideally suited for use in research, manufacturing and process control applications.

For further details, request Bulletin 322.

Micro-Measurements Strain Gage Accessories

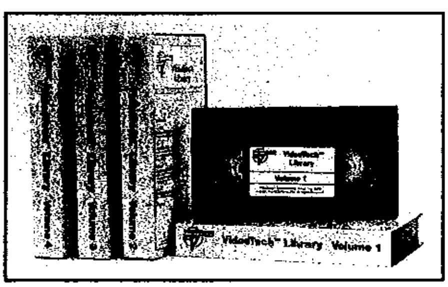
Micro-Measurements strain gages are produced under rigidly controlled manufacturing conditions, with the utmost care and attention given to ensuring the high level of quality and precision for which these gages have gained world-wide recognition. However, the gages' full potential for accurate strain measurement can be realized only when they are properly installed. There are, in fact, three principal components in every strain gage installation: (1) The strain gage itself, (2) the tools, materials, and supplies (accessories) needed to install the gage, and (3) the techniques employed in performing the installation. Professional stress analysts have learned from experience that compromising any of these may lead to compromising the quality of the installation and the accuracy of the strain data.

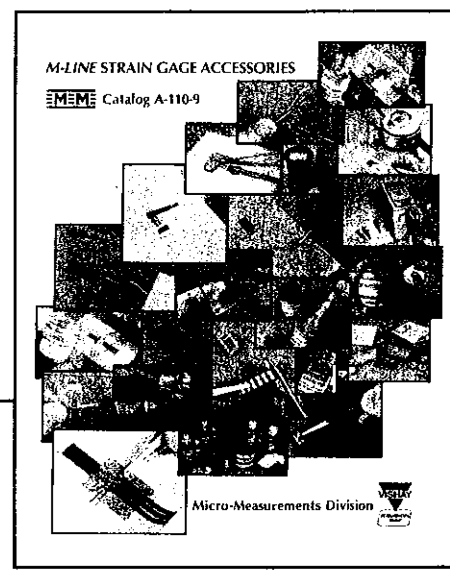
The well-established formula for making consistently successful strain gage installations is quite simple:

- select high-quality precision strain gages.
- select professional-caliber accessories which have been laboratory-tested and field-proven for effectiveness and compatibility with the strain gages.
- follow the installation procedures recommended by the manufacturer of the gages and accessories.

A small sample of the Micro-Measurements *M-LINE* strain gage installation accessories is featured on the following two pages. As indicated, the appropriate materials, supplies, and tools are available for each important step in the gage installation process — from preparing the surface of the test piece to applying a protective coating over the bonded and wired gage. All accessory items, whether manufactured directly by Micro-Measurements or specified for purchase from an outside supplier, are of the highest quality, and have been designed or selected specifically to help ensure successful installation of Micro-Measurements strain gages.

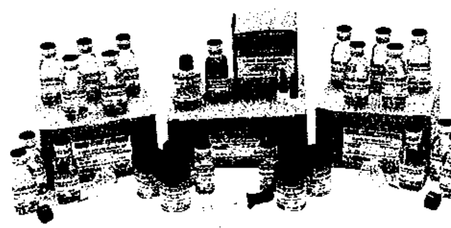
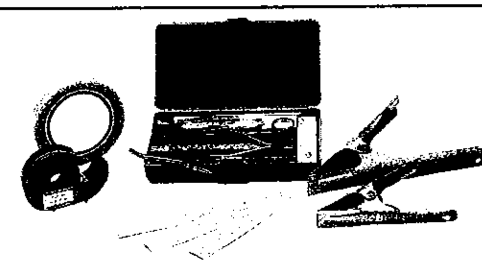
Regular users of strain gages will want to request a copy of Catalog A-110. This 40-page, fully illustrated catalog describes the complete line of gage installation accessories and related equipment. In addition to detailed product descriptions and specifications, it includes, where applicable, extensive recommendations for the appropriate selection and application of the accessories. Catalog A-110 is available on request from our Applications Engineering Department.





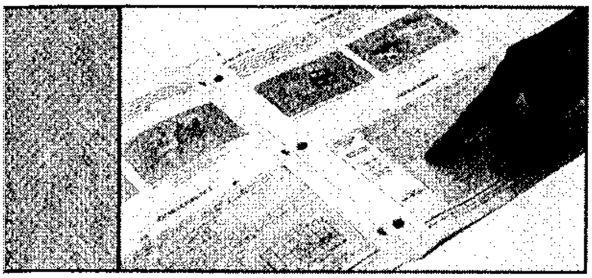
Also available from our accessories line is the VideoTech® Library, a series of videotapes that provides step-by-step instructions for making general-purpose strain gage installations. For detailed information request Bulletin 318.

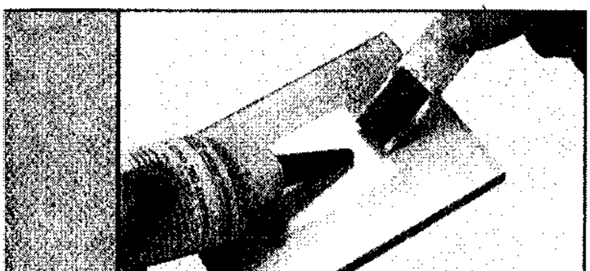
6 Simple Steps To Successful

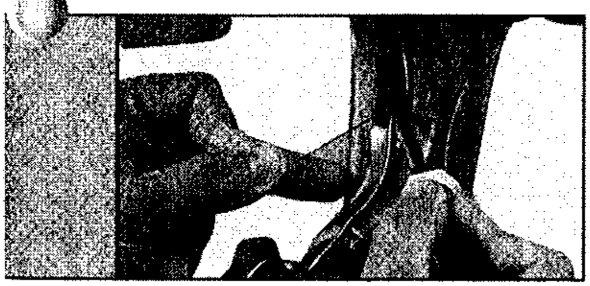
Surface Preparation		CSM-1A Degreaser *M-Prep* Conditioner A *M-Prep* Neutralizer 5A Silicon-Carbide Paper Cotton Swabs Gauze Sponges
Adhesive Selection		M-Bond 200 M-Bond AE-10 M-Bond AE-15 M-Bond 600 M-Bond 610
Gage Handling and Bonding		Cellophane Tape Mylar® Tape Spring Clamps Teflon® Film Silicone Rubber Application Tools ®Registered Trademark of DuPont
Leadwire Attachment		Solder Terminals Wires, Cables — Solid, Stranded, Tinned Solders Soldering Station Wiring Tools
Protective Coating Application		M-Coat A Polyurethane M-Coat B Nitrile Rubber M-Coat C Silicone Rubber M-Coat D Acrylic M-Coat W-1 Microcrystalline Wax
Gage Installation Tester		• Reads insulation resistance (leakage) to 20 000 MΩ with 15 Vdc. • Measures deviation of installed gage resistance from precise standards to a resolution of 0.02%. • Auxiliary ohmmeter scale for troubleshooting questionable installations. • Reads with the push of a button. • Verifies the complete gage circuit including leadwires.

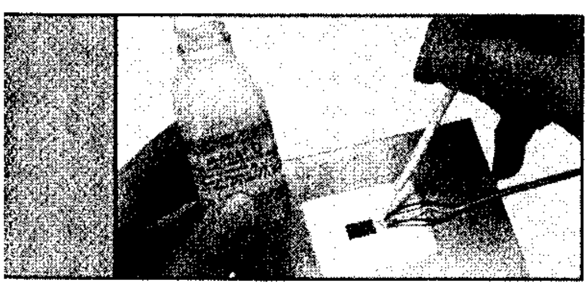
. . . With *M-LINE* Accessories

Strain Gage Installations . . .





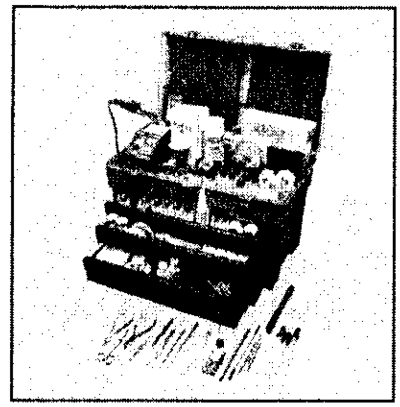




General Application Kits

It is often of greatest convenience for the strain gage user to purchase all of the needed accessory supplies and materials in a single package.

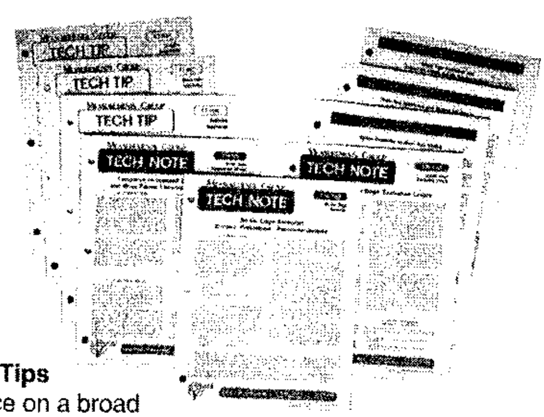
GAK-2-Series Kits provide specific selections of *M-LINE* accessories for making basic strain gage installations with the M-Bond 200, AE-10, AE-15, or 610 Adhesives.



The ultimate in gage installation capability is provided by the **MAK-1, Master Strain Gage Application Kit**. The MAK-1 includes all of the supplies and special tools necessary for making a wide range of gage installations for both laboratory and field applications.

Instructional Materials

Because technique is such an important ingredient in successful strain gage installation, detailed **Instruction Bulletins** have been prepared for virtually all Micro-Measurements strain gage installation products.



In addition, a library of **Tech Notes and Tech Tips** is available for reference on a broad range of subjects within Strain Gage Technology.

Tech Tips present practical strain gage application techniques for "out-of-the-ordinary" situations, and represent, as much as possible, a practical "how-to" approach to strain gage installation.

Tech Notes contain in-depth technical treatments of specific subjects having direct or indirect bearing on the successful application of stress/strain measurement technology.

— Lab-Tested — Field-Proven

Ordering Information

The Vishay Measurements Group Customer Service Department can provide immediate stock and delivery information. Most products are available for same-day shipment or can be produced on short delivery cycles. Vishay Measurements Group, Inc. maintains regional sales representatives throughout the world to further assist you. For additional information on any of our product lines, contact us or our representative serving your area.

Quantity discounts are available on strain gages and special sensors. All other items are sold on a net basis only. All prices are subject to change without notice.

Micro-Measurements Division Warranty Policy

The Micro-Measurements Division of Vishay Measurements Group, Inc., warrants that the products sold under its name are fit for the purpose for which they were intended by the supplier and guarantees said items against defects in workmanship or material for a period of ninety (90) days, or otherwise specified limits, from date of delivery. Every reported case of nonstandard material is thoroughly investigated by our Quality Assurance Department. It should be recognized that there is no method to 100% test our type of products since many tests would be destructive. Both Micro-Measurements and the purchasers must depend upon statistical sampling techniques that have in the past proved to be reliable and economical in respect to the cost of the product.

This warranty is in lieu of any other warranties, expressed or implied, including any implied warranties of merchantability or fitness for a particular purpose. There are no warranties which extend beyond the description of the face hereof. Purchaser acknowledges that all goods purchased from Vishay Measurements Group are purchased as is, and buyer states that no salesman, agent, employee or other person has made any such representations or warranties or otherwise assumed for Vishay Measurements Group any liability in connection with the sale of any goods to the Purchaser. Buyer hereby waives all rights buyer may have arising out of any breach of contract or breach of warranty on the part of Vishay Measurements Group, to any incidental or consequential damages, including but not limited to damages to property, damages for injury to the person, damages for loss of use, loss of time, loss of profits or income, or loss resulting from personal injury.

Some states do not allow the exclusion or limitation of incidental or consequential damages for consumer products, so the above limitations or exclusions may not apply to you.

The Purchaser agrees that the Purchaser is responsible for notifying any subsequent buyer of goods manufactured by Vishay Measurements Group of the warranty provisions, limitations, exclusions and disclaimers stated herein prior to the time any such goods are purchased by such buyers, and the Purchaser hereby agrees to indemnify and hold Vishay Measurements Group harmless from any claim asserted against or liability imposed on Vishay Measurements Group occasioned by the failure of the Purchaser to so notify such buyer. This provision is not intended to afford subsequent purchasers any warranties or rights not expressly granted to such subsequent purchasers under the law.

This catalog lists a variety of standard products commercially offered to all of our customers. The prices shown are based upon Vishay Measurements Group's standard terms and conditions, the only valid terms and conditions that will apply. Any modification or addition to these terms and conditions could result in a pricing change for these products, and would require negotiation.

If Source Inspection is required by the Buyer, it would be arranged at a mutually agreed upon time by the Buyer and Vishay Measurements Group. A fee which is commensurate with the costs associated with displacing key, qualified, technical specialists from their normal duties will be charged to the Buyer for such inspection.

Vishay Measurements Group is solely a manufacturer and assumes no responsibility of any form for the accuracy or adequacy of any test results, data, or conclusions which may result from the use of its equipment.

The manner in which the equipment is employed and the use to which the data and test results may be put are completely in the hands of the purchaser. Vishay Measurements Group, Inc. shall in no way be liable for damages consequential or incidental to defects in any of its products.

LIMITATION OF REMEDY: In the event any discrepancy is found to be Vishay Measurements Group 's responsibility, the buyer's sole and exclusive remedy will be the replacement of, or full credit for, the discrepant product.

We will provide immediate assistance to the best of our ability in locating and identifying the source of any difficulties involving our product.

VISHAY

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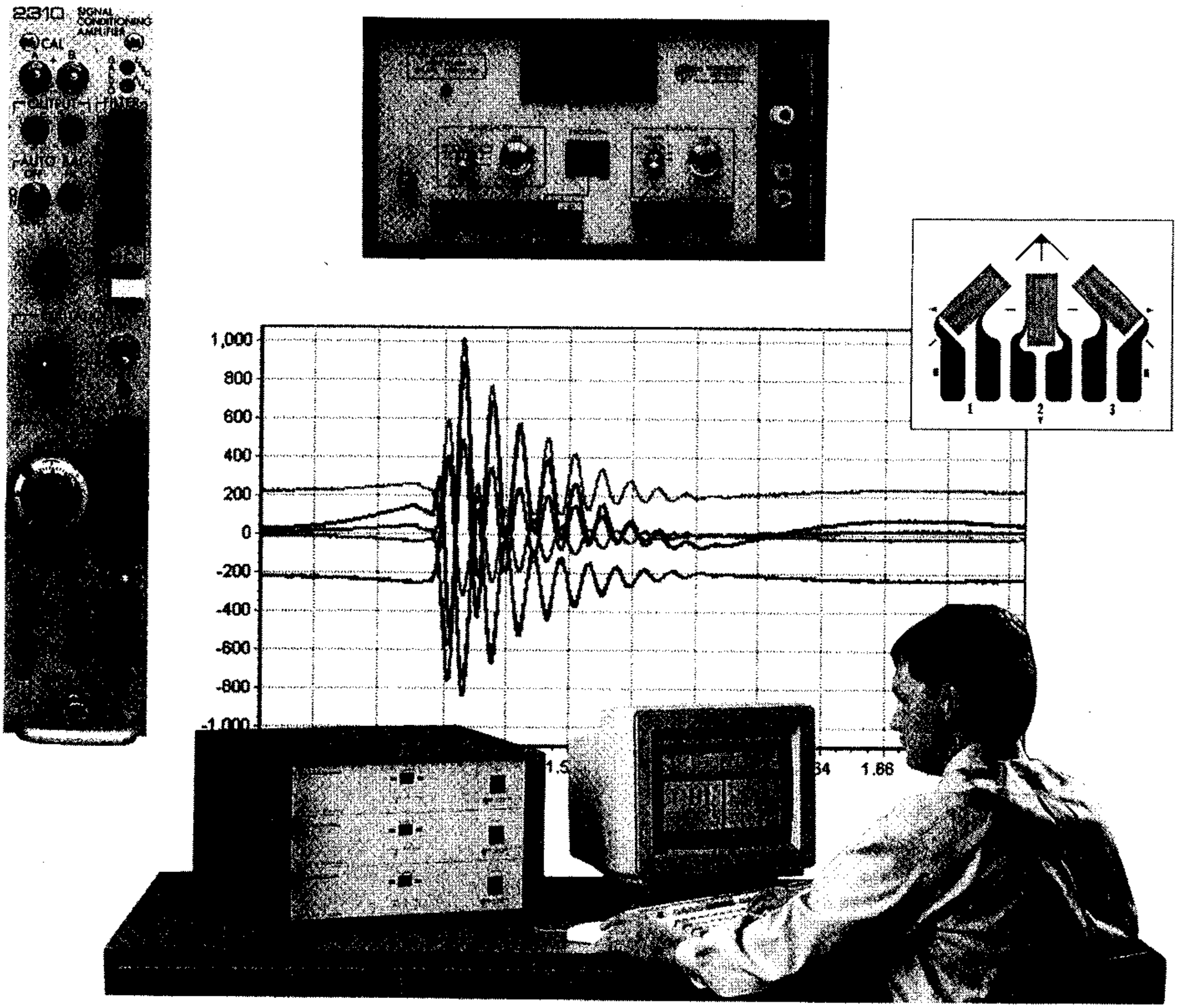
STRAIN GAGE INSTRUMENTATION

SELECTION GUIDE



The Instruments Division of Vishay Measurements Group, Inc. offers a wide selection of reliable, precision strain gage instrumentation for stress-analysis, structural, and materials testing.

This Selection Guide will introduce you to our instruments, and assist you in selecting those most appropriate for your measurement needs.

Considerations for Instrument Selection

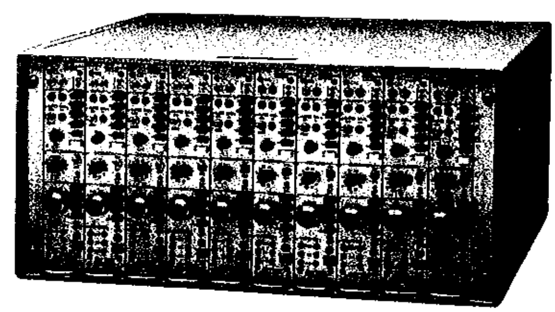
For Static Signals

Basic instrumentation requirements call for stability, accuracy and high resolution when making measurements under static loading conditions, and particularly where measurements are to be taken over long periods of time.

If test conditions involve predominantly constant measurement signals, the first choice for a measuring instrument will ideally incorporate a digital or analog display, and, depending on the degree of sophistication, output to a printer, microprocessor or computer. Multi-channel capability can be provided by manual or automatic switching/multiplexing units, which may include balance and/or span control facilities.

Many strain indicators have an analog output available for making single-channel measurements in conjunction with, for example, an oscilloscope, recorder, peak-read indicator, or analog-to-digital converter. However, this capability may have limitations with respect to frequency response and amplifier gain compared to an instrument designed specifically for high speed measurements.

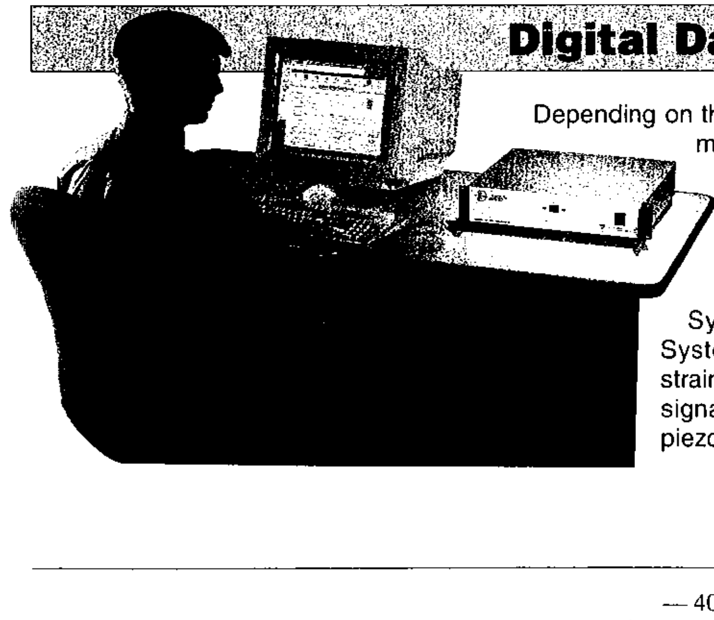
For Dynamic Signals



When signals are produced by dynamically applied loads at frequencies above 0.1 Hz, or are transients, measuring instrumentation requires adequate frequency response, and a wide amplifier gain range for output to the appropriate recording or display device. Such an instrument consists of an amplifier and signal conditioner with a built-in or shared power supply. Individual units are normally required for each channel when simultaneous recording or multiple channels are needed. With the output sent to a suitable display device, signal conditioning amplifiers can be used for making long-term measurements under static loading conditions, when maximum stability and accuracy are not primary considerations.

The 2100, 2200, and 2300 Systems accept low-level signals, and condition and amplify them into high-level outputs suitable for multiple-channel, simultaneous, dynamic recording. All of these systems can be used in conjunction with a variety of recording devices.

Digital Data Systems



Depending on their design, digital data systems can be used for measurement of static, dynamic, or both kinds of signals. System 6000, with higher sampling rates and digital filters, is suitable for signals of up to 4 kHz. System 5000, with a 5-Hz low-pass analog filter and lower sampling rates, can be used for static or quasi-static signals.

System 5000 and System 6000, the StrainSmart® Data Systems, accept inputs not only from strain gages but also strain-gage-based transducers, other transducers with high-level signals, LVDT's, thermocouples, and (for System 6000 only) piezoelectric sensors.

Instrument Selection Guide

Strain Indicators

INSTRUMENT	DISPLAY	OPERATION	BRIDGE EXCITATION	INPUT POWER	MULTI-CHANNEL	REMARKS	DETAILS
P-3500	Digital	Manual, Direct-Reading	2.0 Vdc	Battery (AC Optional)	Manual (1)	Portable, 0.05% Accuracy	Bulletin 245
3800	Digital	Manual, Direct-Reading	DC Step Selectable 1.0-15.0V	AC	Manual (1)	Wide-Range, High-Precision Laboratory Strain Indicator	Bulletin 249

(1) Switch and balance units are used to sequentially read the outputs of two or more strain gage inputs on a single indicator.

Signal Conditioning Amplifiers

INSTRUMENT	FREQUENCY RESPONSE (2)	OUTPUT (±)	AMPLIFIER GAIN	BRIDGE EXCITATION	INPUT POWER	REMARKS	DETAILS
2100	DC 17 kHz, –0.5 dB DC 50 kHz, –3 dB	10V at 100 mA	Continuously Variable 1-2100	DC 0.5-12V	AC or Battery	General-Purpose Signal Conditioner	Bulletin 250
2200	DC 50 kHz, –0.5 dB DC 100 kHz, –3 dB	10V at 10 mA and 1 Vrms at 10 mA	Continuously Variable 1-3300	DC: 0.5-15V or 0.5-15 mA	AC	High Performance, for Demanding Environments	Bulletin 252
2300 (2310)	DC 25 kHz, –0.5 dB DC 65 kHz, –3 dB	10V or 100 mA	Continuously Variable 1-11 000	DC 0.5-15V	AC	Multi-Feature Signal Conditioner	Bulletin 251
2300 (2311)	DC 50 kHz, –0.5 dB DC 125 kHz, –3 dB	10V or 100 mA	Continuously Variable 1-11 000	DC: 0.5-15V 0.3-6V Variable	AC	High Frequency Response Multi-Feature Signal Conditioner	Bulletin 251

(2) Typical — see specific product bulletin and/or instruction manual for detailed performance specifications.

Digital Data Systems

INSTRUMENT	OPERATING MODE (3)	CHANNELS	SCANNING RATE	BRIDGE EXCITATION (4)	INPUT POWER	REMARKS	DETAILS
5000 (5100)	Stationary, Online	5-1200 (in sets of 5)	1-50 Samples/ Sec/Channel	0-10 Vdc Programmable	AC	5-Hz Low-Pass Filter	Bulletin 257
6000 (6100)	Stationary, Online	1-1200	10-10,000 Samples/ Sec/Channel	0-10 Vdc Programmable	AC	Programmable Digital Filters to 4 kHz	Bulletin 257
6000 (6200)	Remote, Stand-alone	1-1200	10-10,000 Samples/ Sec/Channel	0-10 Vdc Programmable	DC (AC Optional)	Programmable Digital Filters to 4 kHz	Bulletin 257

(3) All systems can be operated with StrainSmart software for data acquisition, storage, reduction, and presentation, or with other third-party software.

(4) Strain gage cards only.

Considerations for instrument selection are provided on the facing page for all general-purpose instrumentation and data systems produced by Vishay Measurements Group. Additionally, our Applications Engineering staff is always available to assist you in selecting the right instrument for your specific applications.

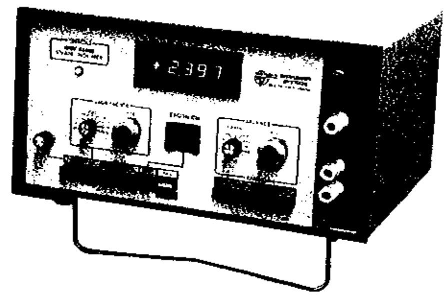
For Static Signals

P-3500

The P-3500 is a portable, battery-powered precision instrument featuring a 4-1/2 digit LCD readout (optional LED available). Color-coded push-button controls provide an easy-to-follow, logical sequence of setup and operational steps. A transducer input connector facilitates connection of strain gage based transducers. *Request Bulletin 245.*

3800

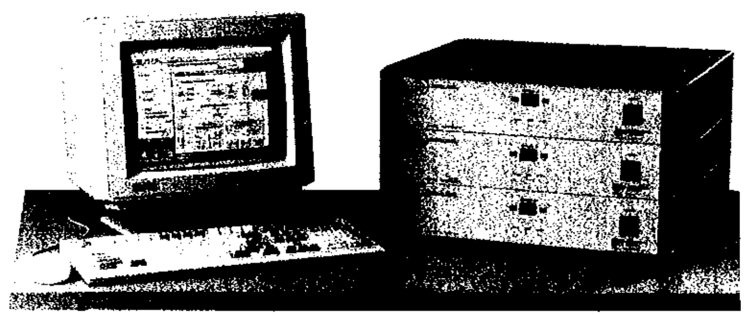
The 3800 is a high-precision, laboratory-type digital display strain indicator. It features extremely wide-range gage factor, balance, and bridge excitation controls. The wide-range feature enables measurement resolution of 0.1$\mu\epsilon$. The 3800 can also be used as a high-performance transducer indicator. *Request Bulletin 249.*



Digital Data Systems

StrainSmart®

StrainSmart is a ready-to-use, Windows®-based software system for acquiring, reducing, presenting, and storing measurement data from strain gages, strain-gage-based transducers, thermocouples, temperature sensors, LVDT's, potentiometers, piezoelectric sensors, and other commonly used transducers. And, it is designed to function seamlessly with a variety of Vishay Measurements Group instrumentation hardware, including both System 5000 and System 6000 StrainSmart Data Systems. *Request Bulletin 256 and 257.*



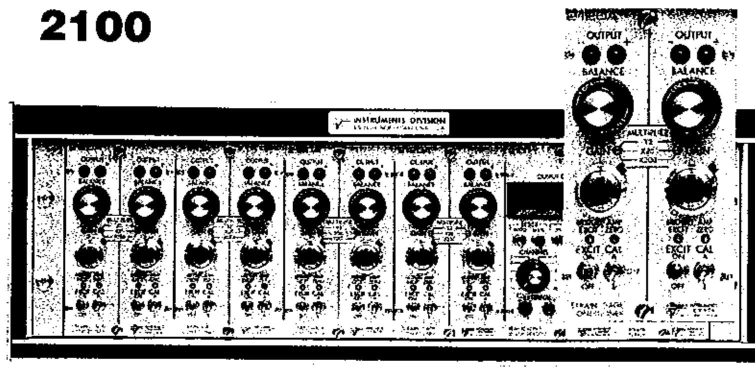
Strain gage technology is the stress/strain measurement technique most widely used around the world. Over the years, through our Micro-Measurements Division, we have developed the tools necessary for accurate acquisition and understanding of strain gage measurements. The primary factors affecting strain gage and instrument performance are incorporated into our extensive selection of Tech Notes, Tech Tips, Instruction Bulletins, and other technical publications that are recognized and used as the authoritative references for strain gage mea-surement by practitioners throughout the world. StrainSmart software automatically applies the techniques and corrections covered by these publications to your test measurements.

For Dynamic Signals

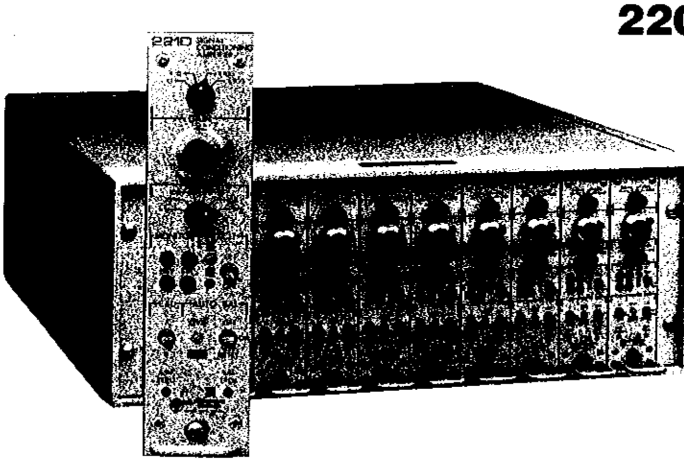
The 2100, 2200, and 2300 Systems accept low-level signals, and condition and amplify them into high-level outputs suitable for multiple-channel simultaneous dynamic recording. These systems can be used in conjunction with various recording devices.

2100

The 2100 is an economial system with a central power supply, and two active channels per unit module. *Request Bulletin 250.*



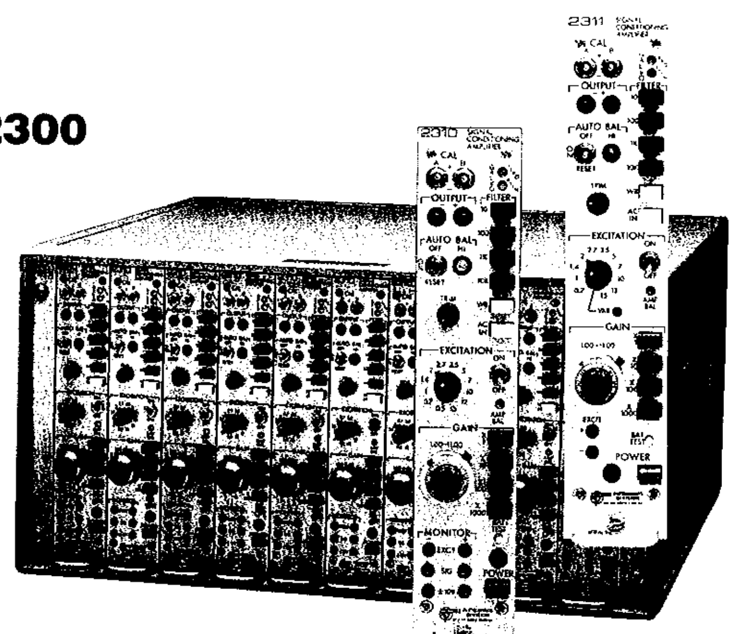
2200

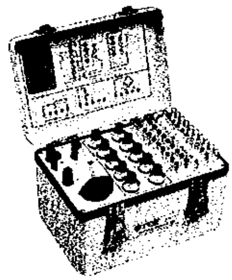


The 2200 System offers high performance in its most severe operating environments. Among its features are isolated constant-voltage/constant-current excitation, guarded input structure with ±350V common-mode capability, automatic wide-range bridge balance, and four-pole Bessel low-pass filter. The plug-in amplifiers are removable from the rack mount without having to disconnect the input wiring. *Request Bulletin 252.*

2300

The 2300 is a sophisticated system incorporating such advanced features as an individual power supply per channel, active filtering, three simultaneous outputs, tape playback mode, wide frequency response, and electronic bridge balance. *Request Bulletin 251.*





SB-10

The SB-10 is a high-quality, 10-channel switch and balance unit for use with strain indicators. It features gold-plated binding posts for reliable connection of input circuits, and incorporates fine-balance control with turns-counting dials for each individual channel.
Request Bulletin 247.

1300

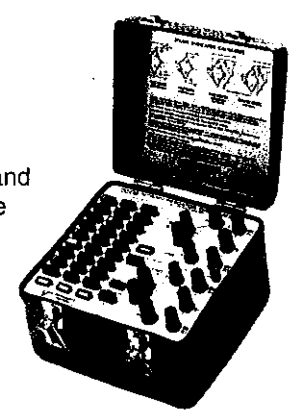
The 1300 Gage Installation Tester is used to verify the quality of an installed strain gage, as well as the complete gage installation, including leadwires. A carefully selected individualized test voltage is used for each measurement mode. Operation is by push buttons.
Request Bulletin 301.

V/E-40

This decade resistor/strain gage simulator can be used as a resistance standard, decade box, instrumentation calibrator, strain simulator, or investigative tool. It is also useful in measurement of arbitrary resistances and large strains.
Request Bulletin 316.

1550A

A true Wheatstone-bridge simulator, the 1550A Strain Indicator Calibrator presents known and repeatable resistance changes to the input of the indicator. Three decades of push buttons are used to produce incremental resistance changes. The 1550A is NIST-traceable.
Request Bulletin 313.



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Recommended Reference Materials

Experimental Stress Analysis, by J.W. Dally and W.F. Riley.

Prepared to serve as a teaching text for courses in experimental stress analysis. Topics covered include elementary elasticity, brittle coatings, photoelasticity, strain gages, and related instrumentation.

Formulas for Stress and Strain, by R.J. Roark and W.C. Young.

A comprehensive summary of the formulas, facts, and principles pertaining to the strength of materials, for the design engineer and stress analyst.

Experimental Stress Analysis and Motion Measurement, by R.C. Dove and P.H. Adams.

A thorough discussion of stress analysis and strain measurement. Part two covers techniques and instruments used for measuring and analyzing displacements, velocities, and accelerations.

A broader selection of Experimental Stress Analysis related literature is available from:

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Web site: www.sem.org