CHAPTER 17

STRAIN-GAGE INSTRUMENTATION

Earl J. Wilson

INTRODUCTION

A strain-sensitive material is one whose electrical resistance is proportional to the instantaneous spatial-average strain over its surface. Such materials are of two types: metallic (i.e., foil or wire) or semiconductor (described in Chap. 12 under *Piezoresistive Accelerometers*). When such a material is stretched, its length increases and its cross-section decreases; consequently, there is an increase in its electrical resistance. This change in resistance is a measure of its mechanical motion. Thus, a *strain gage* is a device which uses change in electrical resistance to measure strain.

The resistance strain gage may be employed in shock or vibration instrumentation in either of two ways. The strain gage may be the active element in a commercial or special-purpose transducer or pickup, or it may be bonded directly to a critical area on a vibrating member. Both of these applications are considered in this chapter, together with a discussion of strain-gage types and characteristics, cements and bonding techniques, circuitry for signal enhancement and temperature compensation, and related aspects of strain-gage technology.

The electrical resistance strain gage discussed in this chapter is basically a piece of very thin foil or fine wire which exhibits a change in resistance proportional to the mechanical strain imposed on it. In order to handle such a delicate filament, it is either mounted on, encapsulated in, or bonded to some type of carrier material and is known as the *bonded strain gage.* Bonded strain gages are available in a wide range of sizes and resistances. Unbonded strain gages, where the wire is free, are rarely used because of their limited frequency range and lack of sensitivity.

The strain gage is used universally by stress analysts in the experimental determination of stresses. Since strain always accompanies vibration, the strain gage or the principle by which it works is broadly applicable in the field of shock and vibration measurement. Here it serves to determine not only the magnitude of the strains produced by the shock or vibration, but also the entire time-history of the event, no matter how great the frequency of the phenomenon.

BASIC STRAIN-GAGE THEORY AND PROPERTIES

The relationship between resistance change and strain in the foil or wire used in strain-gage construction can be expressed as

$$\frac{\Delta L}{L} = \frac{1}{K}\,\frac{\Delta R}{R}$$

or

$$K = \frac{\Delta R/R}{\Delta L/L} \tag{17.1}$$

where K is defined as the *gage factor* of the foil or wire, ΔR is the resistance change due to strain, R is the initial resistance, ΔL is the change in length, L is the original length of the wire or foil, and $\Delta L/L$ is the unit strain to which the wire or foil is subjected.

Not all materials exhibit this strain-sensitivity effect, and different materials have different gage factors. Filament materials in common use in strain gages are Constantan (Ni 0.45, Cu 0.55), which has a gage factor of approximately +2.0; Iso-elastic (Ni 0.36, Cu 0.08, Fe 0.52, and Mo 0.005), which has a gage factor of about +3.5; and modified Karma (Ni 0.75, Cr 0.20, plus additions), which has a gage factor of +2.1.

STRAIN-GAGE CONSTRUCTION

Most strain gages are of foil construction, illustrated in Fig. 17.1, although fine-wire strain gages are used for special purposes, such as at high temperatures. Foil strain gages are usually made by a printed-circuit process.

Since the foil used in a strain gage must be very fine or thin to have a sufficiently high electrical resistance (usually between 60 and 350 ohms), it is difficult to handle. For example, the foil used in gages is often about 0.1 mil in thickness. Some use has been made of wire filaments in strain gages, but this type of gage is seldom used except in special or high-temperature applications. In order to handle this foil, it must be provided with a carrier medium or backing material, usually a piece of paper, plastic, or epoxy. The backing material performs another very important function in addition to providing ease of handling and simplicity of application. The cement provides so much lateral resistance to the foil that it can be shortened significantly without buckling; then compressive as well as tensile strains can be measured. Lead wires or connection terminals are often provided on foil gages, as illustrated in the typical foil gage shown in Fig. 17.1. A protective coating, recommended or supplied by the manufacturer, is usually applied over the strain gage, especially where the lead wires are attached.

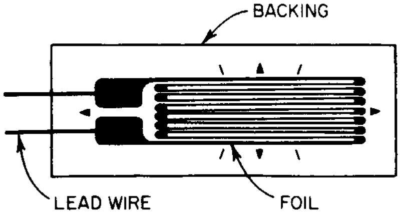

FIGURE 17.1 Typical construction of a foil strain gage.

TRANSVERSE SENSITIVITY

Because of its construction, a portion of the foil in each gage lies in the transverse direction and will respond to transverse strain.[1] Therefore the gage factor K of a gage* is always slightly smaller than the gage factor of the material of which it is fabricated. One of the desirable features of foil-type gages is their low transverse sensitivity. In this case, the gage consists of a flat foil grid; a sufficiently large amount of the foil is left at the ends of each strand to reduce the transverse sensitivity of the gage to one-half the value for wire gages for some types and to essentially zero for others.

TEMPERATURE EFFECTS

The effects of temperature on the gage factor of several alloys are illustrated in Figs. 17.2 and 17.3. When a bonded strain gage is used in measurements, any change in resistance in the strain-gage measurement system is interpreted as resulting from a strain. If thermal expansion is not induced, then this change will result from a mechanical strain. However, if thermal expansion is induced, then there will be a change in resistance resulting from the mechanical strain, and in addition, there will be a change in resistance resulting from the response of the strain gage to changes in temperature. The strain indication which results from such a temperature effect is known as an “apparent strain.” Figure 17.3 shows typical apparent strain for three commonly used alloys. This effect is usually negligible in the measurement of dynamic strains, since the readout instrument associated with the strain gage usually does not respond to static or slow changes in its resistance. However, in the measurement of static strains, the effects of temperature represent the largest potential source of error and require some form of temperature compensation.[2] It is therefore important to know the temperature at which a strain gage is used.

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* In determining the *gage factor* of the gage, it is assumed that the gage is mounted on a material having a Poisson’s ratio of 0.285 and subjected to uniaxial stress in the direction of the gage axis.

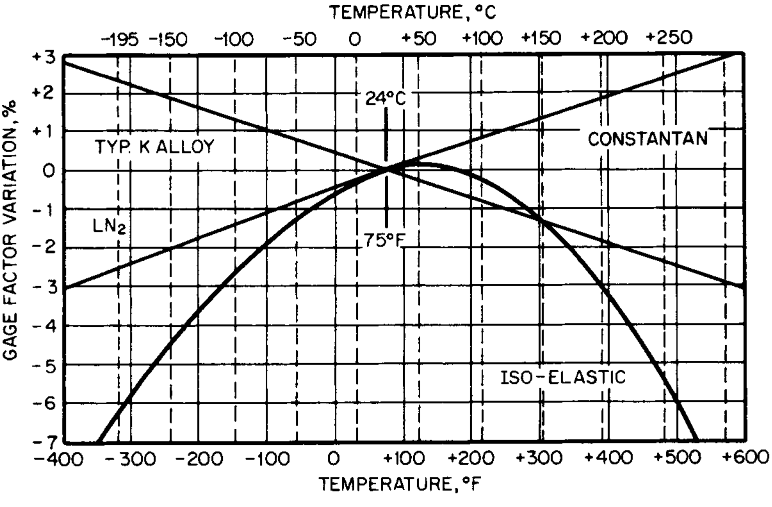

FIGURE 17.2 Typical variation in the gage factor of strain-gage alloys as a function of temperature.

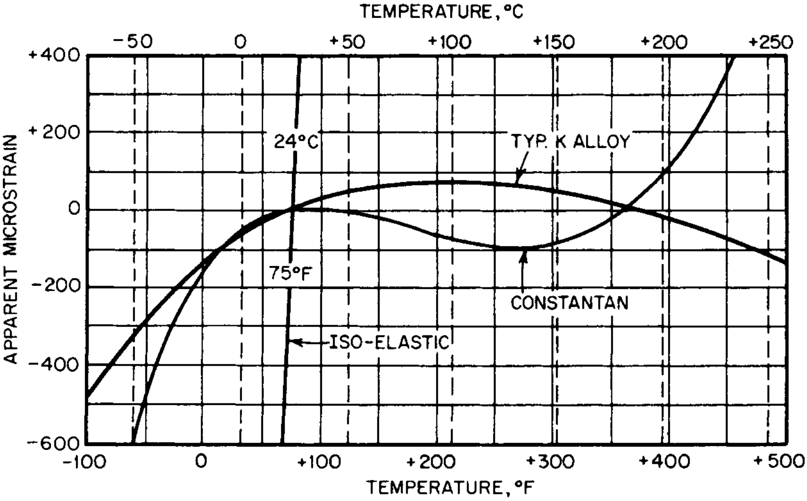

FIGURE 17.3 Typical apparent strain for three alloys commonly used in strain gages. These data are based on an instrument gage factor of 2.00.

STRAIN-GAGE CLASSIFICATIONS

Strain gages are classified in several ways. One classification cites the purpose for which the gage is to be used, that is, for static or dynamic strain measurement. Static gages are often made up with Constantan foil (a copper-nickel alloy), which has a minimum change of resistance with temperature. Dynamic strain gages occasionally are made up with Iso-elastic foil (iron-nickel-chrome alloy), which provides a greater gage factor than Constantan. Another common alloy used in strain gages is Karma, an alloy primarily of nickel and chrome. The dynamic gages, while having a much greater resistance change for a given strain than the static gages, also are much more sensitive to changes in temperature. They are used only where the phenomenon to be measured is so short in time duration that no temperature change of any consequence can occur during the time of measurement. Gages also are available for the measurement of very large strains (up to 20 percent) occurring in the plastic region of the material, as distinguished from the more common gages which are used to measure elastic strains (up to 1 percent).

STRAIN-GAGE SELECTION CONSIDERATIONS

In the case of shock measurements, a transient may be applied to the structure that is under investigation only once, or it may be repetitive. Shock is of very short time duration, and the problem of temperature compensation is nonexistent because in most cases the temperature does not have time to change during the impact. For this reason a dynamic-type gage usually can be employed for the measurement of shock. This type of gage has the advantage of a higher gage factor than the static gage, and so it will provide the greatest possible electrical signal for a given strain.

For vibration measurement, the type of gage selected is dependent on the kind of information desired. If only the frequency of vibration and the magnitude of the cyclic stresses are desired, dynamic-type gages can be used since temperature changes will not affect the results obtained unless the temperature fluctuates at the same rate as the stress. If, however, a measurement of the static or slowly varying component of the stress is also to be determined (i.e., if the absolute values of the stresses are desired), a static-type gage must be employed. Since changes in temperature will affect the gage reading, temperature compensation must be incorporated to obtain true values of stress.

Gage selection is dependent on the space limitation and steepness of strain gradient in any region. The strain gage indicates the average strain over the length of the gage; in a region of steep strain gradient, this indicated value may be much less than the maximum strain. The shorter the gage used in such a region, the closer is the gage indication to the maximum strain (Fig. 17.4). However, two possible objectives must be considered quite carefully in selecting a gage for a particular installation: (1) the determination of the frequency of vibration, or comparison of relative amplitudes and frequencies with different conditions of excitation, and (2) the determination of the maximum stress pattern resulting from the vibration set up. In the first case there is considerable freedom with regard to the location of the gage on the structure, and therefore with the selection of the gage itself. In the second case severe restrictions exist in regard to the region of application of the gage and its possible dimensions. In general, very short gage-length gages are more difficult to apply properly. Therefore it is desirable to employ gage lengths of ¼ in. whenever possible. When the actual magnitude of the maximum stress resulting from shock or vibration is to be determined, a much more complicated system of gages must be employed. A single gage can be used in only the very limited case where a stress exists in one direction only, and that direction must be known. If stresses exist in several directions, or if the direction of a singly existing stress is unknown, a strain-gage rosette consisting of three or more gages must be employed.[3]

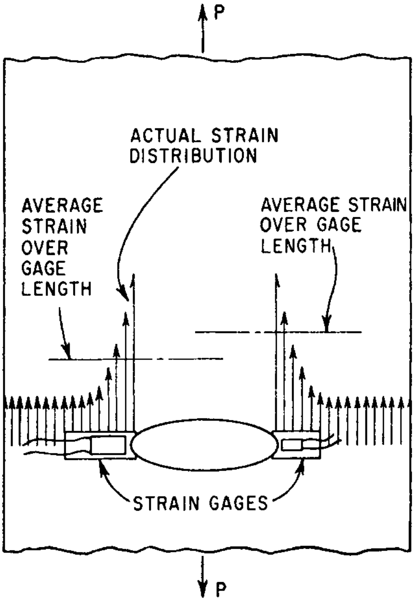

FIGURE 17.4 Effect of gage length on indicated strain in the presence of a severe strain gradient. The shorter gage on the right indicates a higher strain. An infinitesimal gage length would be necessary to indicate the peak strain.

PHYSICAL ENVIRONMENT

The physical environment of the applied gage is an important factor which must be considered in gage selection and protective treatment. Temperature, pressure, humidity, oil, corrosive acid, abrasive action, and possible electromagnetic, neutron, and radiation fields are conditions which affect the choice of gage and its required protection.

If high temperatures (up to 500°F or 260°C) are to be encountered, a Bakelite or other high-temperature-type gage must be selected. If even higher temperatures must be withstood, a ceramic-type gage should be employed. Gages of this sort are used at temperatures as high as 2000°F (1100°C). If the temperature never exceeds 200°F (95°C), however, any type of gage can be used.

ACCURACY CONSIDERATIONS

Gages must be selected with regard to the desired precision of the results. If only the frequency of the vibration or the duration of a shock wave is required, almost any gage, properly chosen for the temperature and humidity conditions to be encountered, gives quite satisfactory results. However, if the magnitude of the stresses produced is to be determined in addition, then considerable care must be exercised to select the proper gage to obtain the desired results. Not only must the gage be the proper one to portray the encountered strain faithfully, but precautions must be taken to install the gage correctly.

The testing "environment" can affect strain-gage accuracy in many ways. Magnetostrictive effects,[4] hydrostatic pressure,[5] nuclear radiation,[6] and high humidity are examples of conditions that may cause large strain-gage errors. Creep, drift, and fatigue life in the gages themselves may be important. In most normal environments these errors are either small or undetectable. Whenever unusual or harsh environments are encountered, it is wise to consult the strain-gage manufacturer to obtain recommendations for gage systems and estimates of expected accuracies.

BONDING TECHNIQUES

The proper functioning of a strain gage is completely dependent on the bond which holds it to the structure undergoing test. If the bond does not faithfully transmit the strain from the test piece to the wire or foil of the gage, the results obtained cannot be accurate. Failure to bond over even a minute area of the gage will result in incorrect strain indications. The greatest weakness in the entire technique of strain measurement by means of wire or foil gages is in the bonding of the gage to the test piece. Usually, the manufacturer of the strain gages will recommend cements which are compatible with their use and will provide instructions for their proper installation.

In order to achieve a good bond, it is essential that the surface to which the gage is bonded be chemically clean. Various cements used for this purpose are described in Chap. 15. It is advisable to protect the bonded strain gage with a coating recommended by the manufacturer for the environment in which the strain gage is to operate.

STRAIN-GAGE MEASUREMENTS

The resistance strain gage,[7] because of its inherent linearity, very small mass, wide frequency response (from zero to more than 100,000 Hz), general versatility, and ease of installation in a variety of applications, is an ideal sensitive component for electrical transducers for use in shock and vibration instrumentation.[8] The Wheatstone bridge circuit, described in a subsequent section, can be used to extend the versatility of the strain gage to still broader applications by performing mathematical operations on the strain-gage output signals. The combination of these two devices can be used effectively for the measurement of acceleration, displacement, force, torque, pressure, and similar mechanical variables. Other useful attributes include the capacity for separation of forces and moments, vector resolution of forces and accelerations, and cancellation of undesired vector components.

The usual technique for employing a strain gage as a transducing element is to attach the gage to some form of mechanical member which is loaded or deformed in such a manner as to produce a signal in the strain gage proportional to the variable being measured. The mechanical member can be utilized in tension, compression, bending, torsion, or any combination of these. All strain-gage-actuated transducers can be considered as either force- or torque-measuring instruments. Any mechanical variable which can be predictably manifested as a force or a couple can be instrumented with strain gages.

There are a number of precautions which should be observed in the design and construction of custom-made strain-gage transducers.[9] First, the elastic member on which the strain gage is to be mounted should be characterized by very low mechanical hysteresis and should have a high ratio of proportional limit to modulus of elasticity (i.e., as large an elastic strain as possible). Although aluminum, bronze, and other metals are often employed for this purpose, steel is the most common material. An alloy steel such as SAE 4340, heat-treated to a hardness of RC 40, will ordinarily function very satisfactorily.

The physical form of the elastic member and the location of the strain gages thereon are not subject to specific recommendation, but vary with the special requirements of each individual instrumentation task. When no such requirements exist, a standard commercial transducer ordinarily should be used. In general, the shape of the member should be such as to (1) allow adequate space for mounting strain gages (preferably in regions of zero or near-zero strain gradient), (2) provide the desired natural frequency, (3) produce a strain in the gages which is great enough at low values of the measured variable to result in an output signal readily subject to accurate indication or recording, and not so great as to cause nonlinearities or abbreviated gage life at peak load values, (4) provide temperature compensation and/or signal augmentation (as described in a subsequent section) whenever feasible, and (5) allow for simplicity of machining, ease of gage attachment and wiring, and, if necessary, protection of the gages.

The strain gages should be cemented to the elastic member with the usual care and cleanliness necessary in all strain-gage applications, special attention being given to minimizing the bulk of the installation if the added mass is significant to the frequency response of the instrument. Other considerations vital to successful strain-gage-application technique are described elsewhere in this chapter.

DISPLACEMENT MEASUREMENT

Measurement of displacement with strain gages can be accomplished by exploiting the fact that the deflection of a beam or other loaded mechanical member is ordinarily proportional to the strain at every point in the member as long as all strains are within the elastic limit.

For small displacements at low frequencies, a cantilever beam arranged as shown in Fig. 17.5 can be employed. The beam should be mounted with sufficient preload on the moving surface that continuous contact at the maximum operating frequency

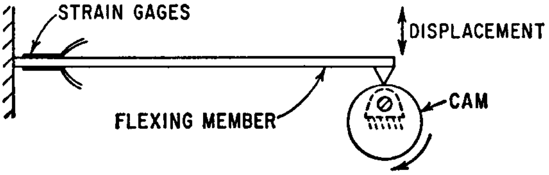

FIGURE 17.5 Strain gages mounted on a cantilever beam for displacement measurement produce electrical signals proportional to cam motion.

is assured. In the case of higher-frequency applications, the beam can be held in contact with the moving surface magnetically or by a fork or yoke arrangement, as illustrated in Fig. 17.6. It is necessary to make certain that the measuring beam will not affect the displacement to be instrumented, and that no natural mode of vibration of the beam itself will be excited.[10]

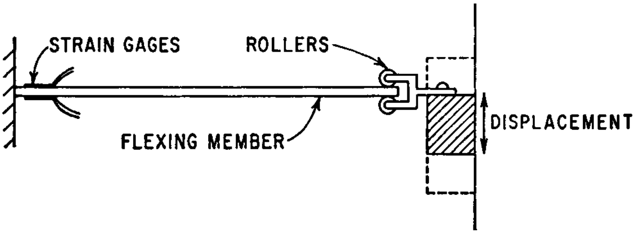

FIGURE 17.6 Displacement transducer designed for continuous, positive contact with moving object.

The measurable displacement magnitude can be increased above that for the cantilever beam by employing other schemes, such as the "clip gage" shown in Fig. 17.7. This gage is constructed by bonding strain gages to the upper and lower sides of a piece of channel-shaped spring steel, as shown in Fig. 17.7. The assembly is then clipped or otherwise mounted on the test specimen so that the legs deflect as the specimen is strained, thus straining the backbone of the clip gage to a greater or lesser extent. Any desired reduction in strain magnitude can be obtained in this manner by merely altering the proportions of the clip gage. Unfortunately, the maximum allowable frequency generally decreases as the displacement amplitude increases, since stiffness and natural frequency tend to change together. Displacement also can be measured through the use of the relative motion of a seismically mounted mass of much lower natural frequency than the applied frequency.

VELOCITY

Velocities can be measured directly with strain-gage transducers only by producing a force such as viscous damping or hydro- or aerodynamic drag force which is uniquely related to velocity. Velocity indication also can be obtained with strain gages by differentiation of a displacement function or integration of an acceleration function. In either case, the transducer-design considerations correspond to those for force measurement described in the following section.

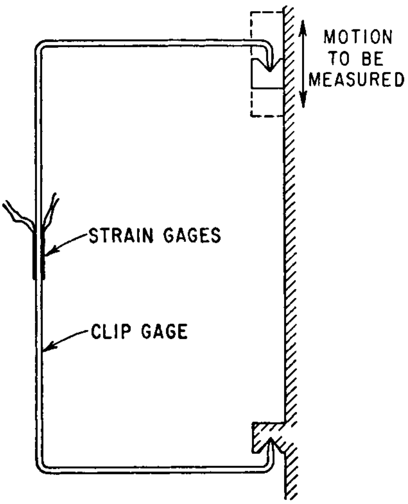

FIGURE 17.7 Clip gage for instrumenting large displacements. Proportions of clip gage are designed to keep strain well within the proportional limit of the material.

FORCE MEASUREMENT

The principle of force measurement with strain-gage-actuated transducers is very similar to that for displacement.[9] The procedure consists of placing a strain-gage-instrumented elastic member in series with the force to be measured. The strain in the transducer, and thus the output signal, is proportional to the force if all stresses are kept within the elastic limit. The proportionality constant between strain and force must be obtained by calibration if precise results are desired. Otherwise, tolerances on the gage factor of the strain gage, and uncertainty as to the elastic properties of the instrumented member, can produce errors of 5 percent or greater—even for transducer configurations with readily calculable strain distributions.

Figure 17.8 illustrates a common form of force transducer, the cantilever beam. Strain gages are mounted on the top and bottom of the beam, producing double sensitivity (output) and virtually complete temperature compensation. While this type of transducer is probably best suited to static or quasi-static measurements such as reaction forces, it also can be used very successfully for many shock and vibration problems as long as the natural frequency of the beam is higher than the frequency of the force being measured. The ring gage (Fig. 17.9) can be categorized with the cantilever beam, and is equally applicable to static or dynamic force measurement within the limitations imposed by its comparatively low natural frequency.

For most dynamic force-instrumentation problems a small compression or tension member (Fig. 17.10) is ordinarily employed. If the load is characterized by alternation between compression and tension, the transducer must be designed for a rigid, integral connection, with no backlash or clearance. This can be accomplished by employing threaded ends with lock nuts for joining the transducer to the remainder of the assembly. In many problems involving machine parts or other mechanical components it is possible to measure loads by applying strain gages to the machine member itself, necessitating calibration of the member to determine the relationship between force and strain.

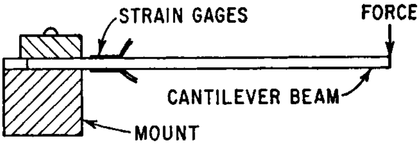

FIGURE 17.8 Cantilever force-measuring transducer, consisting of beam with load applied at free end. Gage strain is a linear function of the force if the proportional limit is not exceeded.

PRESSURE

In hydraulic and aerodynamic devices, pressure fluctuations are often associated with vibration phenomena—either as cause or effect. Strain-gage transducers are widely used in such situations.[11]

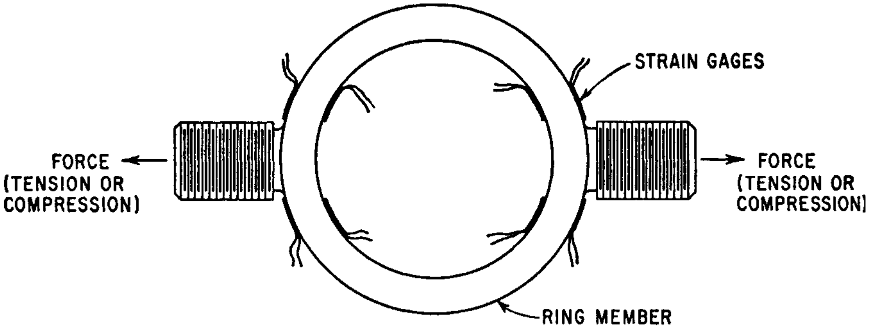

FIGURE 17.9 Ring gage for force measurement. This type of gage provides sensitive axial load measurement without undue loss of rigidity or ruggedness.

Pressure pickups based on strain gages are commonly one of three principal types: piston, diaphragm, or tube. In the piston type the pressure acts against a freely movable flat surface (which may be either a piston or a diaphragm), the motion of which is inhibited by an elastic member instrumented with strain gages to measure the force (Fig. 17.11).

Diaphragm-type pressure transducers, shown in Fig. 17.12, have the strain gages applied directly to the back surface of the diaphragm so that diaphragm strain is a measure of pressure.[12] The simplest form of pressure transducer to construct is the tube type, shown in Fig. 17.13. In this type, strain gages are applied to the outer surface of a tube which has the fluid pressure acting on its inner surface. It is sometimes necessary to thin the wall of the tube or to use a longitudinally crimped tube in order to increase the strain magnitude to a measurable level. As a convenient alternative, the Bourdon tube in a conventional mechanical pressure gage can serve as the transducing element if strain gages are attached to it. The compressibility of the fluid contained in the tube must be considered for its effect on the frequency response of this type of unit. Pressure pickups should be calibrated statically, and preferably dynamically, prior to use.

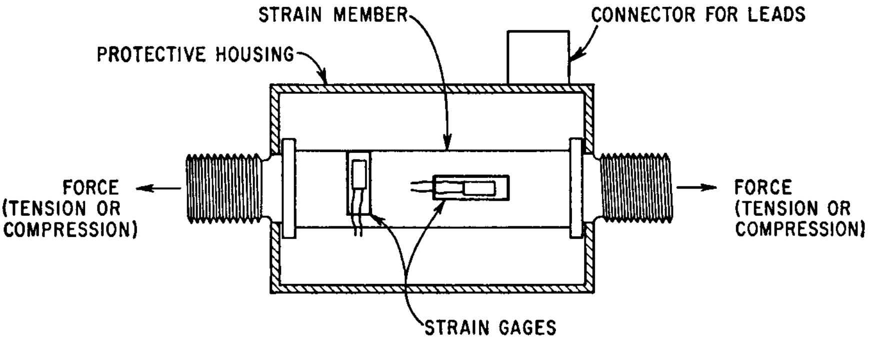

FIGURE 17.10 Widely used commercial form of axial force transducer for large loads.

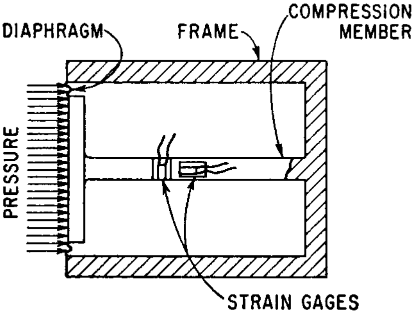

FIGURE 17.11 Piston-type pressure transducer with diaphragm seal for piston. Pressure load on piston head is sensed by strain gages on supporting column.

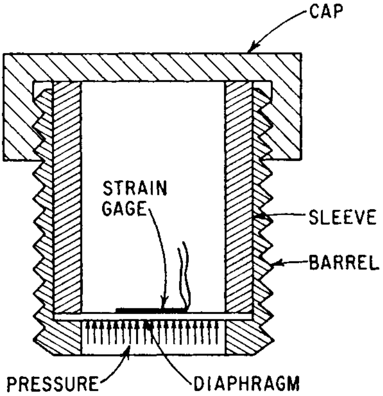

FIGURE 17.12 Pressure pickup whose output is a function of diaphragm strain. As diaphragm deforms under pressure, strain is transmitted to gage to produce electrical signal.

ACCELERATION

At one time, wire or foil strain gages were used as the transducing elements in resistive accelerometers. Now silicon elements are usually used because of their higher sensitivity. See *Piezoresistive Accelerometers,* Chap. 12.

STRAIN-GAGE CIRCUITRY AND INSTRUMENTATION

In order to study the detailed cyclical nature of vibration problems or the transient phenomena commonly associated with mechanical shock, it is usually necessary to obtain some form of meter output or graphical record of the events. To produce an output voltage proportional to resistance change requires (1) electrical amplification, since the output of a resistance strain gage usually is only in the range from 10 to 1000 microvolts, and (2) a stable, well-regulated source of electric current, or excitation. These two factors are of primary importance in determining the nature of the electrical instrumentation system which can be used satisfactorily with the resistance strain gage.

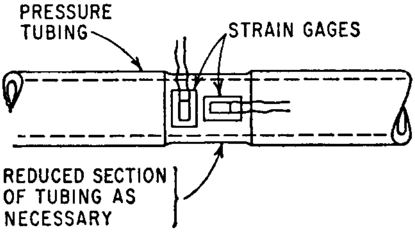

FIGURE 17.13 Readily made pressure transducer consisting of length of tubing with strain gages attached. Dilation of the tube with pressure creates strain in gages.

A signal conditioner, described in Chap. 13, limits the bandwidth of a signal from a transducer so as to restrict the signal to within the frequency range of interest, usually removing extraneous components which may otherwise dominate and restrict the available dynamic range of the useful part of the signal; a signal conditioner may integrate the signal (to velocity and/or displacement). A signal conditioner also supplies power to a strain gage, since such a transducer is not self-generating. To avoid the possibility of the pickup of background noise, the length of cables between the transducer and signal conditioner should be minimized.

There are many circuit arrangements for supplying a strain gage with excitation current and obtaining a signal corresponding to deformation of the gage. Each of these types of circuits has its relative advantages and disadvantages—for example, with respect to sensitivity, temperature compensation, signal enhancement, and ease of operation. Such considerations are further discussed in detail in Refs. 6 and 13. Two of the most common arrangements are the potentiometer circuit and the Wheatstone bridge circuit.

POTENTIOMETER CIRCUIT

Figure 17.14, known as the *potentiometer circuit* (sometimes called a *half-bridge circuit*), is the simplest circuit arrangement for supplying a strain gage with excitation current and obtaining a signal corresponding to deformation of the gage. In this circuit, the resistor R_B (called the *ballast resistor*) is of relatively high value to maintain the current flow in the circuit relatively constant and independent of small changes in resistance of the strain gage R_G. The current is supplied by the dc electrical source *e*. Here, the output signal from the potentiometer circuit, resulting from a variation in the resistance of the strain gage, is designated as e_o.

This circuit is well suited to the instrumentation of dynamic or fluctuating strains, but is totally unsuited for the measurement of static strains or the static component of a combined static and dynamic strain. Therefore, in dynamic applications, it is common practice to block the direct current, i.e., the steady-state (zero-strain) portion of the output voltage, so that only the fluctuating component is measured. This is done by inserting a capacitor *C* between the potentiometer circuit output and the input of the following amplifier, as illustrated in Fig. 17.15. An ac signal, representing the alternations in the strain to which the gage is subjected, is transmitted through the capacitor. Any influences in addition to strain that may modify the resistance of the strain gage (for example, temperature changes) also produce output voltages in this circuit. Since

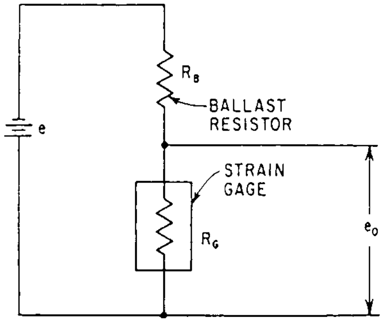

FIGURE 17.14 Potentiometer circuit for dynamic strain signals. Nearly constant current through the circuit, combined with varying gage resistance, produces output signal.

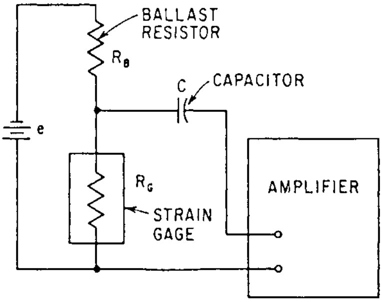

FIGURE 17.15 Overall arrangement of circuits for instrumenting dynamic strain. Signal from gage is taken to ac amplifier through isolating capacitor.

the capacitor coupling to the amplifier is essentially a high-pass filter, temperature-induced output voltage changes are attenuated severely unless the frequency of such changes is high enough to be of the same order of magnitude as the alternating strain. Fortunately, most temperature changes which may affect strain gages occur too slowly to be carried through this circuit arrangement.

WHEATSTONE BRIDGE

In the potentiometer circuit it is necessary to block the dc component of the output voltage with a capacitor before feeding the signal to the input of an amplifier. The same effect can be achieved by suppressing the dc component of the signal by connecting two potentiometer circuits in parallel and taking the output signal from corresponding points in the two branches of the resulting network, as shown in Fig. 17.16. This circuit arrangement is generally referred to as a *Wheatstone bridge,* and represents one of the most precise methods known for measuring (or comparing) resistances. Advantages of the Wheatstone bridge over the potentiometer circuit are (1) much greater flexibility in circuit arrangements for signal augmentation, temperature compensation, and cancellation or separation of variables, (2) capacity for accurately indicating combined static and dynamic strains, and (3) virtually complete freedom from error due to resistive changes in the conductors connecting the supply voltage to the network. As an example of the significance of the last point, consider the effect of the contact resistance variations which might occur in a set of slip rings being used in conjunction with a test of torsional vibration in a rotating shaft.

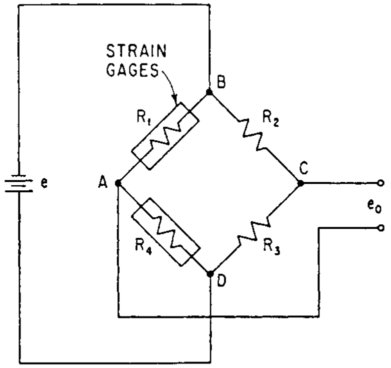

FIGURE 17.16 Wheatstone-bridge circuit for static and dynamic strain measurement.

SELECTION OF INSTRUMENTS FOR STRAIN MEASUREMENT

The output voltage from a strain-gage potentiometer circuit or Wheatstone bridge is, for elastic strain magnitudes in metals, very small. Electrical amplification is required to bring the signal to a level where it can be used conveniently for indication or recording.[13] To assure satisfactory performance and precision, the entire instrument system, from power supply to recording instrument, should be considered as a unit. Figure 17.17 illustrates in block form the basic elements of a strain-gage instrumentation system. The criteria for selecting the individual components of such a system are fixed by the nature of the strain being studied, the type of information required from the system, and the mutual compatibility of the various system components. Consideration should be given to the required frequency response, the input and output impedances of the units in the system, the signal amplitudes being dealt with, and the accuracy of measurement desired. In general, it is safe to assume that the strain gage will respond to considerably higher frequencies than any mechanical device to which it may be attached. In the case of small members vibrating at high frequencies, the limitation is more apt to arise from the change in mass

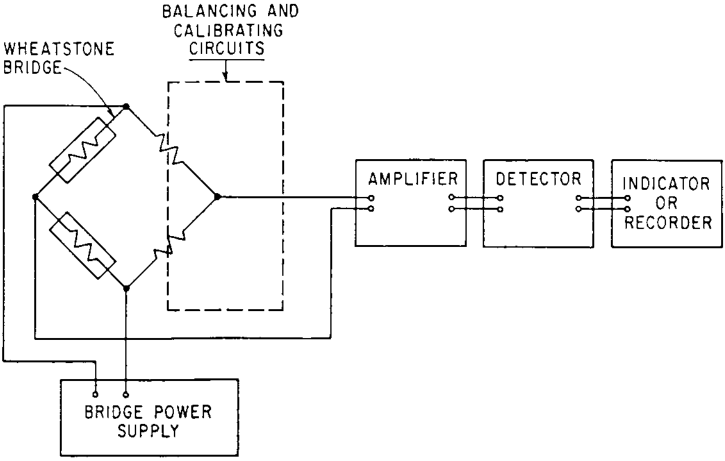

FIGURE 17.17 Block diagram of basic elements of strain-gage instrumentation system.

due to the presence of the gage and its lead wires. The lead wires must be firmly attached to the gage.

Commercial instruments for use with strain gages usually combine several if not all of the components of Fig. 17.17 into a single unit. The limitations of such devices should be investigated prior to purchase. For example, the instrument may include an alternating-frequency source of power for the Wheatstone bridge. This can lead to difficulties in the measurement of high-frequency strains. The frequency of the strain being measured (which will modulate the power supply in the bridge circuit) is limited to approximately 10 to 20 percent of the carrier frequency. If the carrier frequency is high enough to overcome this objection, the capacitive unbalance and pickup in the strain-gage leads is apt to be excessive.

Strain-gage measurements made in the presence of an intense magnetic field present a special problem since the gage resistance may change as a result of the imposed magnetic field.

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