TECHNIQUE

The Three-Wire Quarter-Bridge Circuit

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The Three-Wire Quarter-Bridge Circuit

Introduction

Since the invention of the electrical resistance strain gage more than a half century ago, the Wheatstone bridge has become the sensing circuit of choice in most commercially available strain gage instrumentation. This 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.

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The Wheatstone Bridge

The Wheatstone bridge circuit in its simplest form (Fig. 516.1) 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.

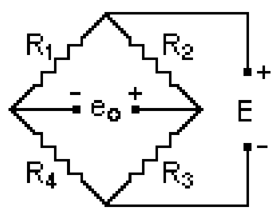

Fig. 516.1 - Basic Wheatstone Bridge Circuit.

While a mathematical proof is beyond the scope of this publication, 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 in this publication) 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.

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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 $R_G + 2R_L$.

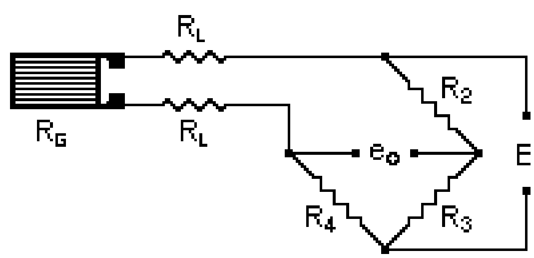

Fig. 516.2 - Two-wire quarter-bridge circuit.

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 microstrain. 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 deg F (55 deg C) temperature change. For the 120-ohm gage circuit above, this would result in an error equivalent to approximately 156 microstrain for a 10 deg F (5.5 deg 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. 516.3 on the next page.

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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. 516.3. 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. 516.3, 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. 516.3 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.

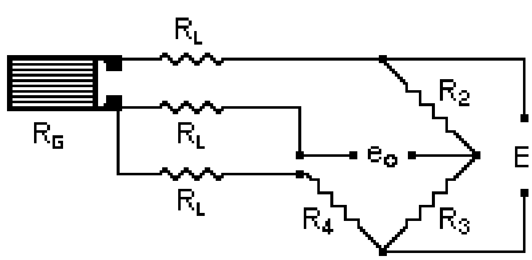

Fig. 516.3 - Three-wire quarter-bridge circuit.

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 decoupling 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.