The Loop Technique for Strain Gage Rosette Signal Conditioning

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Background

The classical approach for signal conditioning individual resistance strain gages is to connect each installed gage with three lead wires to a set of three fixed completion resistors, all arranged electrically in a Wheatstone bridge circuit. An alternative approach for strain gage signal conditioning, sometimes called the Anderson loop, was developed at NASA's Dryden Flight Research Center.[1] This technique offers some significant advantages when used with the strain gage rosettes employed in experimental stress analysis. Invented[2] to eliminate the measurement uncertainties due to random electrical impedance variations in lead wires and connections found in harsh test environments, NASA's loop circuit approach delivers twice the equivalent bridge output level, and simplifies wiring, temperature compensation and data analysis as well. Circuitry

The enabling technology for this technique is the dual-differential subtractor measurement circuit function defined in Fig. 1. As illustrated in eq. 1, a subtractor's output is the difference between two independent floating differential inputs.

$$v_{out} = A_1 v_1 - A_2 v_2 \qquad (1)$$

The subtractor's two differential input voltages, v_1 and v_2, are processed by amplification factors A_1 and A_2, respectively, to yield an output voltage, v_{out}. In a strain rosette application, amplification factors A_1 and A_2 are typically set to unity. Noise voltages rejected by this ideal subtractor arrangement include: all identical noise voltage components at the two inputs, the common-mode voltages, v_{cm1} and v_{cm2} at each differential input, and the interior-mode voltage, v_{im}. Practical subtractors can be designed to operate with sub-microvolt stability and essentially no energy transfer with the strain gage circuitry they observe.

The loop subtractors are typically connected in a Kelvin manner. That is, connected to sense only the voltage drop across each gage while carefully avoiding any voltage drops due to excitation current flowing through lead wires or connectors.

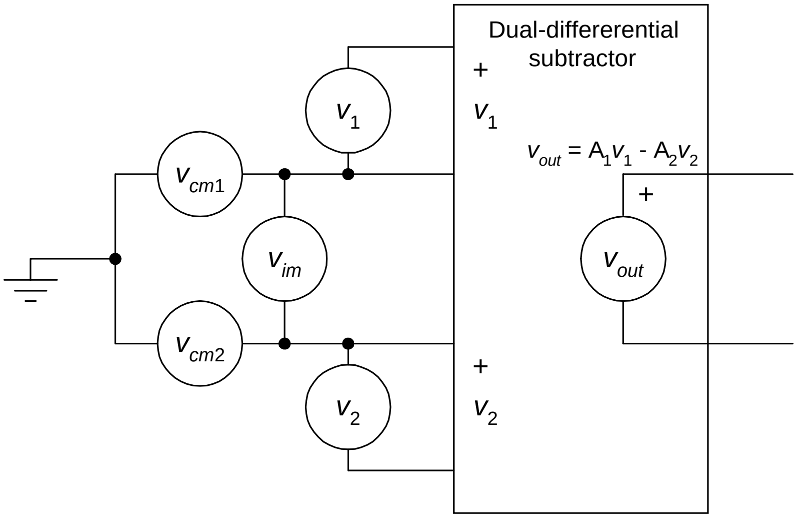

Figure 1, Dual-differential subtractor.

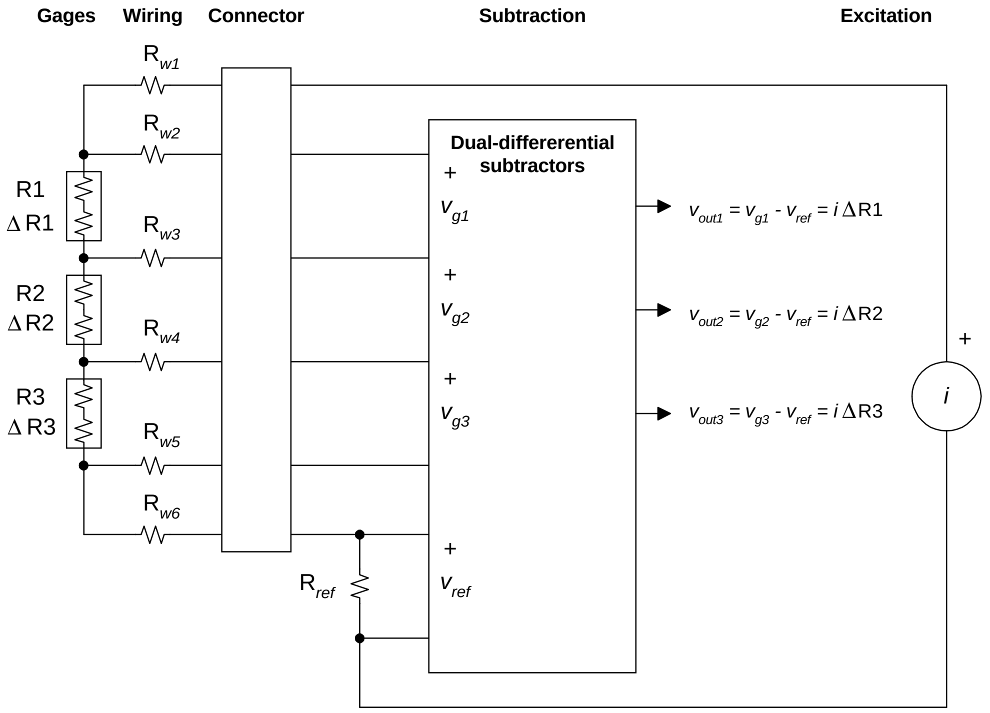

Figure 2, Connection of an uncompensated strain rosette to loop signal conditioning.

This is why the loop circuit can be insensitive to parasitic resistance variations that typically add uncertainty to strain measurements involving bridge circuitry. Corrections for wiring effects are unnecessary because the various subtractor inputs contain no voltage drops caused by the excitation current flowing through wiring or connection resistances.

Voltage dividers are not ordinarily used in the dual-differential subtraction process. When no adjacent resistances exist to absorb signals, the result is an output voltage that, for the same gage and excitation level, is twice what bridge circuitry delivers yet has essentially the same noise floor.[3] Stated another way, loop signal conditioning causes gage factor to seem to double when compared with equivalent bridge signal conditioning outputs.

In the rosette application, Fig. 2, three active strain gages on a test article are connected in a series loop with a precision completion resistor, R_{ref}, installed in the signal conditioner. R_{ref} serves as a common reference resistance for each of the three active gages. An excitation current, *i*, is caused to flow through the circuit and gage voltages are sensed using lead wires $R_{w1\text{-}6}$. For convenience, the excitation is usually a constant DC current. The voltage drop across the reference resistance is often employed as the source of feedback for excitation current regulation.

Practical loop signal conditioners provide for adjustment of the excitation level and for offsets that arise because reference (or compensating gage) resistances are rarely equal to the initial active strain gage resistances.[4] Amplification of the subtractor's output voltage to a high level is usually desirable for data acquisition convenience.

The output voltage from each active gage is simply the excitation current multiplied by the difference between the resistances of the active gage and its reference. When the reference resistance, R_{ref}, is the same as the initial gage resistance, R, the equations contained in figures 2 and 3 define the system output voltages. Note that these simple equations are exact and completely linear.

A total of six lead wires are required from a strain gage rosette to loop signal conditioning. This is one-third less than the number of wires required to connect a strain gage rosette to typical bridge signal conditioning. The seemingly impossible is accomplished—precise and practical measurement of minute electrical resistance variations by using only two wires per resistance. Yet lead wire resistance variations do not influence the observations.

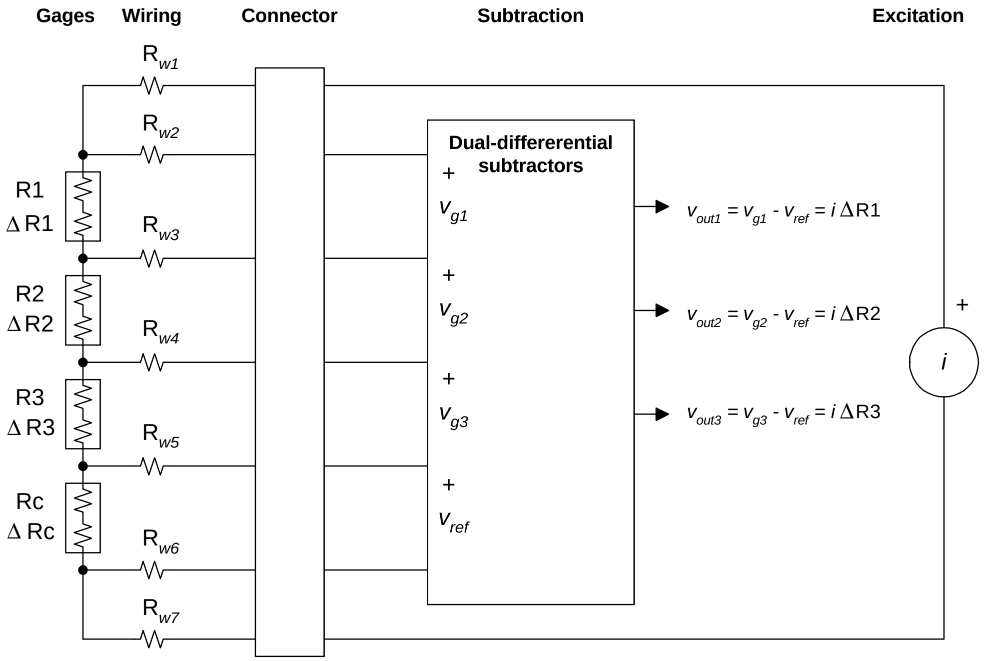

Figure 3, Connection of a compensated strain rosette to loop signal conditioning

A fourth strain gage can be installed in the thermal vicinity of a gage rosette such that it can act as a temperature compensating gage by developing the reference voltage used with all three of the active gages in the rosette (Fig. 3). This application may require only one additional lead wire for a total of seven wires per temperature-compensated rosette measurement.

Ribbon wire is often used to connect from a rosette to its signal conditioner. A standard for loop gage identification and wiring color codes is presently under consideration by the Western Regional Strain Gage Committee of the SEM.

If a design for minimum gage power dissipation is important, the loop configuration can provide the same output voltage as a bridge configuration with only 1/4 the power dissipation per gage. This can be an important consideration when using strain rosettes to test composite structures.

Dual-differential subtractors have also been demonstrated to separately monitor thermoelectric and strain gage voltages while using continuous DC excitation.[5] In this application, thermocouple wire is used as the lead wire from strain gage tabs to the signal conditioning circuitry. The temperature indication is the temperature of the gage tabs.

Limitations

The primary limitation of loop signal conditioning for rosettes is that, should one gage open, the excitation current path for all three gages can open unless appropriate current bypass arrangements have been included. The discussion of this and other electronic circuit design details is beyond the scope of this paper.

Equipment

NASA has constructed and placed in service over 300 channels of loop signal conditioning for strain gages in their structural test facility at Dryden.[3] However, these conditioners are unique to a custom data acquisition system.

A user can choose to construct loop signal conditioning equipment in house from available designs by arrangement with NASA.[2] Educational institutions and government agencies may request an Anderson loop demonstration circuit board from the NASA Dryden Technology Commercialization Office.

Loop signal conditioning is also commercially available.[6] As an example, one style consists of printed circuit cards nominally 3 1/2 by 4 1/4 in. Each card conditions a strain rosette that may include a temperature-compensating gage. An 8 by 16 1/2 in. open backplane holds eight of these cards, provides connecting terminals and supplies the necessary power for the electronics that conditions up to eight rosettes and amplifies their outputs. The voltage outputs from this loop signal conditioning system are observed and recorded in the usual manner.

On request, the author can provide wiring diagrams for connecting various loop signal conditioning equipment to a variety of strain gage applications.

Performance

The performance of the loop signal conditioning technique has been theoretically analyzed and reported with test results in the references. For experimental stress analysis applications, loop circuits can provide advantages to the experimenter that are simply unavailable from bridge circuits.

To summarize the advantages of loop circuits in signal conditioning:

- A strain rosette can be reliably and effectively connected to its signal conditioning with only six lead wires.
- The output voltage is a linear function of each gage resistance change, even for very large measured strains.
- The output is essentially unaffected by random changes in wire and connecting resistance that may even be greater than the gage resistance.
- Twice the output voltage level is available from the loop circuit when compared to an equivalent bridge arrangement, with each gage dissipating the same power.
- To achieve the same output voltage level developed by a bridge circuit, a loop-connected strain gage operates with only 1/4 of the power dissipated by a bridge-connected gage.
- A single gage can be arranged to provide temperature compensation for each of the gages in a rosette while using only one additional lead wire.

References

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5. Anderson, Karl F., Continuous Measurement of Both Thermoelectric and Impedance Based Signals Using Either AC or DC Excitation, *Measurement Science Conference*, January 1997.
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Versions of these and other related references are available through the Internet at:
http://www.vm-usa.com/links.html