A Robust Technique for High-Temperature Strain Measurements

The Push-Push Balanced Constant Current circuit can greatly improve the accuracy of simultaneous static and dynamic strain measurements in extreme environments

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Introduction

It is difficult but often necessary to make strain measurements at high temperatures in harsh, highly variable operating environments. The primary challenge in such applications is separating apparent strain due to thermal expansion of a test article (e.g. gas turbine) from the mechanical strain of interest. Consequently, considerable progress has been made on gage designs that allow for accurate isolation of the strain signal from thermal effects. At temperatures below ~300°C, self-compensating strain gages can be used, which counteract the apparent thermal strain when appropriately matched to the gaged material.

At temperatures above 300°C, an active strain gage must be paired with a compensating gage in an arrangement that ensures equal apparent (thermal) strain for accurate isolation of the target (mechanical) strain. If the paired gages are placed in a conventional Wheatstone half-bridge circuit, the interconnecting cable resistance can cause gage desensitization and zero shift, introducing significant errors to strain measurements. The Wheatstone half bridge is also unbalanced and susceptible to noise pickup, necessitating aggressive low-pass filtering that precludes measurement of dynamic strain. For this reason, Precision Filters introduced Push-Push BCC, a variation on their Balanced Constant Current technology that provides superior performance for high-temperature static and dynamic strain measurements using paired gages.

Wheatstone Bridge Circuits

Consider the Wheatstone half bridge depicted in Figure 1. Two strain gages – the active gage R1 and the compensating gage R2 – are affixed to the test article. The remaining two completion resistors, R3 and R4, are inside the signal conditioner. A shielded cable (typically 10s of feet) connects the signal conditioner to high-temperature extension lead wire at the test article. The extension wire typically has high, temperature-dependent resistance and is unshielded from electrostatic noise.

In a standard 3-wire connection, the need for high-temperature extension wires can compromise strain measurement accuracy. High initial resistance and thermally-induced resistance change on the excitation wires (REXT) can cause the sensitivity of the strain gage – defined as the incremental change in voltage output per unit of strain – to change. Gage desensitization caused by extension wire resistance is plotted in Figure 2 and represents a gain error. In addition, if the resistance on the excitation wires is not equivalent, the zero point of the gage will shift: the gage will not report zero output voltage in the unstrained state. For example, a 3.5 Ω mismatch in resistance between the (+) Excitation and (–) Excitation wires will cause a zero-shift error of 2500 microstrain (με) for a 350 Ω gage with a gage factor of 2 (Figure 2).

The unshielded extension wires are also susceptible to noise pickup, which can be severe for a test involving

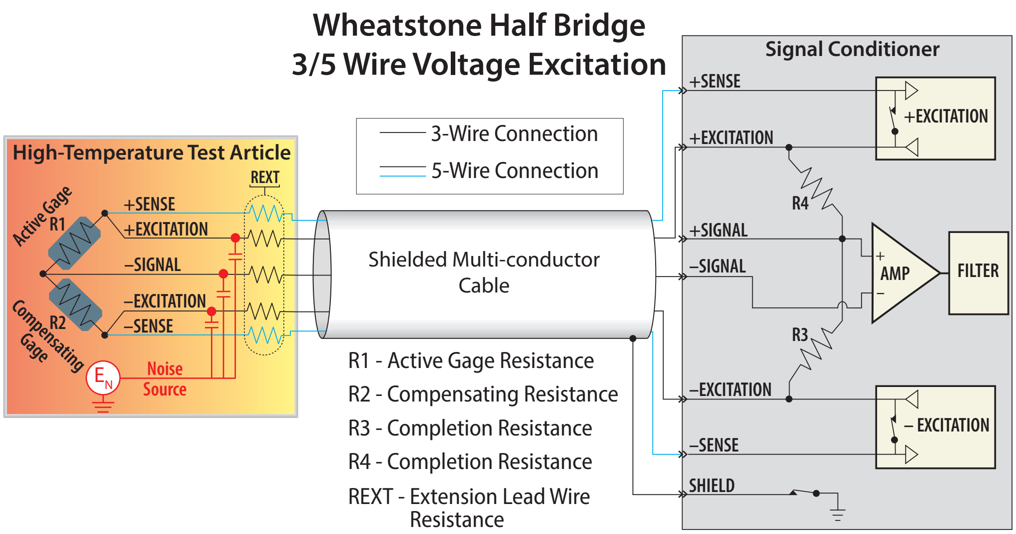

Figure 1. *Circuit diagram depicting 3- and 5-wire Wheatstone half-bridge circuits for measuring strain. The half bridge consists of an active strain gage (R1) and a temperature-compensating gage (R2). The completion resistors (R3 and R4) reside in the remote signal conditioner, which also provides excitation, differential amplification, and filtering. In the 5-wire circuit, remote sense lines are added to monitor the excitation voltage to the bridge. Note that the extension lead wires are unshielded at the test article.*

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rotating or vibrating machinery. In the 3-wire Wheatstone half bridge, only one of the signal inputs to the differential amplifier is exposed, rendering the circuit unbalanced (Figure 1). Hence any noise on the (–) Signal lead will not be removed by the common mode rejection of the amplifier and will require low-pass filtering with a cutoff frequency that limits the measurement to DC (static) strain.

Gage desensitization and zero-shift errors can be effectively removed if remote sense connections are added to produce a 5-wire half-bridge measurement circuit. Remote sensing of the voltage drop between the excitation source and the bridge allows for correction of these errors by the signal conditioner. Notice, however, that the 5-wire Wheatstone half bridge is still unbalanced with respect to noise pickup.

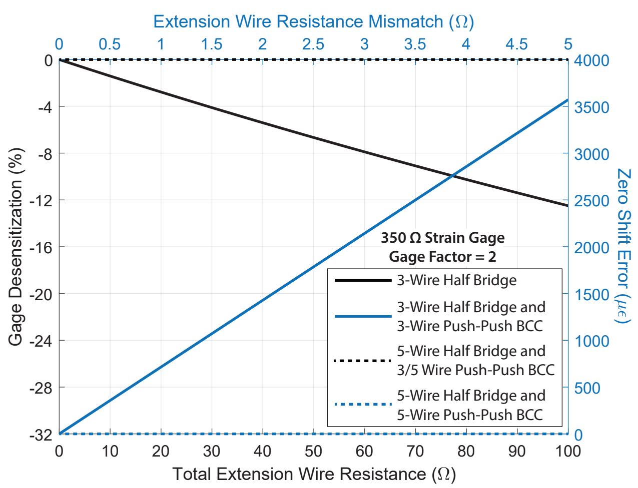

Figure 2. Strain gage desensitization and zero-shift errors

Push-Push BCC

Precision Filters' Push-Push BCC offers an alternative measurement circuit for the half-bridge configuration (Figure 3). In this arrangement, a balanced source of constant current is "pushed" through both the active and compensating gage on the test article. This constant current interacts with each gage's resistance to generate voltages across the bridge arms, the difference of which is measured by the differential amplifier.

Measurement Circuit		Performance Comparison		
Type	Excitation	Desensitization (Gain Error)	Zero-shift Error	Noise Susceptibility
3-Wire Half Bridge	Voltage	Significant	Minimal*	Significant
5-Wire Half Bridge	Voltage	None	None	Significant
3-Wire Push-Push BCC	Current	None	Minimal*	None
5-Wire Push-Push BCC	Current	None	None	None
*Significant for mismatched extension wire resistance on excitation lines				

Table 1. Half-bridge circuit comparison for strain measurements

Lead resistance has no effect on the gage sensitivity in a Push-Push BCC circuit. Because the current source is balanced, the same current flows through each gage regardless of the resistance on the excitation wires. If a 3-wire circuit is employed, in which the excitation and signal lines are connected, then zero-shift errors due to a mismatch in excitation wire resistance will still occur. These errors can be eliminated by using a 5-wire circuit or ensuring the excitation wire resistances are matched (Figure 2).

An important advantage of the Push-Push BCC circuit is noise immunity. Since both the (+) and (–) Signal wires are exposed through the test article, noise pickup should be equal on both lines so long as they are proximal. This ensures common-mode rejection of the noise by the differential amplifier. For this reason, Push-Push BCC can be used to effectively measure both static and dynamic strain from a single gage.

A performance comparison of the measurement circuits described here is given in Table 1. The recommended method for high-temperature strain measurements with a compensating gage in a half-bridge configuration is the 3-wire (with matched excitation wires) or 5-wire Push-Push BCC circuit.

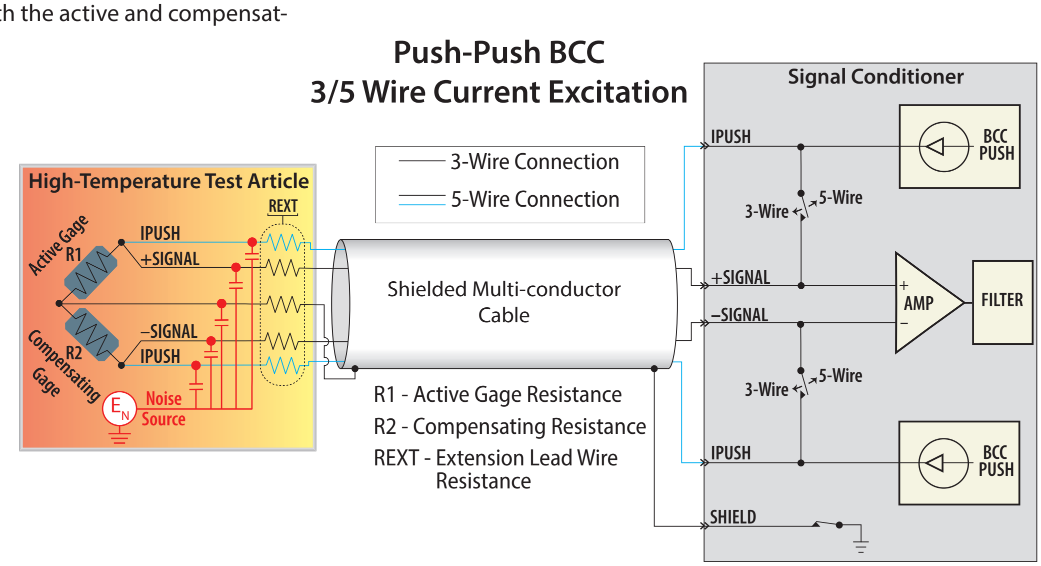

Figure 3. Circuit diagram depicting 3- and 5-wire Push-Push BCC circuits for measuring strain. The half bridge consists of an active strain gage (R1) and a temperature-compensating gage (R2). Excitation current is "pushed" through each gage from a balanced source at the signal conditioner, which also provides differential amplification and filtering. In the 5-wire circuit, bridge output is measured directly at the gages, negating the effects of lead-wire resistance. Note that the extension lead wires are unshielded at the test article.

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