LEMI-70 Comprehensive Resistive Strain Gauge-Based Force Sensor Apparatus

1. Theory

1) Resistive Strain Gauge

Resistive strain gauges come in various forms, with wire-type and foil-type being the most common. A typical strain gauge consists of constantan or ni-chrome wire (with a diameter of 0.02–0.05 mm) wound or etched into a grid pattern, embedded between two insulating backing layers. Tinned copper leads are soldered to the grid to serve as electrical terminals for connection to measuring instruments.

The working principle is based on the fact that the resistance of a metal wire depends not only on the material properties but also on its length and cross-sectional area. When the wire is bonded to a mechanical component and that component deforms under load, the wire experiences the same strain, resulting in a change in resistance. This relationship can be expressed as $\frac{dR}{R} = K_s \varepsilon$, where *Ks* is the gauge factor (sensitivity coefficient) of the strain gauge material, indicating the relative change in resistance per unit strain and ε is the strain at the measurement point (dimensionless, often expressed in micro-strain $\mu\varepsilon$).

2) Strain Gauge-Based Tension/Compression Sensor

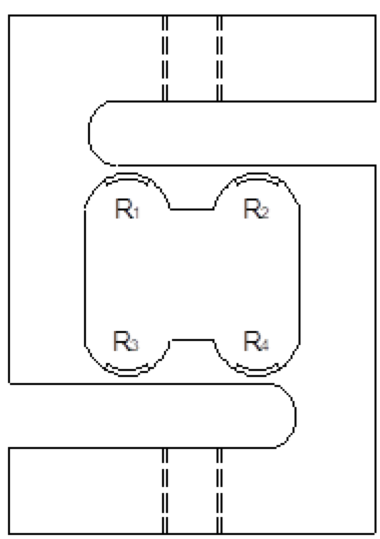

Figure 2: Schematic of S-type weighting sensor with strain gauges

Figure 2 shows a typical S-type weighting sensor with strain gauges. The sensor is shaped like the letter “S”, with mounting holes on both upper and lower arms and a central cut-out design. The four arc-shaped regions, which experience the greatest deformation under stress, each have a strain gauge bonded to them.

When the sensor is subjected to compressive force, the resistance of R_1 and R_4 increases, while R2 and R3 decreases. Under tensile force, R_1 and R_4 decrease, while R_2 and R_3 increase.

In applications such as electronic scales, If the lower arm is fixed, it can measure the weight of objects placed on the upper arm. If the upper arm is fixed, it can measure the weight of suspended objects.

3) Unbalanced Wheatstone Bridge

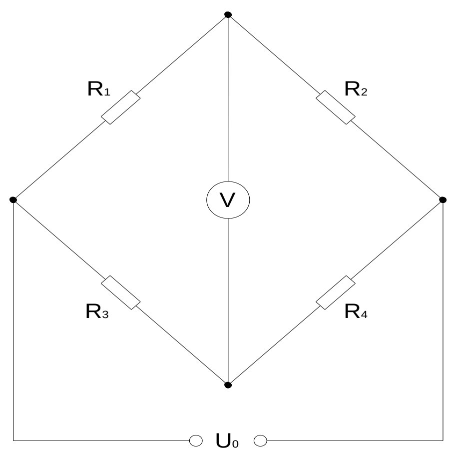

Figure 3: Schematic of unbalanced bridge circuit

Compared to balanced bridges, unbalanced Wheatstone bridges are more widely used in engineering. In such a circuit, one or more arms may include sensing elements whose resistance changes in response to a physical parameter. This configuration allows real-time and continuous monitoring of that parameter.

The bridge configurations include equal-arm, horizontal, vertical, and proportional bridges. Weighting sensors typically resemble equal-arm bridges, where all four resistances are nearly equal. Depending on how many strain gauges are included in the bridge, three classifications apply: (1) Quarter-bridge: One active strain gauge, three fixed resistors, (2) Half-bridge: Two strain gauges, two fixed resistors, and (3) Full-bridge: Four active strain gauges.

Assuming the resistance change ΔR is much smaller than R, the bridge output voltage $\boldsymbol{U}$ is approximately: $U \approx (U_0 / 4R) \times \Delta R$ for quarter-bridge, $U \approx (U_0 / 2R) \times \Delta R$ for half-bridge and $U \approx (U_0 / R) \times \Delta R$ for full-bridge.

Thus, sensitivity increases with the number of strain gauges used. Full-bridge circuits offer the highest sensitivity, followed by half-bridge, with quarter-bridge being the lowest. In practice, full- and half-bridge configurations are most common.

4) Sensitivity of Weighting Sensor

The sensitivity k of a strain gauge-based weighting sensor depends on several factors, including: the gauge factor ($\boldsymbol{Ks}$), local strain ($\boldsymbol{\varepsilon}$), bridge excitation voltage (U_0) and the bridge configuration (quarter, half, or full).

Since the output corresponds to the mass being measured, sensitivity is defined as the rate of change of output voltage per unit mass and unit excitation voltage:

$$k = (\Delta U / \Delta m) \times (1 / U_0). \tag{1}$$

The unit of sensitivity is typically expressed as *mV/V/kg*.

5) Differential Amplifier

A differential amplifier is a circuit that amplifies the difference between two input signals (U_1 and U_2) while rejecting any common-mode signals. This makes it widely useful in electronic systems. Figure 4 shows a classic operational amplifier-based differential amplifier.

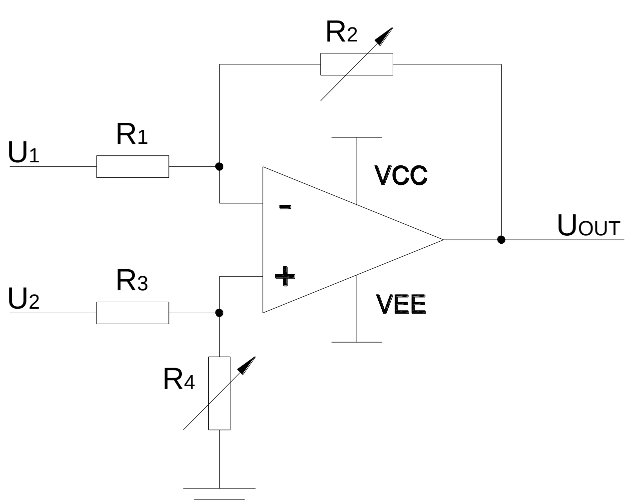

Figure 4: Schematic of four-resistor differential amplifier

The transfer function is:

$$U_{OUT} = \left(\frac{R_4}{R_3 + R_4}\right)\left(\frac{R_1 + R_2}{R_1}\right)U_2 - \frac{R_2}{R_1}U_1 . \tag{2}$$

If $R_1 = R_3$ and $R_2 = R_4$, the expression simplifies to:

$$U_{OUT} = \frac{R_2}{R_1}\left(U_2 - U_1\right). \tag{3}$$

Hence, using equal values for R_1 and R_3, and adjusting R_2 and R_4 simultaneously allows control over the amplifier gain.

6) Electronic Scale Design

Using the weighting sensor as the core component, its output signal can be zeroed and amplified through the differential amplifier to generate a voltage proportional to the object's mass. By calibrating this voltage output to a mass unit (g or kg), the system functions as an electronic scale. Figure 5 is the schematic of an electronic scale circuit.

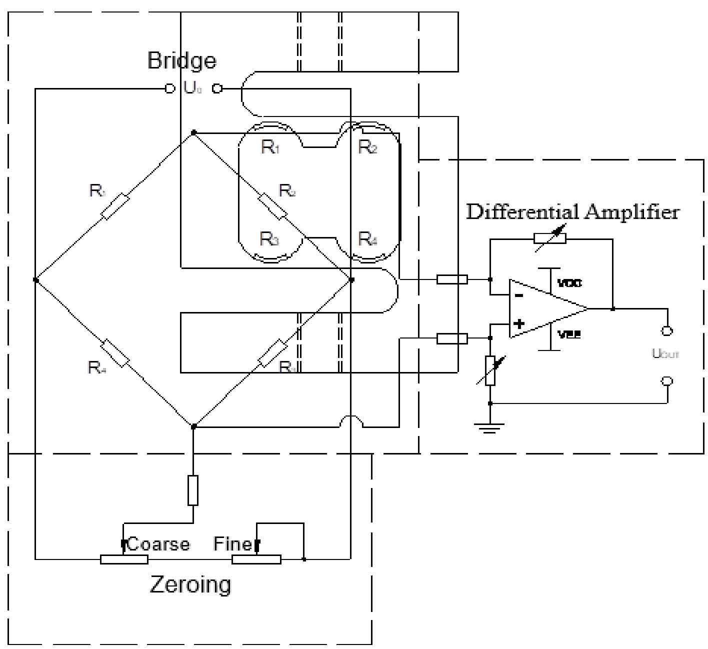

Figure 5: Schematic of an electronic scale circuit

This simplified schematic includes: weighting sensor in full-bridge configuration, zeroing circuit, differential amplifier and digital voltage display for output (UOUT).