2. Resistive Strain Gauge

Resistive potentiometers were described in the previous section, and they measure involved displacement that was being measured by potentiometry but without altering the properties of the used resistance used. However, in contrast, resistive strain gauges measure displacement with changes to a resistance that results from the transducer element being strained by a displacement (National Instruments, 1998). A fractional change in length defines the strain (Figure 3; Equation 5), as shown in Figure 3.

Figure 3. Definition of strain as a fractional change in length (Adapted from National Instruments, 1998).

\[ \varepsilon = \frac{\Delta L}{L} \]  

(5)

There are various designs of resistive strain gauge designs (National Instruments, 1998). A piezoresistive strain gauge is a semiconductor device where the resistance varies nonlinearly.
with strain is called a piezoresistive strain gauge. The most commonly used design of a resistive strain gauge is the bonded metallic strain gauge, that consists of fine wire or metallic foil arranged in a grid pattern. This design maximizes the amount of metal subjected to parallel strain. The grid is bonded onto a thin “carrier” backing, and this carrier is attached to the subject being measured. So, any strain experienced by the test subject is transferred to the strain gauge, producing a response of a linear change in electrical resistance.

Gauge factor (GF) is a parameter which expresses a strain gauge’s sensitivity to strain. It is the ratio of fractional change in electrical resistance to the fractional change in length (strain):

\[ GF = \frac{\Delta R / R}{\Delta L / L} = \frac{\Delta R / R}{\varepsilon} \]  

For metallic strain gauges, GF mostly has a value of \(~2\) values are typically around 2. Because most strain measurements involve very small quantities of strain, and the GF is approximately two, tiny changes in electrical resistance are generally small. To measure these small resistance changes, you should use strain gauges in a bridge configuration with a voltage or current excitation source. Strain gauges are used in a bridge configuration with a voltage or current excitation source.
to measure these small resistance changes. A Wheatstone bridge (Figure 4) consists of four resistive arms plus an excitation voltage ($V_{ex}$) applied across the bridge.

![Wheatstone bridge](image)

Figure 4. Wheatstone bridge (Adapted from National Instruments, 1998).

**Output** The output voltage of the bridge, $V_o$, can be calculated using Equation 7:

$$V_o = \frac{R_2}{R_3 + R_4} - \frac{R_2}{R_1 + R_2} \cdot V_{ex}$$

**Drawbacks to strain** Strain gauges suffer from several drawbacks, including the facts that great precision is required during the manufacturing process, and that moisture effects can reduce long-term reliability of measurements due to moisture effects unless the strain gauge is hermetically sealed (Measurements Group, 2001).

Strain gauges have a number of benefits (Measurements Group, 2001). They are typically, including their typically small size and have a low mass. They are also durable and...
shock-resistant due to have a bonded construction and a lack of moving parts, and this makes them durable and shock-resistant. Linearity is excellent for over a large range of strains, and their measurements are stable over time. Strain gauges are also reasonably cheap.

Omega Engineering, Inc. (Stamford, CT) offers many models of strain gauges which have measurement ranges appropriate for human kinematic studies. These gauges are cheap and long-lasting, with a fatigue limit exceeding 10,000,000 ten million cycles (Omega Engineering Inc., 2007). Their SGD series of gauges have a gauge factor $GF$ of $2.0 \pm 5\%$.

Applications that strain gauges have been used to measure include human movements, such as shoulder tension (Hughes et al., 1999) and ankle strain (Vandervoort et al., 1992) include the human movement applications that strain gauges have been used for.

### Inductive displacement transducer

This inductive type of displacement transducer employs methods using the inductance variation of inductance of single coils or the mutual inductance of two coils (Cobbold, 1974). The first type of methods is based on inductance change in one coil either through a change in the geometry of the coil or in the properties of magnetic path properties. The second type of systems, which involves two or more coils, uses a change in mutual coupling which results from relative coil displacement or from the movement of a coupling core movement.

Among the various types of inductive displacement transducers, the linear variable differential transformer (LVDT) is one of the most popular inductive displacement.
transducer types (Cobbold, 1974). One reason that for the LVDT’s is popularity is its large output for small movements. The LVDT is made up of consists of 3 coils: one primary coil and two identical secondary coils that are the same. It has a shifting core that can alter the coupling between the 3 coils, producing the output displacement signal (Figure 5).

![Magnetic shield diagram](image.png)

Figure 5. Construction of a linear variable differential transformer (LVDT). Displacement is measured by the movable core’s interaction with the 3 coils makes a measure of the displacement. (Adapted from Cobbold, 1974.)

In general, voltages in the 1–10 V range are generally used, and commercial LVDTs have sensitivities of approximately 0.5–2.0 mV per 0.001 cm displacement per volt of excitation. The RDP Group (Pottstown, PA) makes their ACT LVDT Displacement Transducer, produced by the RDP Group (Pottstown, PA), featuring a measurement range up to ±470 mm, excellent accuracy, sensitivity of 700 mV/V, and infinite resolution. Their ACT8000C model, which has a range of ±200 mm and costs $635 (Socié, 2007). LVDTs are many times often used for

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physiological measurements of displacement, force, and pressure measurements (Cobbold, 1974).

4. Capacitive displacement transducer

Capacitive displacement transducers function by the fact on the principle that a change in capacitance is proportional to the change in displacement of the object that is being measured (Norton, 1989). Displacement can be converted to an electrical output using the capacitor plate separation distance, the plate area dependence, of capacitance on plate area and the permittivity of the medium between the capacitor plates (Cobbold, 1974). While it is an issue that all capacitive transducers face the problem of capacitance that displacement makes relatively small changes in capacitance, by the use of particular specialized circuit techniques allows these transducers to have results in great excellent accuracies and sensitivities $\leq 10^{-12}$ cm or better (Sydenham, 1972).

If we ignore the effects of electrical field fringing at the plate edges are ignored, capacitance is given by Equation 8:

$$C = \frac{\varepsilon A}{d} \quad \text{(in Farads)}$$  \(8\)

where A is the plate area (in cm$^2$), d is the plate separation (in cm), and $\varepsilon$ (in F/cm) is the medium-permittivity of the medium separating the plates.
A basic capacitive displacement transducer is shown in Figure 6, where C represents a capacitive plate, and x is the distance between plates.

Figure 6. Basic design of a capacitive displacement transducer. (Adapted from Cobbold, 1974.)

The direct current (DC) polarizing circuit is shown in Figure 7 and it is one of the simplest circuits that is able to respond proportionally to the displacement of such a parallel-plate capacitor transducers (Figure 7).
Figure 7. DC-polarized capacitive displacement transducer. \( V_s \) is the voltage source, \( C \) represents a capacitor plate, \( R \) is resistance, \( v \) is the voltage across the resistance, \( A \) is the amplifier gain, and \( V_o \) is the output voltage. (Adapted from Cobbold 1974.)

For this system, the output voltage \( v \) is given by Equation 9:

\[
v = \frac{V C_0 R}{d} \left( \frac{j \omega}{1 + j \omega C_0 R} \right) x_0 e^{j \omega t}
\]  

(9)

where \( d \) is the plate separation distance, \( x_0 \) is the sinusoidal plate displacement amplitude, \( C_0 = (\varepsilon A)/d \), and \( V \) is the DC-polarization voltage. If \( \omega C_0 R \gg 1 \), Equation 9 becomes:

\[
v = \frac{V x_0 \sin \omega t}{d}
\]  

(10)
By inspection of Equations 9 and Equation 10, we see that at higher frequencies the system’s response is proportional to the inverse displacement at higher frequencies.

However, for the response is reduced at lower frequencies. Lower frequencies the response is reduced, and becomes zero when \( \omega = 0 \). This system’s lack of DC response is a concerning when measuring many physiological quantities.

To solve this problem can be solved by using, we should use the transducer as the feedback component of a high-gain operational amplifier, since the transducer transforms the problematic inverse displacement vs. capacitance relation now to become a simpler linear output voltage vs. displacement relation that we can work with. The circuit diagram of this such a different system is shown in Figure 8.

Figure 8. System diagram of a linear displacement measurement system using capacitive sensing. (Adapted from Cobbold, 1974.)

As an example, one such linear displacement measurement system, the Sensagap capacitive displacement sensor from the RDP Group can be acquired and used for kinematic measurements in...
over a variety of measurement ranges that are able to be used for kinematic measurements. It features a linearity of ±0.5% of full-scale or better and can withstand shocks up to 20 g (RDP Group: Sensagap Capacitive Displacement Transducer, 2007).

References:


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