2. Resistive ~~Strain~~ strain ~~Gauge~~ gauge

Resistive potentiometers were described in the previous section~~,~~. ~~and they~~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 result~~resulting from the transducer element being strained by ~~a~~ the displacement (National Instruments, 1998). A fractional change in length defines the strain (Figure 3; Equation 5)~~, as shown in Figure 3~~.

Commented [CP1]: In the remainder of the text, the headings are in "sentence case," which is where only the first word and proper nouns are capitalized. I changed this heading to ensure a consistent style.

Commented [CP2]: Paragraph indentation was added here for consistency with the rest of the document.

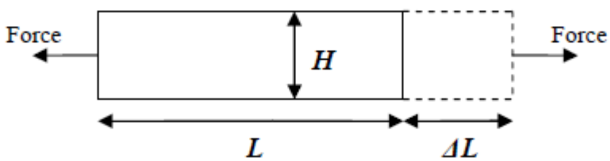

Figure 3. Definition of ~~S~~strain ~~is~~ as a fractional change in length (Adapted from National Instruments, 1998).

$$\varepsilon = \frac{\Delta L}{L} \qquad (5)$$

There are various ~~designs of~~ resistive strain gauge designs~~s~~ (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~~ ~~for a~~ resistive strain gauge is the bonded metallic strain gauge, ~~that~~ which consists of fine wire or metallic foil arranged in a grid pattern~~, t~~. This design maximizes the amount of metal subjected to parallel strain. Th~~e~~~~is~~ grid is bonded onto a thin "carrier" backing, and ~~this~~ the carrier is attached to the ~~subject being measured~~measured subject. ~~So~~Therefore, any strain experienced by the test subject is transferred to the strain gauge, ~~this~~ produc~~ing~~~~es~~ a ~~response of a linear change in electrical resistance~~linear change in electrical resistance response.

Gauge factor (GF) is a parameter ~~which~~ that ~~expresses~~ defines a strain gauge's sensitivity to strain. It ~~means~~ is expressed as the ratio of fractional change in electrical resistance to the fractional change in length (strain):

$$GF = \frac{\Delta R / R}{\Delta L / L} = \frac{\Delta R / R}{\varepsilon} \qquad (6)$$

For metallic strain gauges, GF ~~mostly has a value of ~ 2~~values are ~~typically around~~approximately two.

~~Because~~ As most strain measurements involve very small ~~quantities of~~ strains~~,~~ and ~~the~~ GF is approximately two~~~2~~, ~~tiny small~~ changes in electrical resistance are generally small ~~usually result~~ (National Instruments, 1998). ~~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

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to measure the~~se~~ small resistance changes. A Wheatstone bridge (Figure 4) ~~is composed~~consists of ~~4~~ four resistive arms ~~plus~~ with an excitation voltage (V_{ex}~~ex~~) applied across the bridge.

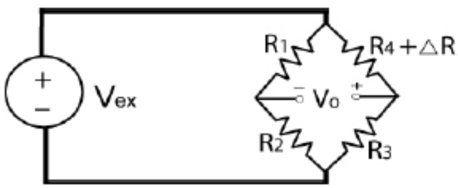

Figure 4. Wheatstone bridge (Adapted from National Instruments, 1998).

~~Output~~ The output voltage of the bridge, V_o, can be ~~calcluated~~ calculated ~~in~~ using Equation 7:

$$V_o = \left[\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2} \right] \cdot V_{ex} \qquad (7)$$

~~Drawbacks to strain~~ Strain gauges suffer from several drawbacks, ~~include~~ including the ~~facts that great~~ precision ~~is~~ required during the manufacturing process~~,~~ and th~~at moisture effects can~~ e ~~reduce~~ reduction in ~~the long~~ 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~~several benefits (Measurements Group, 2001), ~~. They are typically~~ including their typically small size and ~~have a~~ low mass. They are also durable and

Commented [CP4]: I would suggest moving the drawbacks after the benefits to place more emphasis on the benefits of strain gauges.

Commented [CP5]: I combined these two paragraphs because they share a common focus (**highlighting the characteristics of strain gauges**). Paragraphs only need to be divided when you are describing different subjects.

Additionally, having the drawbacks and benefits in the same paragraph allows the reader to observe the contrasting features more directly. Ideas within a given paragraph are assumed to be connected, so your audience will already be in the mindset to connect these ideas.

shock-resistant due to ~~have a~~their bonded construction and ~~a~~ lack of ~~of~~ moving parts~~, and this makinges them durable and shock-resistant~~. Linearity is ~~great~~ excellent ~~for~~ over a ~~large~~ wide range of strains, and their measurements are stable over time. Strain gauges are also ~~fairly~~ reasonably ~~cheap~~inexpensive.

Omega Engineering, Inc. (Stamford, CT) offers many models of strain gauges ~~which~~ that have measurement ranges appropriate for human kinematic studies. These gauges are ~~cheap~~ inexpensive and long-lasting, with a fatigue limit exceeding ~~10000000~~ ten million cycles (Omega Engineering Inc., 2007). Their SGD series of gauges ~~has~~ have a ~~gauge factor~~GF of 2.0 ± 5%.

~~Applications that s~~Strain gauges have been used to measure ~~include~~ human movements~~s~~, such as ~~S~~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~~.

3. Inductive displacement transducer

~~This~~ Inductive ~~type of~~ displacement transducers ~~type employs methods using~~uses~~es methods using~~ the inductance variation of ~~inductance of~~ single coils or the mutual inductance of two coils (Cobbold, 1974). The first ~~type of~~ method~~s~~ ~~are~~ is based on inductance change in one coil ~~either~~ through ~~a~~ changes in ~~the~~ its geometry ~~of the coil~~ or ~~in the properties of~~ magnetic path properties. The second ~~type of~~ system~~s~~, which involves ~~2~~ two or more coils, uses a change in mutual coupling ~~which~~ resultings from relative coil displacement or ~~from the movement of a~~ coupling core movement.

~~Among the various types of inductive displacement transducers, t~~The linear variable differential transformer (LVDT) is ~~one of~~among the most popular inductive displacement

Commented [CP6]: Once an acronym has been introduced into the text using its expanded form, only the acronym form is needed.

Commented [CP7]: The indentation was removed here for consistency with the preceding section.

Commented [CP8]: This should not be capitalized because it is not a proper name.

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~~ three coils, ~~this~~ producing ~~es~~ the output displacement signal (Figure 5).

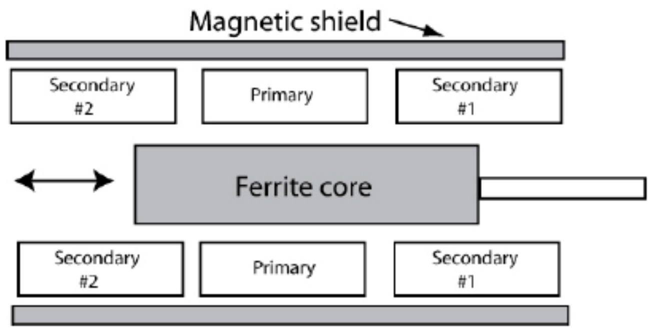

Figure 5. Construction of a linear variable differential transformer ~~(LVDT)~~. Displacement is measured by the ~~It's~~ movable core's interaction with the ~~3~~ three coils ~~makes a measures of the displacement~~. (Adapted from Cobbold, 1974.)

~~In general, v~~Voltages in the 1–10 V range are generally used, and commercial LVDT~~'~~s 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 ~~, this~~ RDP Group (Pottstown, PA), featur~~ing~~es~~es~~ a measurement range up to ±470 mm, ~~great~~excellent accuracy, ~~sensitivity of~~ 700 mV/V sensitivity, and infinite resolution (RDP Group: Menu of Displacement Transducers, 2007). Their ACT8000C model~~,~~ ~~which~~ has a range of ±200 mm and ~~,~~ costs $635 (Socie, 2007). LVDTs are ~~many times~~often used ~~in~~ for

Commented [CP9]: Please check these edits to confirm that your intended meaning has not been altered. From the original sentence, it was unclear if only the secondary coils were the same or if all three of them were the same.

Commented [CP10]: I deleted "LVDT" here. It is unnecessary to include the acronym in the figure legend unless you are going to use it again in the legend.

Commented [CP11]: Does "ACT" have an expanded form, or is this the product's name? If it has an expanded form, it would be useful to include that here.

Commented [CP12]: Note that this reference does not appear in the reference list.

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

4. Capacitive displacement transducer

Capacitive displacement transducers function by the facton the principle that a change in capacitance is proportional to the change in displacement of the object that is being measured (Norton, 1989). Displacement is able tocan 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 problemhave the disadvantage that displacement makes causes relatively small changes in capacitance, by the use of particularusing specialized circuit techniques allows these transducers can to haveresults in great excellent accuracies and sensitivities $\leq$of $10^{-12}$$^{-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:

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

where A is the plate area (in cm^{2}^{2}), d is the plate separation (in cm), and ε (in F/cm) is the mediums permittivity of the medium separating the plates.

A basic capacitive displacement transducer is shown in Figure 6, where C represents a capacitor~~ive~~ plate, and x is the distance between plates~~:~~.

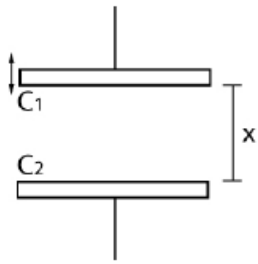

Figure 6. Basic design of a ~~capacitative~~capacitive displacement transducer. (Adapted from Cobbold, 1974.)

The direct current (DC) polarizing circuit ~~is shown in Figure 7 and it~~ is one of the simplest circuits that ~~is able to~~can respond proportionally to the displacement of such ~~a~~ parallel-plate capacitor transducers (~~:~~Figure 7).

Commented [CP13]: This abbreviation should be defined and also capitalized.

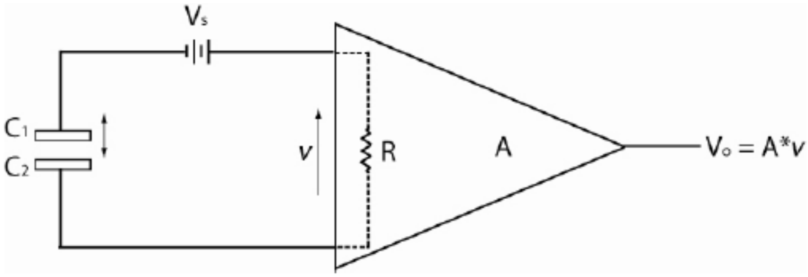

Figure 7. DC-polarized ~~capacitative~~capacitive displacement transducer. V_s is the voltage source, C represents a capacitor plate, R is resistance, *v* is the voltage across the resistance, A is the ~~ampilfier~~amplifier gain, and V_o is the output voltage. (Adapted from Cobbold 1974.)

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

Commented [CP14]: Note that Fig. 7 lists Vo as the output voltage.

$$v = \frac{VC_0R}{d}\left(\frac{j\omega}{1 + j\omega C_0 R}\right)x_0 e^{j\omega t} \qquad (9)$$

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

Commented [CP15]: Note that j, omega, t, and R in Eq. 9 have not been defined here.

$$v = \frac{V x_0 \sin \omega t}{d} \qquad (10)$$

~~By i~~Inspection of Equations 9 and ~~Equation~~ 10~~, we see that at~~ indicates that ~~higher frequencie~~ the ~~s the~~ system's response is proportional to the inverse displacement at higher frequencies~~s~~.~~,~~ ~~h~~However~~-~~, ~~for~~ the response is reduced at lower frequencies~~lower frequencies the response is reduced,~~ and becomes ~~0~~ zero ~~if~~ when ω = 0. This system's~~e~~ lack of DC response ~~of this system~~ is a concern~~ing~~ when measuring many physiological quantities.

~~To solve t~~This problem can be solved by using ~~,~~ a ~~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 ~~becomes~~ 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~~:~~.

Commented [CP16]: Please confirm that 'proportional to the inverse displacement' matches your intended meaning.

Commented [CP17]: I combined these paragraphs because they share related content (addressing the DC response issue).

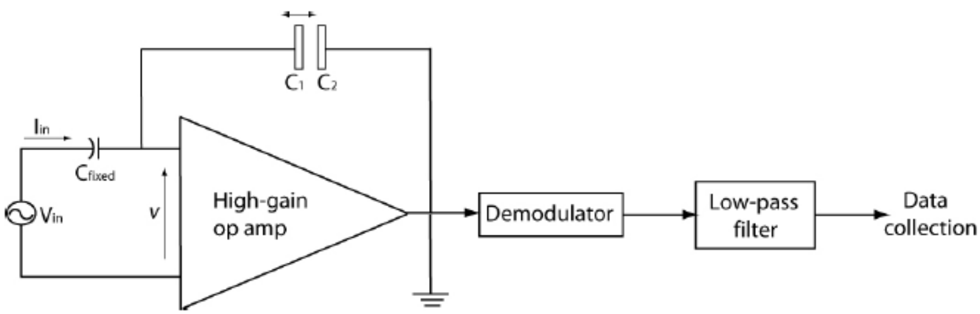

Figure 8. ~~System diagram~~ Diagram of a linear displacement measurement system using ~~capacitative~~capacitive sensing. (Adapted from Cobbold, 1974.)

~~As an example~~One such linear displacement measurement system, the Sensagap capacitive displacement sensor, ~~from the RDP Group~~ can be ~~acquired~~ 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:

Commented [CP18]: As a referencing style was not specified, I edited the reference list for consistency only.

Cobbold RSC. *Transducers for Biomedical Measurements: Principles and Applications*. New York: John Wiley & Sons. 1974.

Hughes CJ, Hurd K, Jones A, Sprigle S. Resistance Properties of Thera-Band Tubing during Shoulder Abduction Exercise. *J Orthop Sports Phys Ther*, Jul 29(7): 413~~—~~–20, 1999.

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RDP Group, Sensagap Capacitive Displacement Transducer. 2007.

http://www.rdpe.com/us/sg.htm

Vandervoort AA, Chesworth BM, Cunningham DA, Rechnitzer PA, Paterson DH, Koval JJ~~,~~. An Outcome Measure to Quantify Passive Stiffness of the ~~a~~Ankle. *Can J Public Health*~~.~~, Jul~~-~~–Aug~~,~~ 83, Suppl 2: S19~~—~~–23, 1992.