Lesson 13: Process Control Sensors and Transducers

ET 438B Sequential Control and Data Acquisition
Department of Technology

Learning Objectives

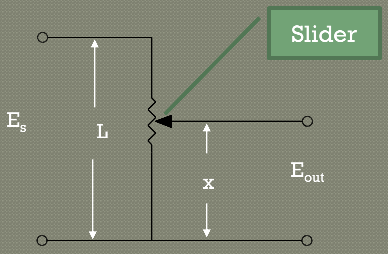
After this presentation you will be able to:

- Identify and apply transducers commonly found in process control applications
- Select a position transducer for both linear and circular applications
- Compute the response of accelerometers
- Use strain gauges to measure force and pressure
- Utilize temperature transducers such as, Resistance Temperature Detectors, Thermisters, and Thermocouples

Position Sensors

Angular and Linear Position Sensors

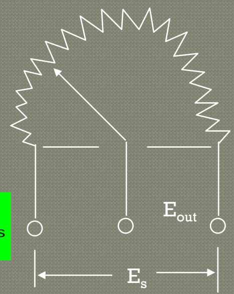
Simple linear displacement transducers: Slide Potentiometer



$$E_{out} = \frac{X}{L} E_s$$

Simple angular transducers: Rotary Potentiometers, multi-turn or single, Wire-wound or carbon composite

$$E_{out} = \frac{\theta}{\theta_L} E_s$$

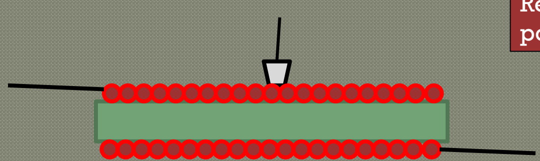


Potentiometer Resolution

Wire-wound potentiometers do not have infinite resolution due to wire diameter

Resistance varies with position

Cross section



Number of turns per unit length determines resolution of the potentiometer

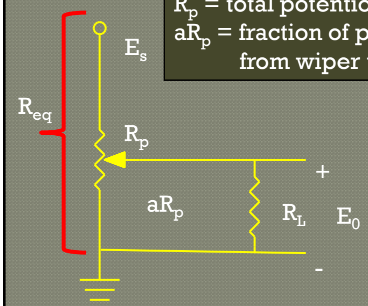
Resolution (%) = 100/N

Where

N = number of turns in the pot.

Potentiometer Loading Error

R_p = total potentiometer R
aR_p = fraction of potentiometer R from wiper to ground



R_L is load on potentiometer. Must include in calculation

$$R_L \parallel a \cdot R_p$$

$$R_{eq} = (1-a) \cdot R_p + R_L \parallel a \cdot R_p$$

Solve using voltage division

$$E_0 = \left(\frac{a}{1 - a \cdot r - a^2 \cdot r}\right) \cdot E_s$$

$$r = \frac{R_p}{R_L}$$

Loading error LE defined as = $aE_s - E_{out}$

$$\%LE = \left(\frac{a^2 \cdot r \cdot (1-a)}{1 + a \cdot r \cdot (1-a)}\right) \cdot 100$$

$$r = \frac{R_p}{R_L}$$

Percent Loading Error

Potentiometer Loading Example

Problem Statement

A linear wire-wound potentiometer has a total resistance of 50,000 ohms The voltage output of the potentiometer will be converted to a digital value by a 12 bit ADC. Determine minimum number of turns required so that the resolution of the potentiometer does not exceed the quantization error of the ADC.

What percent loading error can be expected if the input resistance of the ADC is 100 kΩ and the range of measurement is from 20% to 80% of the potentiometer value?

Example Solution

Find the resolution of the 12-bit ADC then convert it to a percentage. Assume 1 volt range

$$Q.E. = \frac{V_{LSB}}{2} \qquad V_{LSB} = \frac{V_{FS}}{2^n} = \frac{1\ V}{2^{12}} = \frac{1}{4096} = 2.441 \cdot 10^{-4}\ V$$

$Q.E = \frac{2.441 \times 10^{-4}}{2} = 1.221 \times 10^{-4}\ V$ convert to per unit of span then percent

$QE\% = \frac{1.221 \times 10^{-4}\ V}{1\ V} \times 100\% = 0.0122\%$ MAKE POT. RESOLUTION EQUAL TO Q.E%

$0.0122\% = 100/N \Rightarrow \frac{100\%}{0.0122\%} = N = \boxed{8192\ \text{TURNS}}$

Example Solution (cont.)

Percent loading errors

$$\%LE = \left(\frac{a^2 r(1-a)}{1 + ar(1-a)}\right) 100\%$$

$r = \frac{R_P}{R_L}$ $R_P = 50{,}000\ \Omega$ $R_L = 100{,}000\ \Omega$

$r = \frac{50{,}000}{100{,}000} = 0.5$

$a = 20\%$

$a = \frac{20\%}{100\%} = 0.2$

$$\%LE = \left(\frac{0.2^2(0.5)(1-0.2)}{1 + 0.2(0.5)(1-0.2)}\right) 100\%$$

$$\%LE = \left(\frac{0.04(0.8)}{1 + 0.1(0.8)}\right) 100\%$$

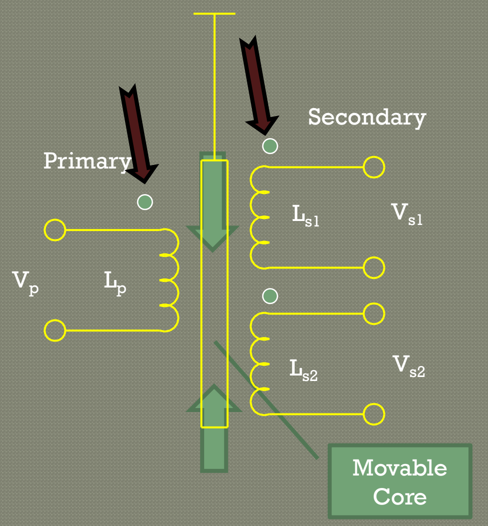
$\%LE = \boxed{1.481\%}$

at $a = 80\%$ $a = \frac{80\%}{100\%} = 0.8$

$$\%LE = \left[\frac{0.8^2(0.5)(1-0.8)}{1 + 0.8(0.5)(1-0.8)}\right] \times 100\% = \frac{0.064}{1 + 0.4(0.2)} = \boxed{5.93\ \%}$$

Loading error depends on position of potentiometer

Linear Variable Differential Transformers (LVDTs)



Note: dots indicates instantaneously positive voltages in transformers

V_p must be AC typical frequency 50k - 15 kHz

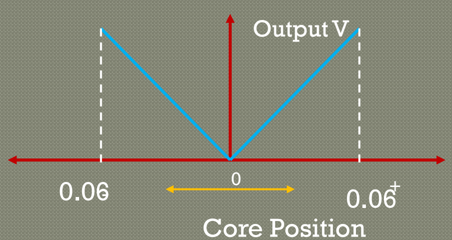
Core Motion causes V_{s1} and V_{s2} to change

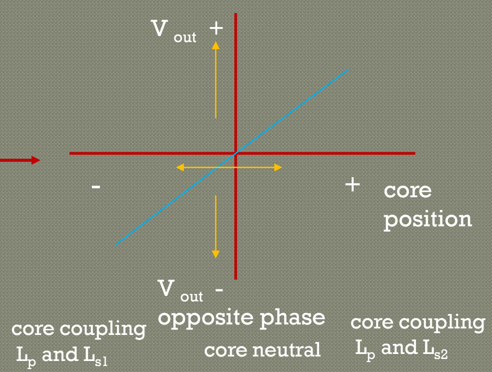
L_p and L_{s1} coupled V_{s1} Increasing

L_p and L_{s2} coupled V_{s2} Increasing

LVDT Output

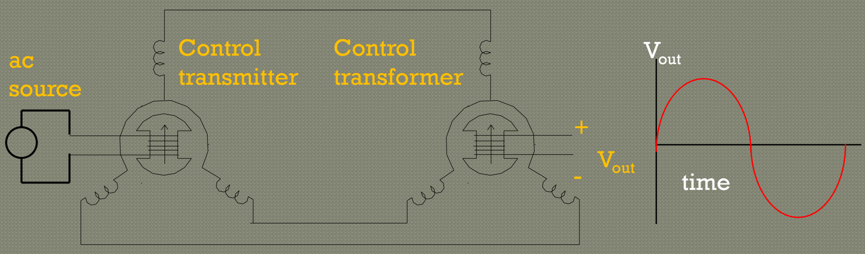
Coils connected so voltages subtract





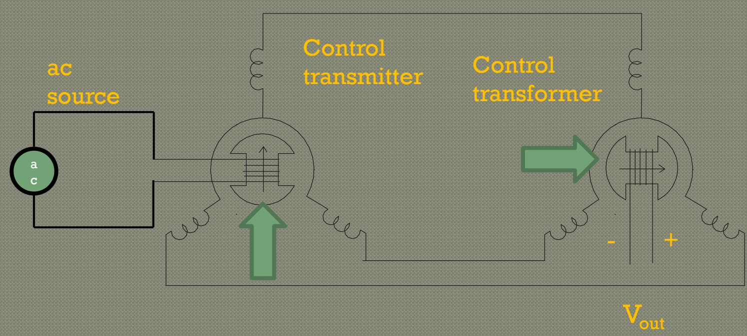
Rotory Position Transducer
Synchro Systems

Three parts to system 1.) Control Transmitter 2.) Control Transformer 3.) Control Differential



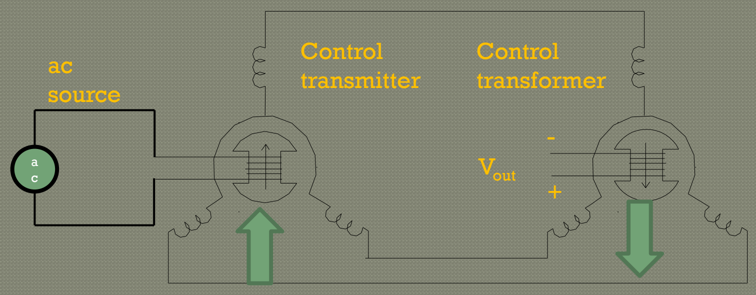
Sinusoidal output with maximum value from this position

Synchro Systems



Output voltage is zero when rotors in this position

Synchro Systems



Output voltage 180 degrees out of phase from initial position

Synchro Systems

Output voltage magnitude is a function of the angular displacement between the control transmitter and the control transformer

$$V_{out} = (E_m \cos(\theta))\sin(\omega t)$$

Where E_m = the maximum amplitude of excitation
θ = the angular position difference between the transmitter and the transformer rotor
ω = frequency of excitation voltage

Synchro Systems

Control differential transformer can be added to add constant phase shift.

$$V_{out} = (E_m \cos(\theta + \theta_d)) \sin(\omega t)$$

Sending and receiving devices will have a constant angular difference given by the value of θ_d.

System can be used to maintain a constant position difference between two shafts. It can also be used to keep two shafts synchronized.

Synchro Example

A syncho system operates at a frequency of 400 Hz. The maximum amplitude of the transformer rotor voltage is 22.5 V. Determine the ac error signal produced by each of the following pairs of angular displacements

a.) $\theta = 90^\circ$ $\theta_d = 0^\circ$ b.) $\theta = 60^\circ$ $\theta_d = 0$
c.) $\theta = 135^\circ$ $\theta_d = -15^\circ$ d.) $\theta = 100^\circ$ $\theta_d = -45^\circ$

At 400 Hz $\omega = 2\pi \cdot (400\ \text{Hz}) = 2570\ \text{rad/s}$

a.)

$$V_0 = (E_m \cdot \cos(\theta + \theta_d)) \sin(\omega \cdot t)$$
$$E_m = 22.5$$
$$V_0 = (22.5 \cdot \cos(90 + 0)) \sin(2570 \cdot t) = 0$$

b.)

$$V_0 = (22.5 \cdot \cos(60 + 0)) \sin(2570 \cdot t)$$
$$V_0 = 11.25 \sin(2570 \cdot t)$$

Synchro Example (Cont.)

c.) $V_{out} = E_m[\cos(\theta+\theta_d)]\sin\omega t$

$V_{out} = 22.5[\cos(135^\circ - 15^\circ)]\sin 2570t = 22.5(-0.5)\sin(2570t)$

$V_{out} = \underline{-11.25\sin(2570t)}$

OR $V_{out} = 11.25\sin(2570t + 180^\circ)$ 180° shift removes negative sign

d.) $V_{out} = 22.5[\cos(100^\circ - 45)]\sin(2570t)$

$V_{out} = 22.5[\cos(55^\circ)]\sin(2570t) = \underline{12.91\sin 2570t}$

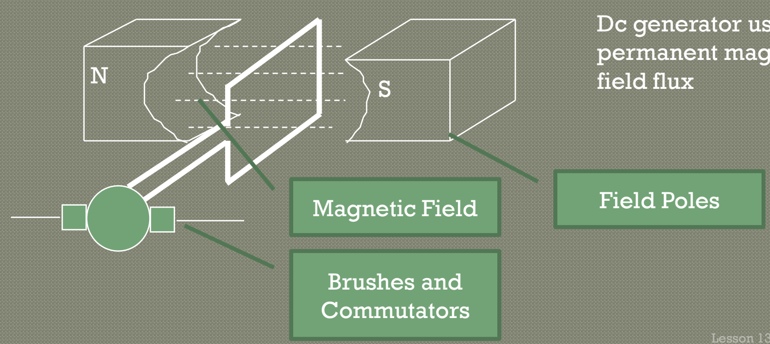
Velocity Measurements

Angular and Linear Velocity

Angular Velocity Measurement Methods
- dc tachometer
- ac tachometer
- optical tachometer

DC tachometer

Dc generator using permanent magnets for field flux



Velocity Measurements
Dc Tachometer

Tachometer produces a dc voltage that is proportional to angular velocity

Proportionality constant = emf constant K_E (V/rpm)

K_E depends on the construction of tachometer

$$K_E = \frac{2\pi \cdot R \cdot B \cdot N \cdot L}{60}$$ **emf constant**

$$E = K_E \cdot s = \frac{30 \cdot K_E \cdot \omega}{\pi}$$ **Induced emf**

Where

E = tachometer output (V)
K_E = emf constant
s = angular velocity (rpm)
ω = angular velocity (rad/s)
R = average radius (m)
B = flux density (Wb/m^2)
N = number of conductors
L = length of conductor in field (m)

Velocity Measurements
Dc Tachometer

Example: A dc tachometer has the following parameters

R = 0.03 m N = 220
L = 0.15 m B = 0.2 Wb/m^2

Find K_E and the output voltage at the following speeds s = 1000, 2500, and 3250 rpm

$$K_E = \frac{2\pi R \cdot B \cdot N \cdot L}{60} = \frac{2\pi(0.03\text{ m})(0.2\text{ Wb/m}^2)(220)(0.15\text{ m})}{60}$$
$$K_E = 0.0207\text{ V/rpm}$$

For s = 1000 rpm

$$E = K_E \cdot s$$
$$E = 0.0207\text{ V/rpm} \cdot (1000\text{ rpm}) = 20.7\text{ V}$$

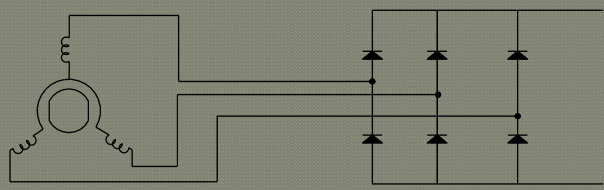
For s= 2500 rpm
And 3250 rpm

$$E_2 = 0.0207\text{ V / rpm}(2500\text{ rpm}) = 51.8\text{ V}$$

$$E_3 = 0.0207\text{ V / rpm}(3250\text{ rpm}) = 67.3\text{ V}$$

Velocity Measurements
Ac Tachometer

Ac Tachometers Construction : a 3-phase alternator with a 3-phase rectifier to convert the output to dc. Must have constant field excitation - Permanent magnet field.



Non-linear at low speeds due to the forward drop of diodes Limited to lower speed ranges due to this. Range 100-1

Ac Tachometers can also produce a variable frequency output that has a constant voltage.

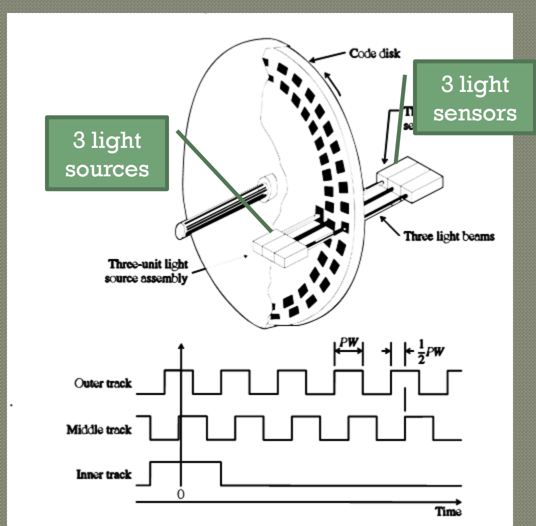
Use frequency-to-voltage conversion to get proportional dc

Optical Tachometers

Digital encoder attached to shaft produces a sequence of pulses.

Encoder tracks
Inner – locates home
Middle - gives direction info

Phase shift between outer and middle tracks
Middle leads or lags outer based on direction



Optical Tachometer Operation

Optical Tachometers

Pulses counted over time interval. Counter is then reset. The number of pulses counted in interval is proportional to the angular velocity

Formulas

$$s = \frac{60 \cdot C}{N \cdot T_c}$$

$$C = \frac{s \cdot N \cdot T_c}{60}$$

Where

s = shaft speed (rpm)

N = number of pulses per shaft revolution

C = total count during time period

T_c = counter time interval (sec)

Optical Tachometer Example

Incremental encoder produces 2000 pulses/rev.

a.) determine count produced by shaft speed of 1200 rpm with a count interval of 5 mS

b.) determine the speed measured at a count of 224 for a timer interval of 5 mS

a.) $$C = \frac{s \cdot N \cdot T_s}{60} = \frac{(1200\,\text{rpm})\cdot(2000)\cdot(0.005\,\text{s})}{60} = 200$$

Number of counts for 1200 rpm speed

b.) $$s = \frac{60 \cdot C}{N \cdot T_s} = \frac{60 \cdot (224)}{2000 \cdot (0.005\,\text{s})} = 1344\,\text{rpm}$$

Speed for 224 counts

Acceleration Measurement

Definition - acceleration is rate of change of velocity

$$a = \frac{dv}{dt} = \text{limit}\frac{\Delta v}{\Delta t}$$

Sensing Methods

Newton's Law f = Ma

Where: f = force acting on body
M = mass of body
a = acceleration

Can measure acceleration by measuring force required to accelerate known mass.

For angular acceleration, differentiate the velocity signal from velocity sensors

Acceleration Measurement

Sensing Methods

For angular acceleration, differentiate the velocity signal from velocity sensors

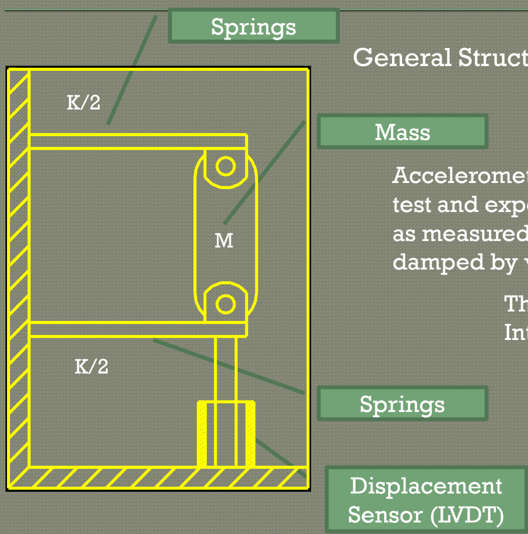
For sampled data systems, derivative is given by difference of readings

$$a_t = \frac{\Delta v}{\Delta t} = \frac{v_{t-1} - v_t}{T_s}$$

Where

a_t = acceleration at time t
v_{t-1} = velocity sample at t-1
v_t = velocity sample at t
T_s = sampling time

Accelerometers



General Structure

Accelerometer attached to device under test and experiences same acceleration as measured object. Motion of mass damped by viscous fluid around mass

Theory of operation same for Integrated devices.

Applications
Gaming
Automotive
Appliance control
Disk Drive protection
Bearing Condition Monitoring

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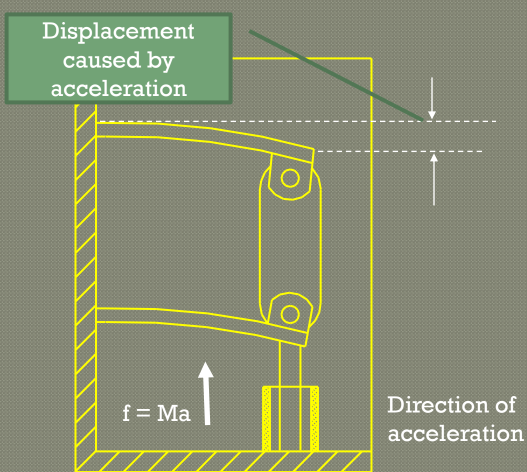
Accelerometers

Accelerometer forms a second order mechanical system.

Accelerometer in action



For small deflections, spring force offsets force due to acceleration so....

$$Kx = Ma$$

Which gives

$$x = (M/K)a$$

so acceleration is proportional to displacement

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Accuracy of Acceleration Measurements

Acceleration is dynamic measurement, interested in a(t), acceleration as function of time.

Consider second order response

$$f_o = \frac{1}{2\pi}\sqrt{\frac{K}{M}}$$

$$\zeta = \sqrt{\frac{b^2}{4KM}}$$

Where f_o = resonant frequency of accelerometer (Hz)
ζ = damping ratio
K = spring constant (N/m)
M = mass (Kg)
b = damping constant (N-s/m)

f_a = max. frequency of a(t)

Accuracy of Acceleration Measurements

Accuracy of response related to resonant frequency of device

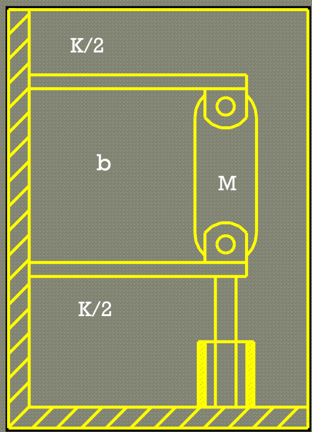
Must have sufficient range to measure changes

if $f_a << f_o$ then measurements will be accurate
if $f_a >> f_o$ then the mass does not have time to react
incorrect measurement
$f_a = f_o$ then displacement is greatly exaggerated
incorrect measurement

Make f_o at least 2.5 times greater than f_a max for < 0.5% error

Accelerometer Example

The accelerometer shown below has the following specifications:



$M = 0.0156$ kg
$K = 260$ N/m
$b = 2.4$ N-s/m
$x_{max} = \pm 0.3$ cm

<u>Find the following</u>

a.) maximum acceleration that can be measured
b.) resonant frequency
c.) damping ratio
d.) maximum frequency that can be used with 0.5% error or less

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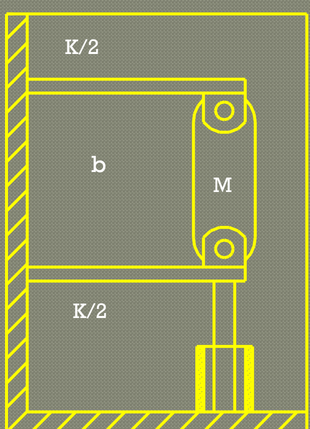
Accelerometer Example



$M = 0.0156$ kg $K = 260$ N/m
$b = 2.4$ N-s/m $x_{max} = \pm 0.3$ cm

a.) $$k \cdot x = M \cdot a \Rightarrow \frac{k \cdot x_{max}}{M} = a_{max}$$

$$a_{max} = \frac{(260\ \text{N/m}) \cdot (0.003\ \text{m})}{0.0156\ \text{kg}} = 50\ \text{m/s}^2$$

b.) $$f_0 = \frac{1}{2\pi} \cdot \sqrt{\frac{k}{M}} = \frac{1}{2\pi} \cdot \sqrt{\frac{260\ \text{N/m}}{0.0156\ \text{kg}}} = 20.6\ \text{Hz}$$

c.) $$\varsigma = \sqrt{\frac{b^2}{4 \cdot k \cdot M}} = \sqrt{\frac{(2.4\ \text{N-s/m})^2}{4(260\ \text{N/m}) \cdot (0.0156\ \text{kg})}} = 0.595$$

d.) Maximum frequency of a(t) with 0.5% error is.....

$$f_0 / 2.5 \qquad f_{max} = 20.6\ \text{Hz}/2.5 = 8.25\ \text{Hz}$$

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Force Measurements

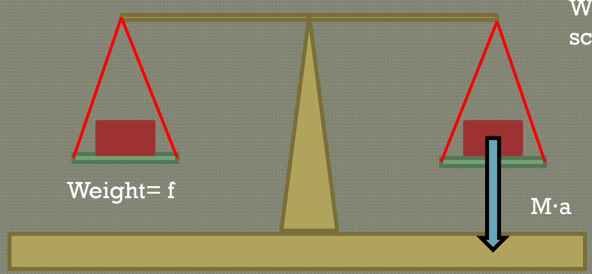
All force measurement based on force balance

$$f = M \cdot a$$

Where : f = force (N) M=Mass (kg) a=acceleration (m/s^2)

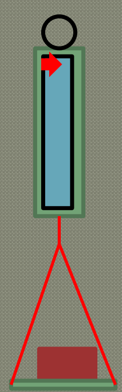
Null Balance – unknown force off set by know weight (beam balance)

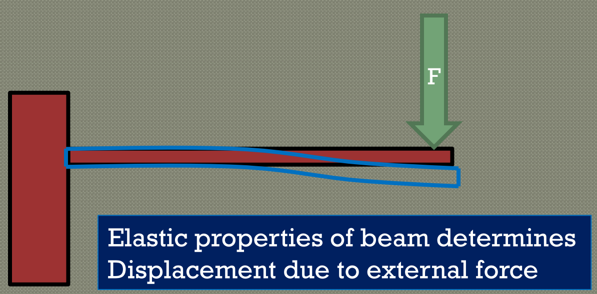
When weights equal
scale balanced



Force Measurements

Displacement – displacement of elastic material with unknown balancing force determines measurement (Spring Scale) (Strain gage load cell)

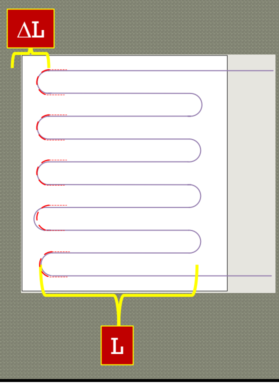




Strain Gages

Strain gages turn changes in displacement into changes in electric resistance. Fine wire bonded to plastic base.

Bonded strain gages measure strain at specific location on deformable body. Cemented to material and change length when body deforms.



Change in length $= L+\Delta L$

Define strain: $\varepsilon = \dfrac{\Delta L}{L}$

Where ΔL = change in length due to force (m)

L = unforced length (m)

Strain Gages- Gage Factor

Gage factor determines the sensitivity of the sensor

$$G = \frac{\dfrac{\Delta R}{R}}{\dfrac{\Delta L}{L}}$$

Typical values of strain gage parameters:

G: 2 to 4
R: 50 to 5000 ohms
L: 0.5 to 4 cm (unstrained)

Stress/Strain and Modulus of Elasticity

Define Stress

$$S = \frac{f}{A}$$

Where

$S = \text{stress}\ (N/m^2)$

$f = \text{force}\ (N)$

$A = \text{area}\ (m^2)$

Stress and strain related through the modulus of elasticity for a given material

$$E = \frac{S}{\varepsilon}$$

Where E = modulus of elasticity (N/m^2)
S = stress (N/m^2)
ε = strain (m/m)

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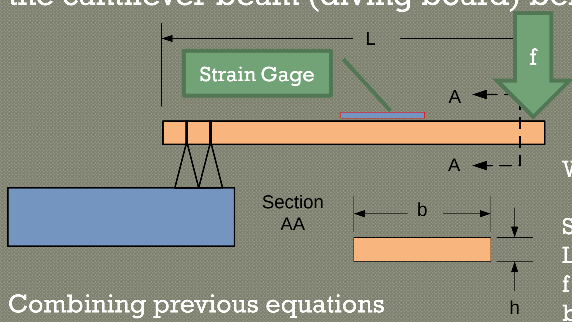
Stress and Force

Stress depends on the geometry of the object. Consider the cantilever beam (diving board) below.



$$S = \frac{6 \cdot f \cdot L}{b \cdot h^2}$$

Where:

S = stress (N/m^2)
L= distance from fixed end (m)
f = applied force (N)
b = width of beam (m)
h = height of beam (m)

Combining previous equations

$$\frac{\Delta R}{R} = \left[\frac{6 \cdot G \cdot L}{b \cdot h^2 \cdot E}\right] \cdot f$$

Normalized gage resistance change proportional to force

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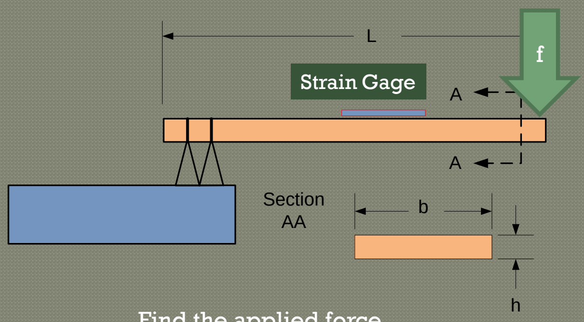
Strain Gage Example



Find the applied force

The beam structure shown has the following parameters

Length =L = 2 m
Width =b = 20 cm
Height=h = 6 cm

It is made from Aluminum with a modulus of elasticity of $E = 6.9\text{x}10^{10}\ N/m^2$

The strain gage has an unstrained R=100 Ω
G = 3
ΔR =0.073 Ω

Strain Gage Example Solution

Define the variables

$L = 2 \cdot m \quad E = 6.9 10^{10} \cdot N \cdot m^{-2} \quad G = 3$

$b = 20 \cdot cm \quad R = 100 \cdot \Omega$

$h = 6 \cdot cm \quad \Delta R = 0.073 \Omega$

Restate the formula

$$\frac{\Delta R}{R} = \left[\frac{6 \cdot G \cdot L}{b \cdot h^2 \cdot E}\right] \cdot f$$

Solve for force

$$f := \frac{\Delta R \cdot \left(b \cdot h^2 \cdot E\right)}{(R \cdot 6 \cdot G \cdot L)}$$

Substitute values and simplify

$$f = \frac{0.073 \Omega \cdot \left[0.20 m \cdot (0.06 m)^2 \cdot 6.9 10^{10} \cdot N \cdot m^{-2}\right]}{100 \Omega \cdot 6 \cdot 3 \cdot 2 \cdot m}$$

$$f = 1007 N$$

Temperature Measurement

Survey of Types

Resistance Temperature Detector (RTD)-change in resistance of pure metals relates to temperature. Key features: wide temperature range, high accuracy, excellent repeatability, good linearity. Need constant current source and other electronics to produce output signal

Thermistor – temperature-sensitive semiconductor. Resistance inversely proportional to temperature. Increasing temperature causes decreasing resistance. Key features: high sensitivity, small size, fast response., narrow temperature range Not recommended in applications requiring high accuracy.

Thermocouple – junctions of two dissimilar metals produces small (mV) voltages when placed at different temperatures. Magnitude of voltage depends on temperature difference. Key features: small size , low cost, rugged, wide measurement range. Limitations: noise pickup, low signal levels, high minimum span (40° C.)

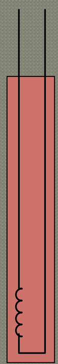
Temperature Measurement

Survey of Types

Integrated Circuit Temperature Sensors –precision solid-state devices with linear output to temperature. Directly calibrated to various temperature scales (Celsius, Fahrenheit, Kelvin, Rankine). Key features: calibrated output voltages, linear scaling, low voltage and current draws, good linearity. Typical devices LM34, LM 35. Limitations: low temperature range typically (-55 C to 155 C)

Resistance Temperature Detectors (RTDs)

Construction: Coil of Nickel or Platinum wire in protective tube. Need to detect small changes in resistance.



Platinum –high accuracy, linearity, and cost

Nickel –moderate cost, higher output than Platinum

Typical Relationship

$$R = R_o(1 + a_1 \cdot T + a_2 \cdot T^2)$$

Where: R = resistance at given Temp, T C
R_o = resistance at 0 degrees C
T = temperature
a_1, a_2 = constants

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Resistance Temperature Detectors (RTDs)

Finding constants from data

Typical values for Platinum

T(°C)	Resistance (Ω)
0	100.00
25	109.90
50	119.80
75	129.60
100	139.30

Use table values to find constants R_o, a_1 and a_2. Substitute data into previous equation.

$$100 = R_o(1 + a_1 0 + a_2 0^2) \Rightarrow R_o = 100\,\Omega$$

$$109.9 = 100(1 + a_1 25 + a_2 25^2) = 100(1 + a_1 25 + a_2 635)$$

$$139.9 = 100(1 + a_1 100 + a_2 100^2) = 100(1 + a_1 100 + a_2 10000)$$

Simplify equations and solve simultaneously

$$0.099 = a_1 25 + a_2 625$$

$$0.399 = a_1 100 + a_2 10000$$

Mainly linear

$$a_1 = 0.00395$$

$$a_2 = 4 \times 10^{-7}$$

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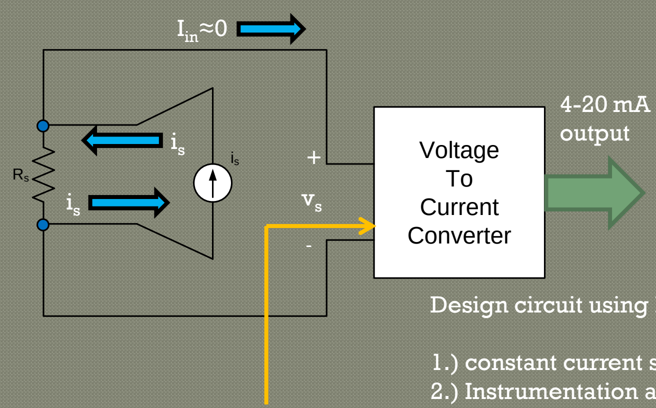
RTD Signal Conditioning

Must convert RTD resistance changes into usable voltage or current signals

Direct Methods (2 and 4 wire) - Constant current supplied to RTD and voltage measured across it. The 4 wire method removes lead-wire error.

Bridge Methods (2 and 3 wire) –Use dc bridge to convert resistance changes into voltage changes. Three wire method removes most lead-wire resistance error.

RTD Signal Conditioning- 4 Wire Direct Methods



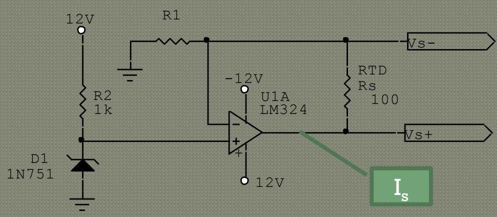
Z_{in} very high
I_{in} approx. zero

Design circuit using Platinum RTD

1.) constant current source i_s = 1 mA
2.) Instrumentation amp. G=50
3.)Summing amp
4.) V-to-I converter 4 mA @ 0 C
20 mA @ 100 C

RTD Circuit Design- Constant Current Source

5.1 V regulated source available. Remember the V-to-I converter . Use LM324\ quad OP AMPs.



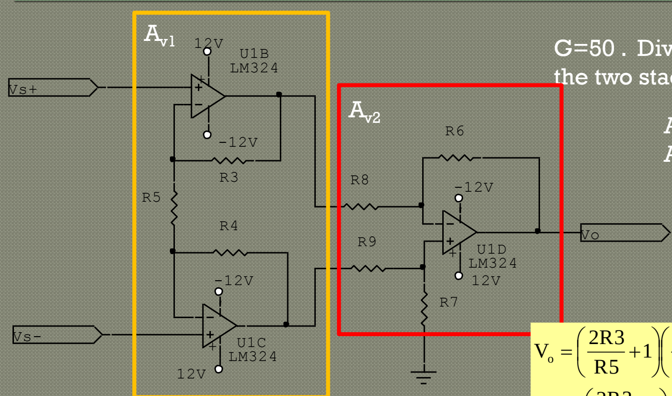
$I_s = 1\,\mathrm{mA}$

$V_{in} = 5.1\,\mathrm{V}$

$I_o = \frac{V_{in}}{R_1} \Rightarrow R_1 = \frac{V_{in}}{I_s} = \frac{5.1\,\mathrm{V}}{1\,\mathrm{mA}} = 5.1\,\mathrm{k\Omega}$

Now design the Instrumentation amplifier using the two stage amplification circuit

RTD Circuit Design- Instrumentation Amplifier



G=50 . Divide gain between the two stages.

$A_{v1} = 5$
$A_{v2} = 10$

$$V_o = \left(\frac{2R3}{R5}+1\right)\left(\frac{R6}{R8}\right)((Vs-)-(Vs+))$$

$A_{v1} = \left(\frac{2R3}{R5}+1\right)$ Let $R3 = 10\,\mathrm{k\Omega}$

$5 = \left(\frac{2(10{,}000)}{R5}+1\right) \Rightarrow R5 = \frac{20{,}000}{4} = 5\,\mathrm{k\Omega}$

Use $5.1\,\mathrm{k\Omega}$ standard value

Gain formula

$$V_o = \left(\frac{2R3}{R5}+1\right)\left(\frac{R6}{R8}\right)((Vs-)-(Vs+))$$

Where R3=R4 R8=R9 and R6=R7

RTD Circuit Design- Instrumentation Amplifier and V-to-I converter

Stage 2 gain is 10

$$A_{v1} = \left(\frac{R6}{R8}\right) \quad \text{Let } R6 = 56\ k\Omega$$

$$10 = \left(\frac{56\ k\Omega}{R8}\right) \Rightarrow R8 = \frac{56{,}000}{10} = 5.6\ k\Omega$$

Now determine the span of the RTD output voltage

$$@0^\circ\ C\ \ (0.001\ A)(100\Omega) = 0.1V$$

$$@100^\circ\ C\ \ (0.001\ A)(139.3\Omega) = 0.1393V$$

After Amp

$$V_{o(min)} = 50(0.1\ V) = -5.0\ V$$

$$V_{o(max)} = 50(0.1393V) = -6.965\ V$$

Desired output span 16 mA – 4 mA
Input span -6.965 - -5.0

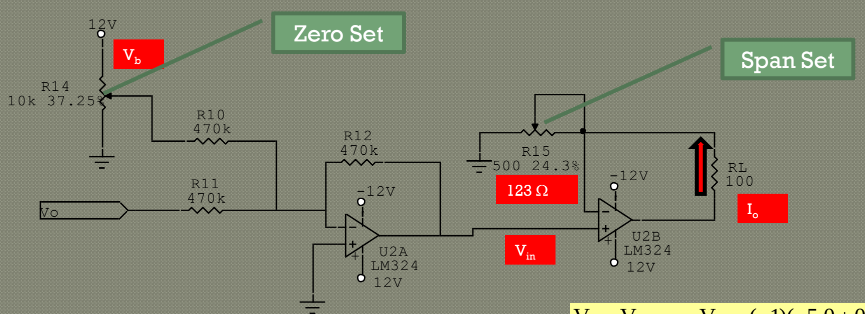
Size the R of the V-to-I converter based on span ratio

$$\frac{1}{R} = \frac{(I_{o(max)} - I_{o(min)})}{(V_{in(max)} - V_{in(min)})} = \frac{(20\ mA - 4\ mA)}{(6.965\ V - 5.0\ V)} = \frac{16\ mA}{1.965\ V}$$

$$R = \frac{1.965\ V}{16\ mA} \approx 123\,\Omega$$

RTD Design- V-to-I Converter

Now determine the offset voltage for the 0 degree input to the converter. Set I_o to minimum and compute V_{in} using the computed R.



$$I_o = \frac{V_{in}}{R} \Rightarrow V_{in} = I_o \cdot R$$

$$V_{in} = (0.004\ A)(123\Omega) = 0.492\ V$$

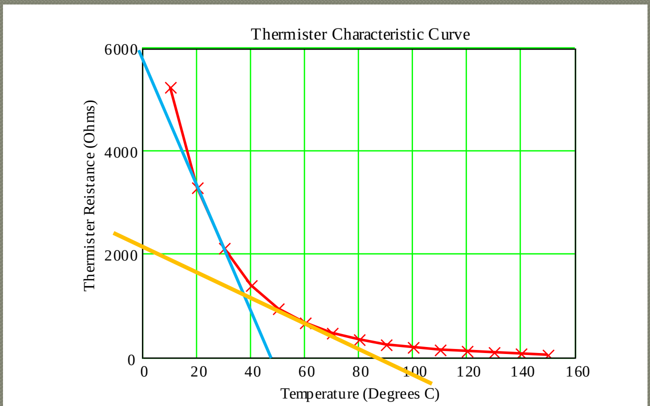
@ 4 mA

U2A inverting summer
Find value of V_b

$$V_b = V_{in(max)} - V_{in} = (-1)(-5.0 + 0.492\ V)$$

$$V_b = 4.508\ V$$

Thermister Characteristics



Photoresistor has similar characteristic

Very Non-linear- High sensitivity in (0-40 C range)

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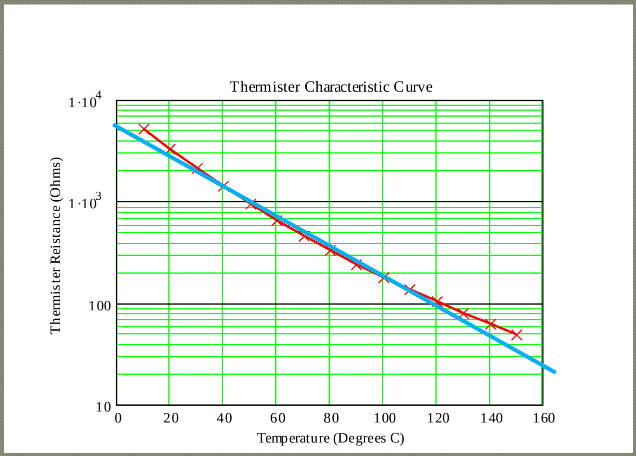
Thermister Characteristics

Semi-log plot (y axis logarithmic) of thermister data



Approximately linear over small range 40-100 C

Log(R)=mT+b

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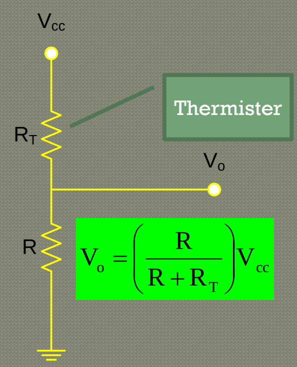
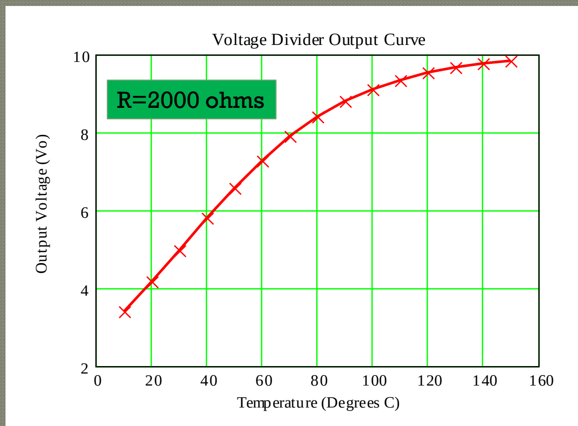
Thermister Characteristics

Linearizing Thermister Characterisitcs



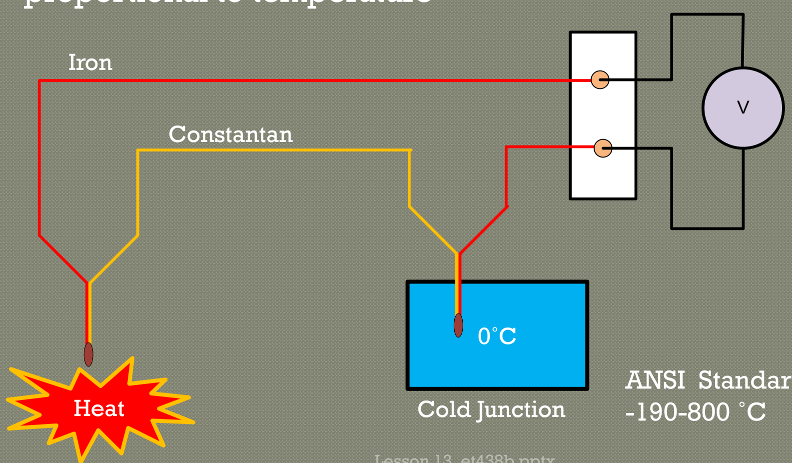
$$V_o = \left(\frac{R}{R + R_T}\right) V_{cc}$$



Changing value of R changes output curve shape

Thermocouples

Junctions of dissimilar metals produces voltage proportional to temperature



ANSI Standard Type J
-190-800 °C

End Lesson 13: Process Control Sensors and Transducers

ET 438B Sequential Control and Data Acquisition
Department of Technology