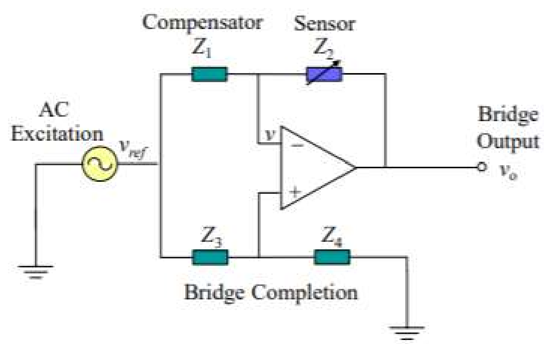
Examples to do

December 14, 2019 12:51 PM



$$\frac{v_{ref} - v}{Z_1} + \frac{v_o - v}{Z_2} = 0 \qquad \frac{v_{ref} - v}{Z_3} + \frac{0 - v}{Z_4} = 0$$

$$v_o = \frac{(Z_4 / Z_3 - Z_2 / Z_1)}{1 + Z_4 / Z_3} v_{ref}$$

Prove.

For a balanced circuit:

$$\frac{Z_2}{Z_1} = \frac{Z_4}{Z_3}$$

Bridge output due to sensor change:

$$\delta v_o = -\frac{v_{ref}}{Z_1(1 + Z_4 / Z_3)} \delta Z$$

Torque Sensor Location Example

Joint of a Direct-drive Robotic Arm:

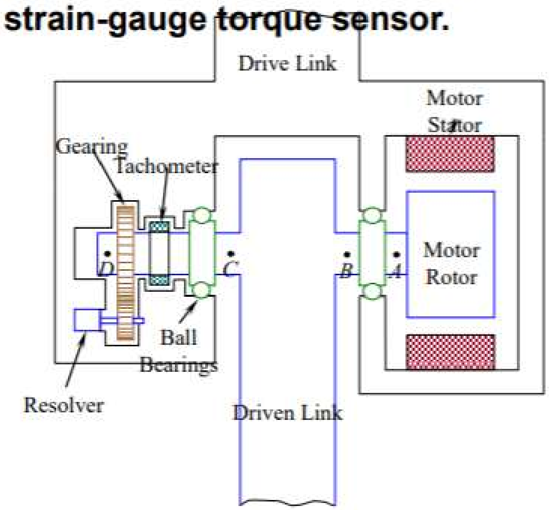
***Note*:** **Rotor of drive motor is integral with driven link (no speed reducers); Motor stator is integral with drive link.**

Tachometer measures the joint speed; Resolver measures joint rotation. Note; Gearing is used to improve resolver resolution.

Neglect mechanical loading from sensors and gearing; including bearing friction

(a) Sketch torque distribution along the joint axis

(b) Suggest a location (or locations) for measuring net torque transmitted to driven link using a strain-gauge torque sensor.



Sensing Bandwidth Example

Rigid load of inertia J_L driven by motor with rigid rotor of inertia J_m.

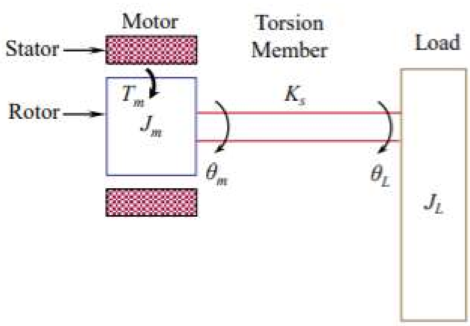
Torque sensing member: Stiffness K_s between rotor and load

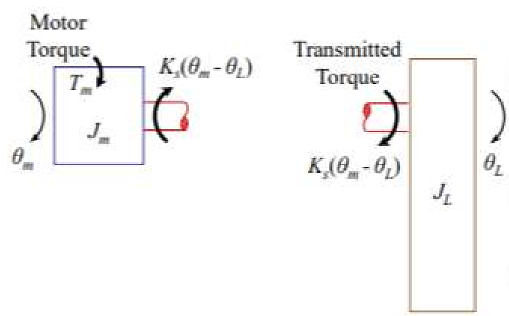
(a) Determine transfer function between motor torque T_m and twist angle of torsion member

(b) What is the torsional natural frequency ω_n of the system?

(c) Discuss why system bandwidth depends on ω_n. Show that the bandwidth can be improved by increasing K_s, decreasing J_m, or decreasing J_L

(d) Mention advantages and disadvantages of introducing a gearbox at motor output.





Example

Strain Gauge Load Cell (Force Sensor): Four identical strain gauges in Wheatstone bridge; Mounted on a rod of square X-section.

One opposite pair mounted axially; Other pair mounted transversey

To maximize bridge sensitivity, SGs are connected in bridge as shown.

Determine the bridge constant *k* in terms of *Poisson's ratio v* of the rod material.

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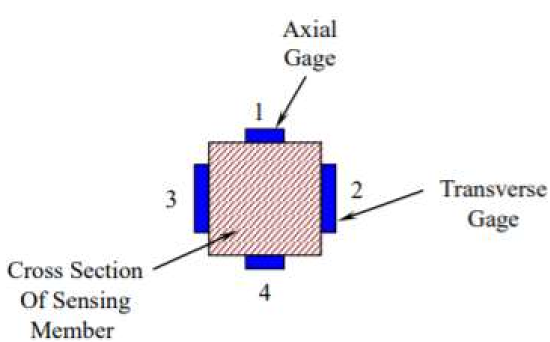
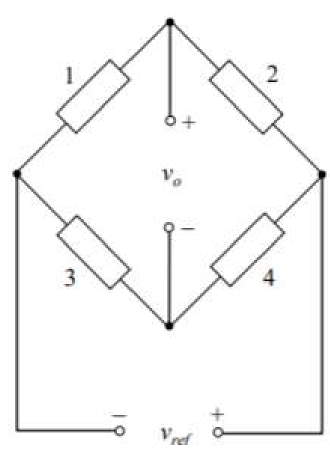
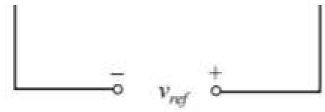






Transverse strain = (-*v*) x longitudinal strain

Example

Strain Gauge Accelerometer: **Point mass of weight *W* (sensing element)**

Light cantilever of rectangular X-section, mounted I housing

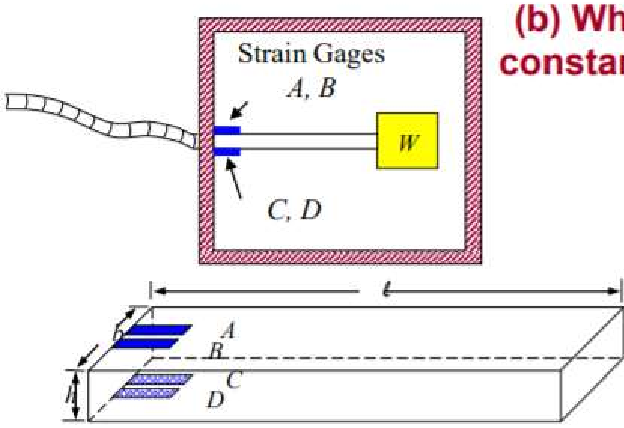
Front End Element (converts the inertia force of W into strain)

Max bending strain at cantilever root is measured using four identical active semiconductor SGs

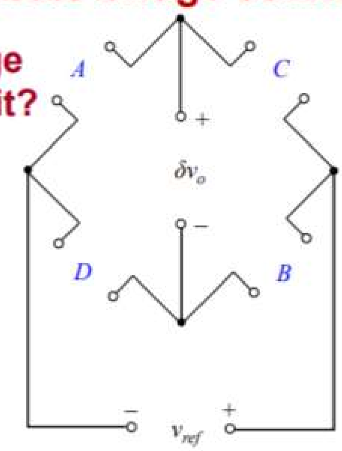
Two SGs (*A* and *B*) are mounted axially on top surface of cantilever

Remaining two (*C* and *D*) are mounted on bottom surface

(a) To maximize accelerometer sensitivity, indicate bridge connection.



(b) What is the bridge constant of the circuit?



Example

For an ideal design of an incremental encoder, obtain an equation relating the parameters *d*, *w*, and *r*, where

d = diameter of encoder disk
w = number of windows per unit diameter of disk
r = word size (bits) of the angle measurement

Assume that quadrature signals are available. If *r* = 12 and *w* = 500/cm, determine a suitable disk diameter.

SG Torque Sensor Design Example

Design a tubular torsion element.

Design specifications: $\varepsilon_{\max} = 3,000\mu\varepsilon; N_p = 5\%; v_o = 10\,\text{V};$

System bandwidth = 50 Hz, $K = 2.5\text{x}10^3$ N.m/rad.

Use a bridge with 4 active SGs I

Given parameter values:

1. For strain gages: $S_s = S_1 = 115$, $S_2 = 3500$
2. For the torsion element: Outer radius r = 2 cm, Shear modulus $G = 3\text{x}10^{10}$ N/m2, Length L = 2 cm
3. For bridge circuit: v_{ref} = 20 V, K_a = 100

Expected max torque T_{max} = 10 N.m

Compute operating parameter limits for the designed sensor.

Example

The mean values and the standard deviations of the four primary contributions to eccentricity in a shaft encoder are as follows (in millimeters):

Shaft eccentricity = (0.1, 0.01)
Assembly eccentricity = (0.2, 0.05)
Track eccentricity = (0.05, 0.001)
Radial play = (0.1, 0.02)

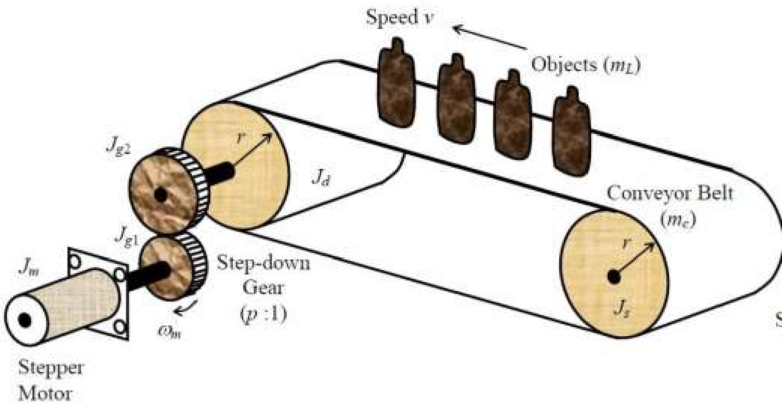
Estimate the overall eccentricity at a confidence level of 96 percent.

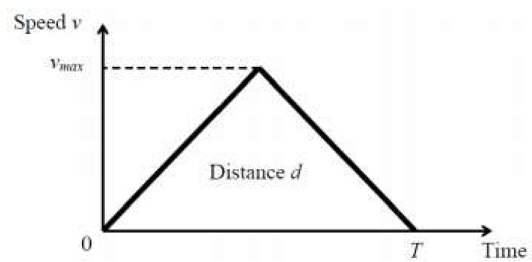
Example

Suppose that in the previous example, the radius of the code disk is 5 cm. Estimate the maximum error due to eccentricity. If each track has 1,000 windows, determine whether the eccentricity error is significant.

Example 8.9: Product Conveyor

- Industrial conveyor for product completion, inspection, movement, grading, etc.
- Conveyor moves intermittently at a fixed rate ➔ indexes objects through distance *d* in time period *T*
- A triangular speed profile is used for each motion interval, with equal acceleration and a deceleration
- A gear unit with step-down speed ratio *p*:1, *p* > 1, may be used if necessary



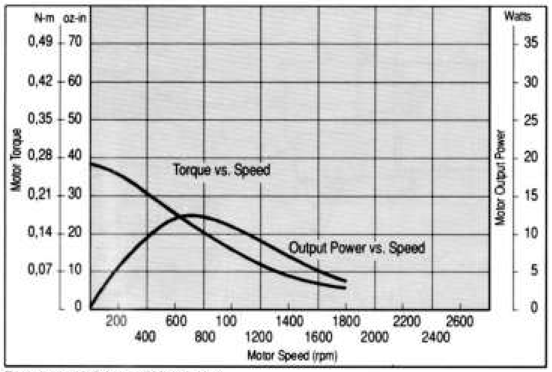


Stepper Motor Data (Example 8.9)

Model		Stepper Motor Specifications 50SM	101SM	310SM	1010SM
NEMA motor frame size		23	23	34	42
Full step angle	Degrees	1.8			
Accuracy	%	±3 (noncumulative)			
Holding torque	oz.in	38	90	370	1050
	N.m	0.27	0.64	2.61	7.42
Detent torque	oz.in	6	18	25	20
	N.m	0.04	0.13	0.18	0.14
Rated phase current	Amps	1	5	6	8.6
Rotor inertia	oz.in.s^2	1.66×10^{-3}	5×10^{-3}	26.5×10^{-3}	114×10^{-3}
	kg.m^2	11.8×10^{-6}	35×10^{-6}	187×10^{-6}	805×10^{-6}
Maximum radial load	lb	15	15	35	40
	N	67	67	156	178
Maximum thrust load	lb	25	25	60	125
	N	111	11	267	556
Weight	lb	1.4	2.8	7.8	20
	kg	0.6	1.3	3.5	9.1
Operating temperature	°C	−55 to +50			
Storage temperature	°C	−55 to +130			

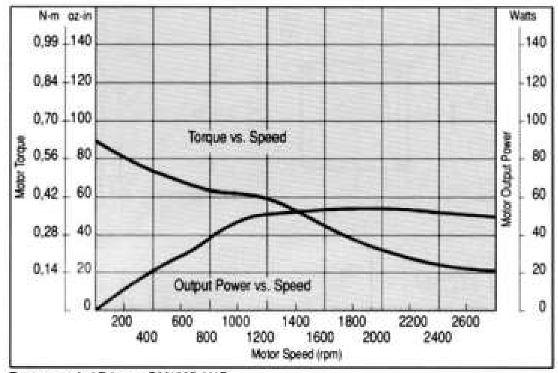
Stepper Motor Characteristics (Example 8.9)

Model 50SM



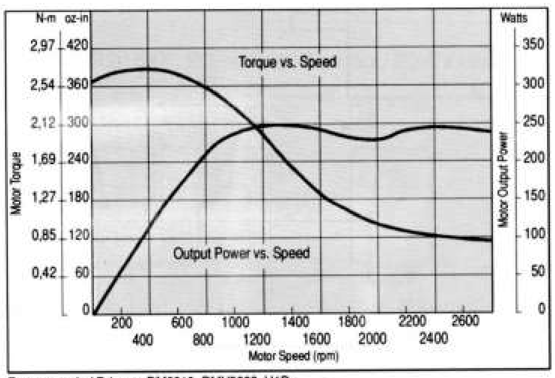
Recommended Drivers : DM4001, U1A

Model 101SM



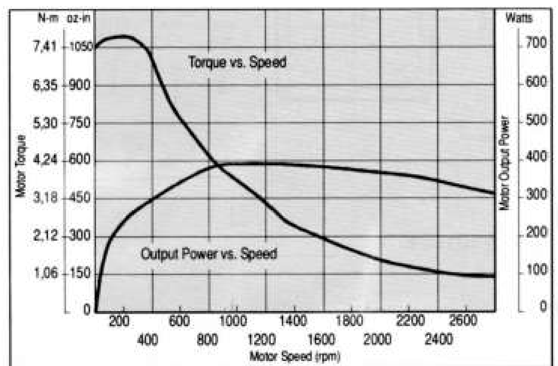
Recommended Drivers: DM4005, U1B

Model 310SM



Recommended Drivers: DM8010, DMV8008, U1D

Model 1010SM



Recommended Drivers: DM16008, DMV16008, U1F

Stepper Motor Selection (Example 8.9)

Equivalent moment of inertia J_e at motor shaft, for the overall system:

$$J_e = J_m + J_{g1} + \frac{1}{p^2}(J_{g2} + J_d + J_s) + \frac{r^2}{p^2}(m_c + m_L)$$

J_m, J_{g1}, J_{g2}, J_d, & J_s: moments of inertia of motor rotor, drive gear, driven gear, drive roller, & driven roller; m_c & m_L: overall masses of conveyor belt and moved objects (load); r = radius of a roller

Given: d = 10 cm, T = 0.2 s, r = 10 cm, m_c = 5 kg, m_L = 5 kg, $J_d = J_s = 2.0 \times 10^{-3}$ kg.m^2

Two gear units: p = 2 & 3; $J_{g1} = 50 \times 10^{-6}$ kg.m^2 & $J_{g2} = 200 \times 10^{-6}$ kg.m^2

What is the positioning resolution of the conveyor (rectilinear) for the final system?

Assume an overall system efficiency of 80% regardless of whether a gear unit is used