Closed book, closed notes. Short answer questions - use the space provided for written answers.

1. [8] Define these terms that apply to position and velocity sensors (use words and/or a sketch as needed).
   a) LVDT

   b) absolute encoder

   c) optical encoder

   d) LVT

2. [6] The setup below is used to measure angular velocity of a shaft. The gear tooth had 8 lobes that are sensed by the magnetic pickup. In a 0.65 second period, a total of 375 pulses are counted. What is the angular velocity in RPM? What is the resolution of this measurement?

   ![Diagram of the setup with a gear tooth and a magnetic pickup]
3. [6pt] An AC induction motor has 4 poles and operates on 115 VAC, 50 Hz input voltage.
   a) What is the shaft speed if the motor operates at 8% slip?
   b) What is the motor’s torque if it develops the full 1.5 hp rated output power at the speed determined in (a)?

4. [10] Select and briefly justify the single "best" motor from the list below for each of the following applications (a motor type can be selected only once):
   - DC motor (w/brushes)
   - brushless DC motor
   - universal motor
   - split phase AC motor
   - PSC AC motor
   - shaded pole AC motor

   a) window air conditioner fan
   b) electric can opener
   c) starter for a motorcycle
   d) swimming pool pump
   e) vacuum cleaner
Closed book, closed notes, one hand-written formula sheet allowed.

5. [20 pt] A thin walled pressure vessel is instrumented with two strain gages to measure hoop strain.
   a) Draw the Wheatstone bridge with strain gages located such that an increase in pressure, $P$, causes an increase in the output voltage, $E_{out}$.
   b) Determine the Wheatstone bridge output voltage, $E_{out}$, and the uncertainty $U_{E_{out}}$, for these parameters:
   - Pressure, $P = 25$ psi $\pm 1\%$
   - Wall thickness, $t = 0.0035 \pm 0.0002$ in
   - Gage factor, $F = 2.15$ (assume exact)
   - $E_{alum} = 11 \times 10^6$ lbf/in$^2$ (assume exact)
   - Poisson’s ratio for aluminum $= 0.33$
   - Diameter, $d = 2.50$ inch $\pm 0.01$ inch
   - Input voltage, $E_{in} = 12.6$ volts $\pm 2\%$

6. [10 pt] A plot of experimental data for the step response of a 1$^{\text{st}}$ order system is given below.
   a) Determine the time constant for the system.
   b) If the 1$^{\text{st}}$ order system consists of a capacitor and a resistor in series, determine the capacitance, $C$, if the resistance is $R = 1234 \Omega$. 

![Graph of experimental data for the step response of a 1$^{\text{st}}$ order system with time on the x-axis and input/output voltage on the y-axis.](image-url)

- Determine the natural frequency, $\omega_n$ (in Hz and rad/sec) for the system using the data given.
- Determine the uncertainty in the natural frequency, $U_\omega_n$, (in Hz and rad/sec) for the system using the data given.
- Determine the spring stiffness, $K$, in units of lbf/in if the mass weighs 3.5 lbf at sea level.

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8. [20pt] A test of a DC permanent magnet motor operated at an armature voltage of $V_a=48\text{ volts}$ generated the torque-speed data points plotted below. Determine:

a) the motor's "no-load" speed, $\omega_{N,L}$, in RPM and rad/sec,

b) the motor’s theoretical back-EMF constant, $k_b$,

c) the motor’s theoretical torque constant, $k_a$, and

d) the motor’s theoretical resistance, $R_a$. 

![Graph of torque-speed data](image-url)