Name: Key

Exam # 2 **ELEC 5760/6760** **Wed 11/29/21**

Constants: $\pi = 3.14159$, $\varepsilon_o = 8.854$ pF/m, 1 atm = 101.325 kPa, 1 G = 9.8 m/s^2,

Equations: $PE = mgh$, $KE = \frac{1}{2}mv^2$, $P_s = \rho gh$, $F_{PPA} = \frac{\varepsilon_o \varepsilon_r A V^2}{2d^2}$

$V_{PI} = \sqrt{\frac{8kd_o^3}{27A\varepsilon_o\varepsilon_r}}$, $A_{circle} = (\pi)r^2$, $d = a(\frac{m}{k}) = aS$, $y(t) = \frac{2m\Omega A_x}{c^2\omega_n}\cos(\omega_n t)$

$P_t = P_s + \frac{\rho v^2}{2}$, $f_d = \frac{f_s}{1 + \frac{v_{object}}{v_{wave}}}$, $V_{rms} = \frac{V_{amplitude}}{\sqrt{2}}$, $C_{PPA} = \frac{\varepsilon_o \varepsilon_r A}{d}$

Laplace Transforms: $\pounds[cu(t)] = \frac{c}{s}$, $\pounds[ce^{-at}] = \frac{c}{s+a}$, $\pounds[cte^{-at}] = \frac{c}{(s+a)^2}$

Problems:

1) An object is dropped from a height of 10 m with G = 9.8 m/s^2 onto a hard surface. If the object took 100 ms to stop moving after impact, estimate the magnitude of the average acceleration the object's onboard shock sensor experienced from the impact, in m/s^2. **(10 points)**

$KE = PE$

$\frac{1}{2}mv^2 = mgh$

$v = \sqrt{2gh}$

$= \sqrt{2(9.8)(10)}$

$= \sqrt{196}$

$= 14$ m/s

$|a| = \left|\frac{\Delta v}{\Delta t}\right|$

$= \frac{14}{0.1}$

$= 140$ m/s^2

Match the question with an answer by writing the letter of the answer in the blank next to the question. No answer is used more than once. (30 points)

Questions

1) This material property is what makes a thermocouple operate: D
2) This can be used as a sensor for an ionizing radiation event: E
3) When a reflected wave from a moving object has a different frequency: I
4) A Taguchi-type tin-oxide sensor is a: N
5) Heating of a resistive element due to current flow: F
6) Nitinol is a material used as a: M
7) The chemical we desire to sense: B
8) This is used to detect a gas based on optical wavelength absorption: O
9) This is a type of pressure sensor: P
10) Closed loop accelerometers make use of: C
11) This is an inertial sensor: H
12) The acceleration of a typical mechanical shock event has a characteristic: K
13) MEMS gyroscopes make use of the: G
14) A BJT based temperature sensor that is compatible with IC technology: A
15) Used as a low-cost medical thermometer: L

Answers to choose from

A. PTAT
B. Analyte
C. Force Feedback
D. Seebeck Coefficient
E. MOSFET
F. Joule Heating
G. Coriolis Force
H. Gyroscope
I. Doppler Shift
J. Diaphragm
K. Half Sine Pulse
L. Thermistor
M. Shape Memory Alloy
N. Conductimetric Device
O. Spectrometer
P. MEMS microphone

2) An object is moving through a fluid with a density of 2 g/cm^3 at 10 m/s. If the static pressure in the fluid is 50 kPa, what is the total pressure in kPa? **(10 points)**

$$\left(2\ g/cm^3\right)\left(\frac{1\ kg}{1000\ g}\right)\left(\frac{100\ cm}{1\ m}\right)^3 = 2000\ kg/m^3$$

$$P_t = P_s + \frac{\rho V^2}{2} = 50{,}000 + \frac{2000(10)^2}{2}$$

$$= 150{,}000\ Pa$$

$$= 150\ kPa$$

3) A parallel plate actuator (PPA) system in a vacuum consists of two square electrodes 100 μm across, and a suspension system with a spring constant is 50 N/m. If the pull-in voltage is measured at 900V, what is the separation distance of the two electrodes in μm? **(10 points)**

$$(V_{PI})^2 = \frac{8kd^3}{27A\varepsilon_0\varepsilon_r}$$

$$d = \sqrt[3]{\frac{27A\varepsilon(V_{PI})^2}{8k}} = \sqrt[3]{\frac{27(100\times10^{-6})^2(8.854\times10^{-12})(900)^2}{8(50)}}$$

$$= 16.916\ \mu m$$

$1\mu g = 1\times10^{-6} g = 1\times10^{-9} kg$

4) What is the amplitude of motion in μm along the sense axis for a certain MEMS gyroscope that has a mass of 1 μg, c = 0.1x10^{-6} Kg/s, f_n = 5 KHz, and A_x = 1 μN when it experiences and angular rate of 180°/s? **(10 points)**

$$y = \frac{2 m \Omega A_x}{c^2 \omega_n} = \frac{2(1\times10^{-9})(180)(\frac{\pi}{180})(1\times10^{-6})}{(0.1\times10^{-6})^2 2\pi(5000)}$$

$$= \frac{(1\times10^{-9})(1\times10^{-6})}{(0.1\times10^{-6})^2 5000}$$

$$= 20\mu m$$

5) A parallel plate actuator (PPA) consists of two square electrodes, 1 mm across, separated by 10 μm, in a vacuum. If one electrode is connected to ground and the other electrode is connected to a high frequency AC voltage (100 V amplitude), what is the average force produced by the PPA in μN? **(10 points)**

$$V_{rms} = \frac{100}{\sqrt{2}}$$

$$F = \frac{\varepsilon_0 \varepsilon_r A (V)^2}{2 d^2} = \frac{(8.854\times10^{-12})(1\times10^{-3})^2 (100)^2}{4(10\times10^{-6})^2}$$

$$= 221.35\ \mu N$$

6) What does PTAT stand for? **(5 points)**

Proportional To Absolute Temperature

7) What is the measurand for a radiation sensor? **(5 points)**

Radiation

8) An open-loop MEMS accelerometer has a natural frequency of 100 Hz. Its proof mass experiences a displacement of 10 μm due to an acceleration. What is the magnitude of that acceleration in m/s^2? **(10 points)**

$$d = aS = \frac{a}{\omega_n^2}$$

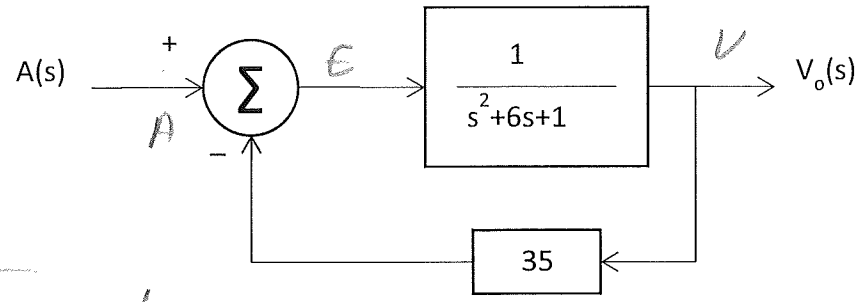
$$a = d\omega_n^2 = (10\times10^{-6})(2\pi 100)^2 = 3.95\ m/s^2$$

Bonus Question (10 points)

A certain open loop MEMS accelerometer has the following transfer function:

$$G(s) = \frac{1}{s^2 + 6s + 1}.$$

It has been placed in a closed-loop controller (shown below) to realize a closed-loop accelerometer. What is the Q for the open loop accelerometer and what is the Q for the closed-loop accelerometer? Show all steps in your calculations.



Open loop

$\omega_n^2 = 1 \rightarrow \omega_n = 1$ rad/s

$\frac{\omega_n}{Q} = 6 \rightarrow Q = \frac{\omega_n}{6} = \frac{1}{6}$

open loop → $Q = 1/6$

closed loop

closed loop → $Q = 1$

① $E = A - 35V$

② $V = \frac{E}{s^2+6s+1} = \frac{A - 35V}{s^2+6s+1}$

$V(s^2+6s+1) = A - 35V$

$V(s^2+6s+36) = A$

$G = \frac{V}{A} = \frac{1}{s^2+6s+36}$

$\omega_n^2 = 36 \rightarrow \omega_n = 6$ rad/s

$6 = \frac{\omega_n}{Q} \rightarrow Q = \frac{\omega_n}{6} = \frac{6}{6} = 1$

Blank sheet for Calculations