Exam in Sensor system, 7.5 credits.
Course code: et2009
Date: 2011-01-03

Allowed items on the exam:
Tables of Mathematical formulas.
Calculator.

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Maximum points: 28.
In order to pass the examination with a grade 3 a minimum of 12 points is required.
To get a grade 4 a minimum of 17 points is required, and to get a grade 5 a minimum of 23 points is required.

Give your answer in a readable way and motivate your assumptions.

Good Luck!

Questions of 2 points.

1.
A thermocouple used between 0 and 500 ˚C has the following input-output characteristic

Input T ˚C	0	100	200	300	500
Output E μV	0	5268	10777	16325	27388

a) Find the equation of the ideal straight line.
b) Find the non-linearity at 100 ˚C and 300 ˚C in μV and as a percentage of f.s.d.

2.
A pressure transducer has an output range of 1.0 to 5.0 V at a standard temperature of 20 ˚C, and an output range of 1.2 to 5.2 V at 30 ˚C. Quantify this environmental effect.

3.
A level measurement system consists of three linear elements with sensitivities 0.050, 21.5 and 0.99. Find the system error for a true value input of 5.0 metres.

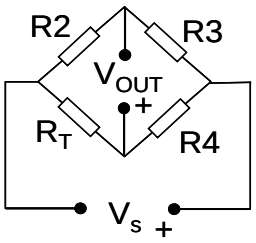
4.
A potentiometer has a supply voltage of 10 V, a resistance of 10 kΩ and a length of 10 cm. A recorder of resistance 10 kΩ is connected across the potentiometer. Calculate the Thevenin equivalent circuit for the sensor and the recorderer voltage for each of the following displacements:
a) 2 cm
b) 8 cm

5.
A platinum resistance sensor has a resistance of 100.0 Ω at 0 ˚C and a temperature coefficient of resistance of 4 x 10^{-3} $^{\circ}C^{-1}$. If the resistance of the sensor is 125 Ω, find the corresponding temperature of the sensor.

6.
The e.m.f. of a type T thermocouple is measured to be 8.561 mV relative to a reference junction temperature of 20 ˚C. Use the attached table to find the temperature of the measured junction.

7.
A parallel plate capacitive displacement sensor consists of two square metal plates 8 cm x 8 cm, separated by a gap of 2 mm. The space between the plates is completely filled by a slab with a dielectric constant of 6.0. If the permittivity of free space is 8.85 pF/m, find the capacitance of the sensor.

8.
A platinum resistance sensor has a resistance of $R_T = R_0(1+\alpha T)$, where R_0=100 Ω
and α=4 x 10^{-3} $^{\circ}C^{-1}$.
a) The above sensor is incorporated into a bridge circuit which has R_3/R_2=100. Find the value of R_4 such that V_{OUT}=0 V at 0 ˚C.
b) Complete the bridge design by calculating the supply voltage required to give V_{OUT}=100 mV at 100 ˚C.

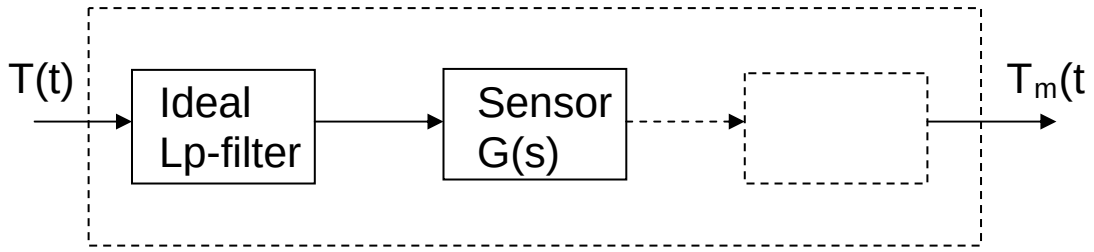


Questions of 4 points.

9.
A temperature measurement system for a gas reactor consists of linear elements and has an overall steady-state sensitivity of unity. The temperature sensor has a time constant of 5.0s; an ideal low-pass filter with a cut-off frequency of 0.05 Hz is also present.
The input temperature signal is periodic with period 63 s and can be approximated by the Fourier series:

$$T(t) = 10\left(\sin(\omega_0 t) + \frac{1}{2}\sin(2\omega_0 t) + \frac{1}{3}\sin(3\omega_0 t) + \frac{1}{4}\sin(4\omega_0 t) \right)$$

where ω_0 is the angular frequency of the fundamental component.



$G(s) = \dfrac{1}{(1+\tau s)}$ where τ is the time constant.

The dynamics of the system is determined by the first-order transfer function G(s) of the sensing element.

Calculate expressions for the time response of:
a) the system output signal $T_m(t)$.
b) the system dynamic error.

Note:
An ideal low-pass filter has a gain of one and zero phase shift up to the cut-off frequency. The gain is zero above the cut-off frequency.

10.
A thermocouple of type T is to be used to measure temperatures between 0 and 300 °C.
The e.m.f. values are as given in the attached table.

a) Find the non-linearity at 100 °C and 200 °C as a percentage of full scale.

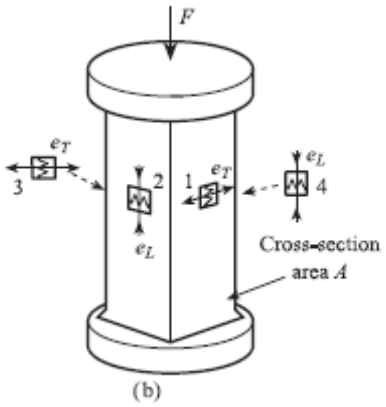
b) Between 100 °C and 200 °C the thermocouple e.m.f. is approximated by:

$$E_{T,0} = a_1 T + a_2 T^2 .$$

Calculate a_1 and a_2.

c) The e.m.f. is 5761 μV relative to a reference junction of 20 °C.
Use the result of b) to estimate the measured junction temperature.

11.
A load cell consists of a domed vertical steel cylinder 20 cm high and 15 cm in diameter. Four flat surfaces, at right angles to each other, are cut on the vertical surface so as to form 10 cm squares. Resistance strain gauges are attached to these flat surfaces so that two gauges (on opposite faces) suffer longitudinal compression and two gauges (on the other pair of opposite faces) suffer transverse tension.



The strain gauges have the following specification:
Resistance = 100 Ω
Gauge factor = 2.1
Maximum gauge current = 30 mA

Young's modulus for steel: E= 2.1×10^{11} Nm^{-2}
Poisson's ratio for steel: υ= 0.29

Some useful formulas:

$$e = \frac{\nabla l}{l}$$

$$e_L = \frac{F}{A \cdot E}$$

$$e_T = -\upsilon \cdot e_L$$

a) Calculate the resistance of the strain gauges for a compressive force F=10^5 N.

b) The gauges are connected in a temperature-compensated bridge and the out-of-balance signal is input to a differential amplifier. Calculate the minimum amplifier gain if the amplifier output voltage is to be 1 V when F=10^5 N.

Table Prob. 22 e.m.f. in mV for type T thermocouple (measured junction at T °C, reference junction at 0 °C).

Temp. °C	0	1	2	3	4	5	6	7	8	9	10
0	0.000	0.039	0.078	0.117	0.156	0.195	0.234	0.273	0.312	0.351	0.391
10	0.391	0.430	0.470	0.510	0.549	0.589	0.629	0.669	0.709	0.749	0.789
20	0.789	0.830	0.870	0.911	0.951	0.992	1.032	1.073	1.114	1.155	1.196
30	1.196	1.237	1.279	1.320	1.361	1.403	1.444	1.486	1.528	1.569	1.611
40	1.611	1.653	1.695	1.738	1.780	1.822	1.865	1.907	1.950	1.992	2.035
50	2.035	2.078	2.121	2.164	2.207	2.250	2.294	2.337	2.380	2.424	2.467
60	2.467	2.511	2.555	2.599	2.643	2.687	2.731	2.775	2.819	2.864	2.908
70	2.908	2.953	2.997	3.042	3.087	3.131	3.176	3.221	3.266	3.312	3.357
80	3.357	3.402	3.447	3.493	3.538	3.584	3.630	3.676	3.721	3.767	3.813
90	3.813	3.859	3.906	3.952	3.998	4.044	4.091	4.137	4.184	4.231	4.277
100	4.277	4.324	4.371	4.418	4.465	4.512	4.559	4.607	4.654	4.701	4.749
110	4.749	4.796	4.844	4.891	4.939	4.987	5.035	5.083	5.131	5.179	5.227
120	5.227	5.275	5.324	5.372	5.420	5.469	5.517	5.566	5.615	5.663	5.712
130	5.712	5.761	5.810	5.859	5.908	5.957	6.007	6.056	6.105	6.155	6.204
140	6.204	6.254	6.303	6.353	6.403	6.452	6.502	6.552	6.602	6.652	6.702
150	6.702	6.753	6.803	6.853	6.903	6.954	7.004	7.055	7.106	7.156	7.207
160	7.207	7.258	7.309	7.360	7.411	7.462	7.513	7.564	7.615	7.666	7.718
170	7.718	7.769	7.821	7.872	7.924	7.975	8.027	8.079	8.131	8.183	8.235
180	8.235	8.287	8.339	8.391	8.443	8.495	8.548	8.600	8.652	8.705	8.757
190	8.757	8.810	8.863	8.915	8.968	9.021	9.074	9.127	9.180	9.233	9.286
200	9.286	9.339	9.392	9.446	9.499	9.553	9.606	9.659	9.713	9.767	9.820
210	9.820	9.874	9.928	9.982	10.036	10.090	10.144	10.198	10.252	10.306	10.360
220	10.360	10.414	10.469	10.523	10.578	10.632	10.687	10.741	10.796	10.851	10.905
230	10.905	10.960	11.015	11.070	11.125	11.180	11.235	11.290	11.345	11.401	11.456
240	11.456	11.511	11.566	11.622	11.677	11.733	11.788	11.844	11.900	11.956	12.011
250	12.011	12.067	12.123	12.179	12.235	12.291	12.347	12.403	12.459	12.515	12.572
260	12.572	12.628	12.684	12.741	12.797	12.854	12.910	12.967	13.024	13.080	13.137
270	13.137	13.194	13.251	13.307	13.364	13.421	13.478	13.535	13.592	13.650	13.707
280	13.707	13.764	13.821	13.879	13.936	13.993	14.051	14.108	14.166	14.223	14.281
290	14.281	14.339	14.396	14.454	14.512	14.570	14.628	14.686	14.744	14.802	14.860
300	14.860	14.918	14.976	15.034	15.092	15.151	15.209	15.267	15.326	15.384	15.443
310	15.443	15.501	15.560	15.619	15.677	15.736	15.795	15.853	15.912	15.971	16.030
320	16.030	16.089	16.148	16.207	16.266	16.325	16.384	16.444	16.503	16.562	16.621
330	16.621	16.681	16.740	16.800	16.859	16.919	16.978	17.038	17.097	17.157	17.217
340	17.217	17.277	17.336	17.396	17.456	17.516	17.576	17.636	17.696	17.756	17.816