

Exam in Sensor system, 7.5 credits.

Course code: et2009

Date: 2011-05-27

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 differential pressure transmitter has an input range of 0 to 2×10^4 Pa and an output range of 4 to 20 mA. Find the equation of the ideal straight line.

2.

A level transducer has an output range of 0 to 10 V. For a 3 metre level, the output voltage for a falling level is 3.05 V and for a rising level 2.95 V. Find the hysteresis as a percentage of span.

3.

A force measurement system consists of four elements with sensitivities 10^{-2} , 5×10^{-2} , 10^3 and 1.9. Find the system error for a true value input of 10 kN.

4.

A potentiometer displacement sensor has a supply voltage of 15 V and a resistance of 50 k Ω . The fractional displacement of the wiper is 0.3. Find the Thévenin voltage and resistance for the circuit.

5.

A linear thermocouple with a sensitivity of 0.04 mV/ $^{\circ}\text{C}$ and resistance of 100 Ω is connected to a load with a resistance of 1 k Ω . Find the voltage across the load for a temperature of 250 $^{\circ}\text{C}$.

6.

Table Prob. 22 (last page in the exam) gives values for the e.m.f. of a Type T thermocouple relative to a reference junction temperature of 0 $^{\circ}\text{C}$. Use the table to calculate:

(a) the percentage non-linearity at 150 $^{\circ}\text{C}$ if the temperature range is 0 to 300 $^{\circ}\text{C}$;

(b) the temperature inside a vessel if an e.m.f. of 11.5 mV is measured relative to a reference junction of 20 $^{\circ}\text{C}$.

7.

A force sensor includes an elastic spring with a stiffness of 10^6 Nm $^{-1}$. If the force input has a range of 0 to 5 kN, find the corresponding displacement output range.

8.

A thermistor has constants $K = 0.1$ Ω , $\beta = 3200$ K. Find the resistance at the ice point.

Hints: $R_{\theta} = K \exp\left(\frac{\beta}{\theta}\right)$

Questions of 4 points.

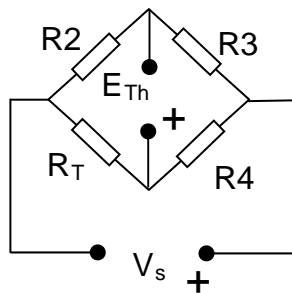
9.

A platinum resistance sensor has a resistance of 100Ω at 0°C and a temperature coefficient of resistance of $4 \times 10^{-3} \text{ }^\circ\text{C}^{-1}$.

a) Given that a 5 V supply is available, design a deflection bridge giving an output of 0 to 20 mV for an input range of 0 to 100°C . Assuming that E_{Th} is measured with a detector of infinite impedance calculate the values of R_2 , R_3 , and R_4 . (2p)

b) Calculate the output when the detector impedance is 5 k Ω . (2p)

Hints:

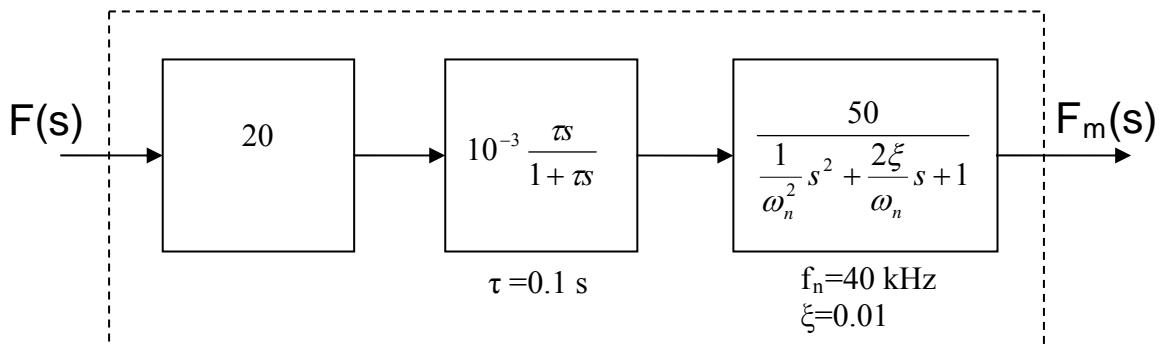


$$R_T = R_0(1 + \alpha T) \text{ (the model equation for the sensor)}$$

$$E_{Th} = V_s \frac{R_2}{R_3} \alpha T \text{ (the unbalanced output of the bridge, valid if } R_3/R_2 \text{ is large)}$$

10.

A force measurement system consisting of a piezoelectric crystal, charge amplifier and recorder is shown in the figure below:



A force input signal:

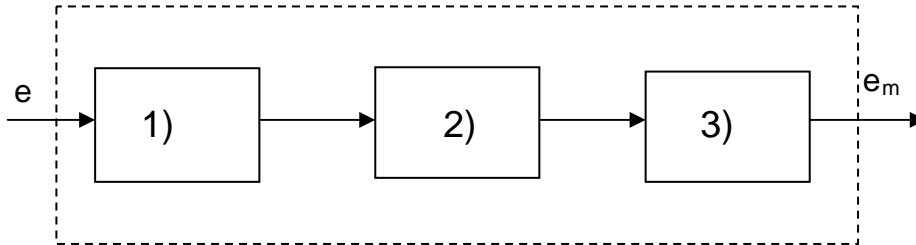
$$F(t) = 50 \left(\sin(400t) + \frac{1}{3} \sin(1200t) + \frac{1}{5} \sin(2000t) \right) \text{ N}$$

is applied to the system.

Verify that the system is suitable for this application, e.g. that $|G(\omega)| \approx 1$ and $\arg G(\omega) \approx 0^\circ$ for values of ω present in the input signal.

11.

a) A strain measurement system consists of strain gauges connected in a Wheatstone bridge, a current transmitter and a recorder. The model equation, and parameters for each element are presented below. Assuming that all probability distributions are normal, calculate the mean and standard deviation for the output when the true strain is $e=2.3 \times 10^{-4}$. (2p)



1) Strain gauges connected in a Wheatstone bridge:

Model equation: $E = \frac{1}{2} V_s G e$ [V]

Mean values: $V_s=10.0$ V, $G=2.10$.

Standard deviations: $\sigma_{V_s}=10$ mV, $\sigma_G=0.02$.

2) Current transmitter:

4 to 20 mA output.

ΔT_a = deviation of ambient temperature from 20 °C.

Model equation: $i=a+KE + K_M E \Delta T_a + K_I \Delta T_a$ [mA]

Mean values: $a=4$ mA, $K=1.52$ mA/mV, $K_M=0.005$ mA/(mV °C), $K_I= 0.01$ mA/°C , $\Delta T_a= +10$ °C.

Standard deviations: $\sigma_a=0.01$ mA, $\sigma_{\Delta T_a}=5.2$ °C, $\sigma_K= \sigma_{K_M}=\sigma_{K_I}=0.0$.

3) Recorder:

Model equation: $e_M=Ki + a$

Mean values: $K = \frac{10^{-3}}{16}$ 1/mA, $a = -\frac{10^{-3}}{4}$.

Standard deviations: $\sigma_a=10^{-5}$, $\sigma_K=0.0$.

b) A repeatability measurement on the above system yielded the following histogram.

Present the measured strain e_m on the format: $e_m = m \pm \sigma$.

Where m is the mean value and σ is the standard deviation. (2p)

$e_m \times 10^{-3}$	h
0.2196	7
0.2247	10
0.2298	41
0.2350	38
0.2401	55
0.2453	56
0.2504	45
0.2555	29
0.2607	12
0.2658	7

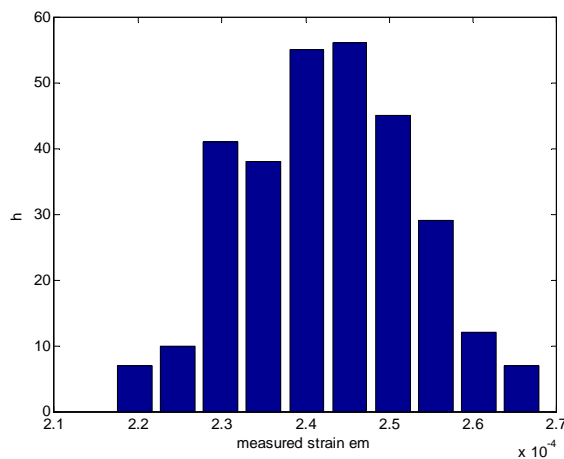


Table Prob. 22 e.m.f. in mV for type T thermocouple (measured junction at T °C, reference junction at 0 °C).

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