Tutorial – 14

Exam Text of 09/09/2005 (Problem 1)

Preamplifier	**Strain gauges**
$A_{pa}=200$	R_S = 100 Ω
$S_V^{1/2} = 4nV/Hz^{1/2}$ white noise power density (unilateral)	Gauge Factor G = 2,5
$S_I^{1/2} = 4pA/Hz^{1/2}$ white noise power density (unilateral)	P_{MAX} =1 μW
f_{pa} = 160kHz upper band-limit (single pole)	
frequency corner 1/f on S_V = 500Hz	
frequency corner 1/f on S_I =1000Hz	

Two metal strain gauges are placed on a metal bar to measure extrusion and compression deformations and to compensate for the thermal effects on the sensors. The deformations to be measured can be both static and dynamic and you want to detect small deformations and track them over time sampling every 5ms. The maximum power dissipated on each sensor must be limited below 1 μW.

A differential preamplifier with the parameters specified above is used to pick-up the signal.

a) Select and explain the circuit configuration to be used to obtain the electrical signal that carries the deformation information. Select the parameters of the circuit to meet the requirements above reported and quantitatively evaluate the transduction factor from deformation (in microstrain) to electrical signal.

b) Select and discuss a filtering method to extract the signal with the required sensitivity. Select the filter parameters and evaluate the minimum deformation value that can be measured in this case.

The metal bar is connected to a motor rotating at about 2500 rpm and the induced vibration in the structure at the motor rotation frequency is to be measured. The minimum sensitivity required in this case is 10microstrain.

c) Select an additional filtering method that allows you to extract the vibration at the frequency of the motor from the overall deformation and measure it separately. Describe the structure and select the parameters of the apparatus to be used. Evaluate in these conditions the minimum amplitude of the deformation that can be measured.

d) discuss if and how it is possible to measure the harmonics of the signal coming from the vibrations induced by the motor with the selected acquisition chain. If it is possible, discuss and explain what is the maximum frequency of the harmonic that can be measured.

A) To meet the power dissipation requirement of the sensor (assuming a constant power supply), we need:

$$\boldsymbol{P_{sensor} = \left(\frac{V_A}{2}\right)^2 \cdot \frac{1}{R} \rightarrow V_A = \sqrt{4P_{sensor}R} \cong 20\ mV}$$

The transduction factor can be expressed as:

$$\boldsymbol{V_{out} = \frac{V_A}{4} G \cdot \varepsilon \rightarrow F = \frac{V_{out}}{\varepsilon} = \frac{V_A}{4} G \cong 3.1 \frac{mV}{\mu strain}}$$

B) We can use a LIA with a sinusoidal modulation at $f_M = f_A = 10\ KHz$, and a low-pass filter with a frequency high enough to not affect the signal:

$$BW_{Signal} \leq \frac{1}{2T_S} \cong 100\ Hz \rightarrow f_{LPF} = 1\ KHz$$

The total noise of the system can be written as:

$$\sigma_v = \sqrt{2\left[S_V\left(1+\frac{f_{c,V}}{f_A}\right) + S_I R^2\left(1+\frac{f_{c,I}}{f_A}\right)\right]\frac{\pi}{2} f_{LPF}} \cong 230\ nV$$

Given we are using a sinusoidally modulated power supply, we can increase V_A of a factor $\sqrt{2}$, thus:

$$V_{out} = \frac{V_A}{4} G \cdot \varepsilon \rightarrow F = \frac{V_{out}}{\varepsilon} = \frac{V_A}{4} G \cong 8.75 \frac{mV}{\mu strain}$$

The minimum measurable strain is:

$$\varepsilon_{min} = \frac{V_{out,min}}{F} = \frac{\sigma_i}{F} \cong 13.5\ \mu strain$$

C) The rotation at $2500\ RPM$ introduces a vibration at a frequency:

$$f_{rot} = \frac{2500}{60} \cong 41.67\ Hz$$

After the first LIA (the one with $f_M = 10\ KHz$) the spectrum is the same as before the modulation, (component introduced by the rotation at $41.67\ Hz$)

Using a second LIA with $f_m = 41.67\ Hz$ and a low-pass frequency $f_{LPF} = 1\ Hz$ we can extract the information on the vibration.

The total noise id equal to:

$$\sigma_v = \sqrt{2 \cdot 2[S_V + S_I R^2]\frac{\pi}{2} f_{LPF}} \cong 10.1\ nV$$

The minimum measurable strain is:

$$\varepsilon_{min} = \frac{V_{out,min}}{F} = \frac{\sigma_i}{F} \cong 1.1\ \mu strain$$

D) The first LIA is followed by a LPF with $f_{LPF} = 1\ KHz$ we can detect all the harmonics with a frequency below f_{LPF}, thus:

$$N = \frac{f_{LPF}}{f_{rot}} \cong 23.99 \rightarrow N = 23$$

Nevertheless, we are sampling the system each $5\ ms$, limiting the bandwidth of the system to $100\ Hz$, we can thus collect only the fundamental and the first harmonic:

$$f_{rot} = 41.67\ Hz$$
$$f_{rot,2} = 83.34\ Hz$$

If we modify the second low-pass filter increasing its frequency to $f_{LPF} = 100\ Hz$, we are able to detect also the second harmonic:

$$f_{rot} = 41.67\ Hz \rightarrow 0\ Hz$$
$$f_{rot,2} = 83.34\ Hz \rightarrow 41.67\ Hz$$
$$f_{rot,3} = 125\ Hz \rightarrow 83.34\ Hz$$

Using a series of LIA with increasing reference frequency we can move all the harmonic below the $1\ KHz$ cut frequency to DC, allowing us the detection of all the components, this however increases the noise by a factor $\sqrt{2}$ for each LIA.