Chapter 1 Exercises and Questions

1-1 What are Biomedical Sensors ?

> Biomedical sensors are special electronic devices which can transfer the various non-electrical quantities in biomedical fields into easily detected electrical quantities. They expand the sensing function of the human sense organ.

1-2 To take examples to explain the classification of biomedical sensors.

> - Physical sensors: It refers to the sensor made according to physical nature and effect. This kind of sensor is mostly represented by sensors such as metal resistance strain sensors, semiconductor piezoresistive sensors, piezoelectric sensors, photoelectric sensors.
> - Chemical sensors: It refers to the sensor made according to chemical nature and effect. This kind of sensors usually uses ion-selective sensitive film to transform non-electrical quantities such as a chemical component, content, density, to related electrical quantities, such as various ion sensitive electrodes, ion sensitive tubes, humidity sensors.
> - Biological sensors or biosensors: It refers to the sensors using biological active material as a molecule recognition system. This kind of sensors usually uses enzyme to catalyze some biochemical reactions or detect the types and contents of large organic molecules through some specific combination. It is a kind of newly developed sensors in the second half of the century, and examples include enzyme sensors, microorganism sensors, immunity sensors, tissue sensors, DNA sensors, etc.

1-3 To take examples to list the specific requirements of biomedical sensors.

> The first and the most important issue in manufacturing sensors is the material selection. The metallic materials used in sensors should be inert metals such as stainless steels, titanium alloys. The polymers should be degradable materials, such as PMMA, silicones. All the materials used for sensor structure should be strictly selected to avoid serious host response and should function normally after being inserted into the animal body. The rigidness and flexibility of materials should also meet the requirement since the implanted sensors need to adjust to anatomical structures of the measured objects.
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> Secondly, a series of experiments on animals and clinical trails should be carried out before clinical applications. Besides choosing inert and least harmful materials at present, we still have to do full sequence tests for biocompatibility because the implanted sensors are under a different physiological environment.
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> Finally, we apply biological methods to evaluate the host responses. The in vivo biocompatibility can be evaluated by analyzing the cell population present, measuring the mediator and metabolite cells excreted, and analyzing the morphologic characteristics of the tissue and the capsule thickness around the implant.

1-4 What are Biomimetic Sensors ?

> Biomimetic sensors are modern sensors applied new detection principle, which formed by using the immobilized cells, enzymes or other bioactive substances to cooperate with the transducer. They mimic the human body to have good features such as high sensitivity, good selectivity, and high density.

1-5 To take examples to describe the trends of modern biomedical sensors and measurement.

> The trends of modern biomedical sensors and measurement are to become smart, micro, multi-parameter, remote-control and non-invasive.
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> - Smart: such as monitoring gesture, posture or respiration.
> - Micro: 1960s Vacuum tube and Normal sensor(cm); 2010s Nano electro-mechanical system and Nano-sensor(nm).
> - Multi-parameter: 1980s integrate blood electrolyte sensors which could monitor 5 parameters; nowadays with the development of MEMS technology, sensors can detect more kinds of parameters and become more precise.
> - Remote-control: biomimetic sensors, using biochips to control sensors over distances.
> - Non-invasive: Traditional body fluids are required to be extracted from patients, and most are invasive or in vitro measurements. Nowadays, percutaneous blood gas sensors which can monitor blood gas non-invasively (Po2, Pco2), and the use of non-blood measuring to monitor blood glucose, urea, etc.

Chapter 2 Exercises and Questions

2-1 One first-order sensor is used to measure the 100Hz sine signal. If the limit of amplitude error is within ±5%, what is value of the time constant ? If the sensor is used to measure the 50Hz sine signal, what are the values for limit of amplitude error and phase error ?

$$|\delta_A| = |1 - A(\omega)| \times 100\% = |1 - \frac{1}{\sqrt{1+(\omega\tau)^2}}| = 5\%$$
$$\Rightarrow \qquad \tau = \frac{\sqrt{(\frac{1}{1-\delta_A})^2 - 1}}{2\pi f} = \frac{\sqrt{(\frac{1}{0.95})^2 - 1}}{200\pi} = 5.23 \times 10^{-4} s$$

To measure the 50Hz sine signal,

$$\delta_A = 1 - A(\omega') = 1 - \frac{1}{\sqrt{1+(\omega'\tau)^2}} = 1.3\%$$
$$\delta_\varphi = \varphi(\omega') = -\tan^{-1}(\omega'\tau) = -9.3^\circ$$

2-2 The natural frequency of a second-order force sensor is 800Hz, and the damping ratio ξ is 0.14. When using this sensor to measure 400Hz sine force, what will be the values of amplitude A(ω) and phase φ(ω)? If the damping ratio ξ is 0.7, how will the values of A(ω) and φ(ω) change?

$$\begin{aligned}
\text{second-order sensor, } \omega_0 &= 800Hz, \xi = 0.14, \omega = 400Hz \\
H(s) &= \frac{\omega_0^2 K}{s^2 + 2\xi\omega_0 s + \omega_0^2} \\
A(\omega) &= \frac{K}{\sqrt{[1-(\omega/\omega_0)^2]^2 + 4\xi^2(\omega/\omega_0)^2}} \\
&= \frac{K}{\sqrt{[1-(400/800)^2]^2 + 4 \times 0.14^2 \times (400/800)^2}} \\
&= 1.31K \\
\varphi(\omega) &= -\arctan\left[\frac{2\xi(\omega/\omega_0)}{1-(\omega/\omega_0)^2}\right] \\
&= -arctan\left[\frac{2 \times 0.14 \times (400/800)}{1-(400/800)^2}\right] \\
&= -10.57^\circ \\
\text{when } \xi &= 0.7 \\
A(\omega) &= \frac{K}{\sqrt{[1-(\omega/\omega_0)^2]^2 + 4\xi^2(\omega/\omega_0)^2}} \\
&= \frac{K}{\sqrt{[1-(400/800)^2]^2 + 4 \times 0.7^2 \times (400/800)^2}} \\
&= 0.975K \\
\varphi(\omega) &= -\arctan\left[\frac{2\xi(\omega/\omega_0)}{1-(\omega/\omega_0)^2}\right] \\
&= -arctan\left[\frac{2 \times 0.7 \times (400/800)}{1-(400/800)^2}\right] \\
&= -43.02^\circ
\end{aligned}$$

2-3 What is the difference between the static and dynamic characteristics of the sensors? What are the biocompatibility of sensors and their main classifications?

Static characteristics are measured under the standard static condition, which means no acceleration, no vibration or shock(unless shock is the measurand), that is after all transient effects have stabilized to their final or steady state, such as static sensitivity of the sensor K.

Dynamic characteristics describe the sensor's transient properties, and they are measured in the sensor's responses to the time-varying inputs.

The term 'biocompatibility' is used extensively within biomaterial science. Sensors used for biological detection and medical diagnosis, such as invasive sensors for implanting and monitoring physiological environment in vivo and sensors for monitoring cell or tissue in vitro, must seriously consider biocompatibility in order to avoid hemo- or histo- problems with direct contact.

There are several factors should be considered. Sensors are not supposed to be corroded or toxic. The shape, size and structure of sensors. Sensors must be solid enough & electrically insulated. Sensors can neither give physical activities a burden, nor should they interfere with the normal physiological function. The in vivo sensors used for long term implantation should not cause any vegetation. The structure of the sensor should be easily disinfected.

Blood compatibility: Biomedical sensors used in the cardiovascular system are in direct contact with blood, thus, the reactions between them should be carefully considered.

Histocompatibility: Biomedical sensors implanted out of cardiovascular system are mainly focused on the interaction between the materials and the tissues or organs.

For in Vitro Biomedical Sensors, biocompatibility of the biomedical materials on sensor surfaces must be enhanced to maintain the activity and viability of these samples such as proteins, cells and tissues. Functional proteins such as enzyme, antigen and antibody play an important role as receptors in biomedical sensor systems.

2-4 A linear pressure sensor with a measuring range of -50~150kPa, the corresponding output voltage is -5~5V. When 140kPa pressure is measured by the sensor and the measurement value is 142kPa. What is the absolute error, the relative error and the static sensitivity of sensor.

$$absolute\ error = 142kPa - 140kPa = 2kPa$$
$$relative\ error = \frac{2kPa}{140kPa} \times 100\% = 1.43\%$$
$$static\ sensitivity = \frac{dy}{dx} = \frac{5V - (-5V)}{150kPa - (-50kPa)} = 0.05V/kPa$$