Lecture Three

Generalized Static Characteristics

Introduction

To enable purchasers to compare commercially available instruments and evaluate new instrument designs, quantitative criteria for the performance of instruments are needed. These criteria must clearly specify how well an instrument measures the desired input and how much the output depends on interfering and modifying inputs.

Static characteristics describe the performance of instruments for dc or very low-frequency inputs. The properties of the output for a wide range of constant inputs demonstrate the quality of the measurement, including non-linear and statistical effects. Some sensors and instruments, such as piezo-electric devices, respond only to time-varying inputs and have no static characteristics.

Static Calibration

All the static performance characteristics are obtained in one form or another by a process called static calibration. The calibration procedures involve a comparison of the particular characteristic with either a primary standard, a secondary standard with higher accuracy than the instrument to be calibrated, or an instrument of known accuracy. It checks the instrument against a known standard and subsequently for errors in accuracy.

Scale range and scale span

The region between the limits within which an instrument is designed to operate for measuring, indicating, or recording a physical quantity is called the range of the instruments. The *Scale Range* of an instrument is thus defined as the difference between the largest and smallest reading of the instrument.

Supposing the highest point of calibration is Xmax units. At the same time, the lowest is Xmin units and the calibration is continuous between the two points, the instrument range is between Xmin and Xmax. Many times, it is also said that the instrument range is Xmax. The instrument span is the difference between the highest and the lowest point of calibration. Thus:

$$Span = Xmax - Xmin$$

For example, for a thermometer calibrated between 30°C to 40°C, the range is 30°C to 40°C, but the span is 40 - 30 = 10°C.

The same is true of digital instruments. There is another factor that must be considered while determining the range of the instrument. This is the *Frequency Range*, defined as frequencies over which measurements can be performed with a specified degree of accuracy. For example, a moving iron instrument (used for measuring voltage or current) may have a 0-250 V range and 0-135Hz frequency range.

ACCURACY

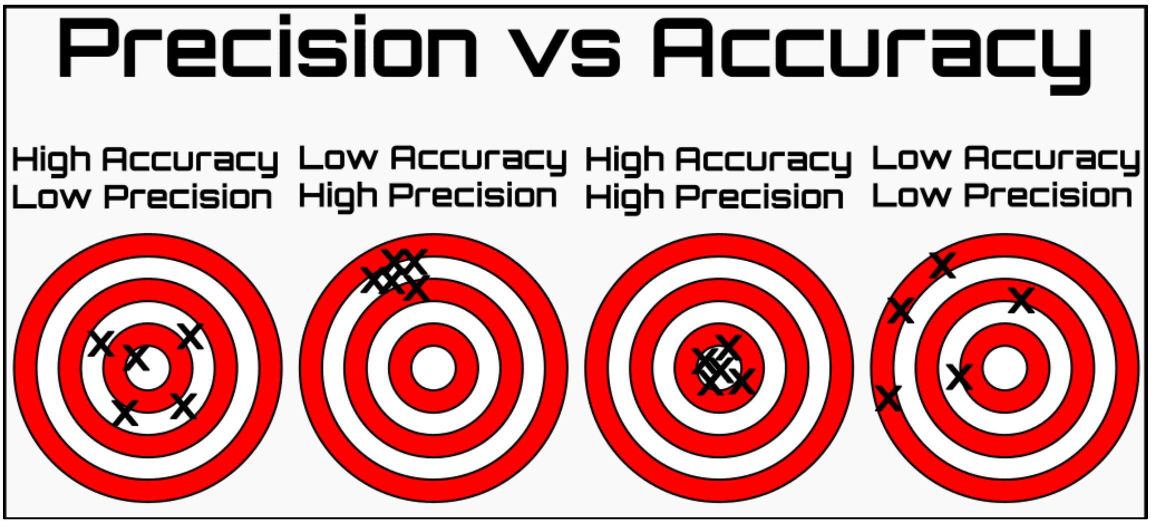
The accuracy of a single measured quantity is the difference between the true value and the measured value divided by the true value.

$$Accuracy = \frac{True\ value - Measured\ Value}{True\ Value}$$

This ratio is usually expressed as a percent. The accuracy can be expressed as the percent of reading, percent of full scale, ± number of digits for digital readouts, or ± 1/2 the smallest division on an analog scale. For example, a converter may be termed 12-bit accurate if its error is 1 part in 4096. The sources of error contribute to a converter's inaccuracy or linear, gain, error, and offset error. Full scale is usually assumed if accuracy is expressed simply as a percentage.

PRECISION

The precision of a measurement expresses the number of distinguishable alternatives from which a given result is selected. For example, a meter that displays a reading of 2.434V is more precise than one that displays a reading of 2.43V. *High-precision measurements do not imply high accuracy*, however, because precision makes no comparison to the true value.



RESOLUTION

The smallest incremental quantity that can be measured with certainty is the resolution. Another definition is **resolution:** which is the smallest increment of measurement, movement, or other output that a machine, instrument, or component is capable of making. If the measured quantity starts from zero, the term threshold is synonymous with resolution. The resolution expresses the degree to which nearly equal values of a quantity can be discriminated. The car's speedometer, with 20Km/h subdivisions, is an example of resolution. The resolution of the A/D converter is a measure of the number of discrete digital codes it can handle and is expressed as a number of bits (binary). For example, for an 8-bit converter, the resolution is 1 part in 256.

REPRODUCIBILITY

The ability of an instrument to give the same output for equal inputs applied over some period of time is called reproducibility or repeatability. It is the closeness of output readings when the same input is used repetitively over a short period. The measurement is made on the same instrument, at the exact location, by the same observer, and under the same measurement conditions. It may be specified in terms of units for a given period of time. Reproducibility relates to the closeness of output readings for the same input when there are changes in the method of measurement, observer, measuring instrument location, conditions of use, and time of measurement. Perfect reproducibility means that the instrument has no drift. Drift means that with a given input, the measured values vary with time. Reproducibility is specified in terms of scale readings over a given period of time. On the other hand, Repeatability is defined as the variation of scale reading and is random in nature.

STATISTICAL CONTROL

The accuracy of an instrument is not meaningful unless all factors, such as the environment and the method of use, are considered. Statistical control ensures that random variations in measured quantities resulting from all factors influencing the measurement process are tolerable. Any systematic errors or biases can be removed by calibration and correction factors, but random variations pose a more complex problem. The measurand and/or the instrument may introduce statistical variations that make outputs unreproducible. If the cause of this variability cannot be eliminated, then the statistical analysis must be used to determine the error variation. Making multiple measurements and averaging the results can improve the estimate of the true value.

Drift

Drift is a departure in the output of the instrument over a period of time. An instrument is said to have no drift if it produces the same reading at different times for the same variation in the measured variable. Drift is unrelated to the operating conditions or load. The following factors could contribute to the drift in the instruments:

i) Wear and tear
ii) Mechanical vibrations
iii) Stresses developed in the parts of the instrument
iv) Temperature variations
v) Stray electric and magnetic fields
vi) Thermal emf

Drift can occur in the flow meters due to wear of the nozzle or venturi. It may occur in the resistance thermometer due to metal contamination etc. Drift may be of any of the following types;

a) Zero drift: Drift is called zero drift if the whole instrument calibration shifts over by the same amount. It may be due to shifting of the pointer or permanent set.

b) Span drift: If the calibration from zero upwards changes proportionately, it is called span drift. It may be due to the change in the spring gradient.

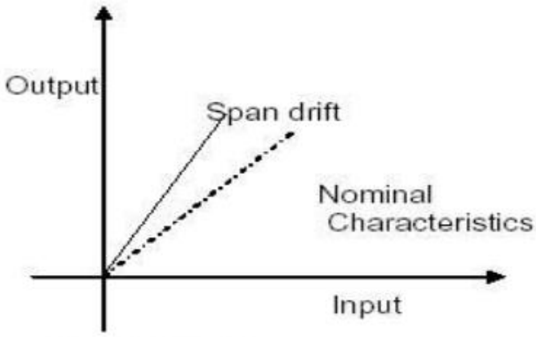
c) Zonal drift: When the drift occurs only over a portion of the span of the instrument it is called zonal drift.

ZERO DRIFT

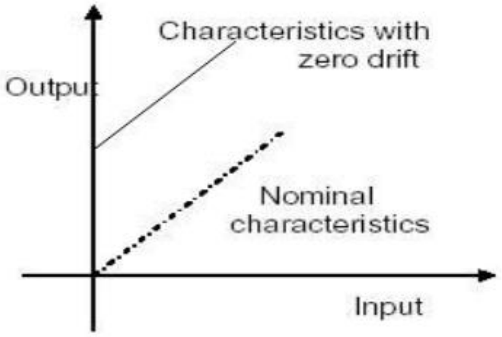
Interfering and/or modifying inputs can affect the static calibration curve in several ways. The following factors can cause zero drift: manufacturing misalignment, variations in ambient temperature, hysteresis, vibration, shock, and sensitivity to forces from undesired directions. Zero drift occurs when all output values increase or decrease by the same absolute amount. The slope of the sensitivity curve is unchanged, but the output-axis intercept increases or decreases, as shown in Figure (2).

SENSITIVITY DRIFT

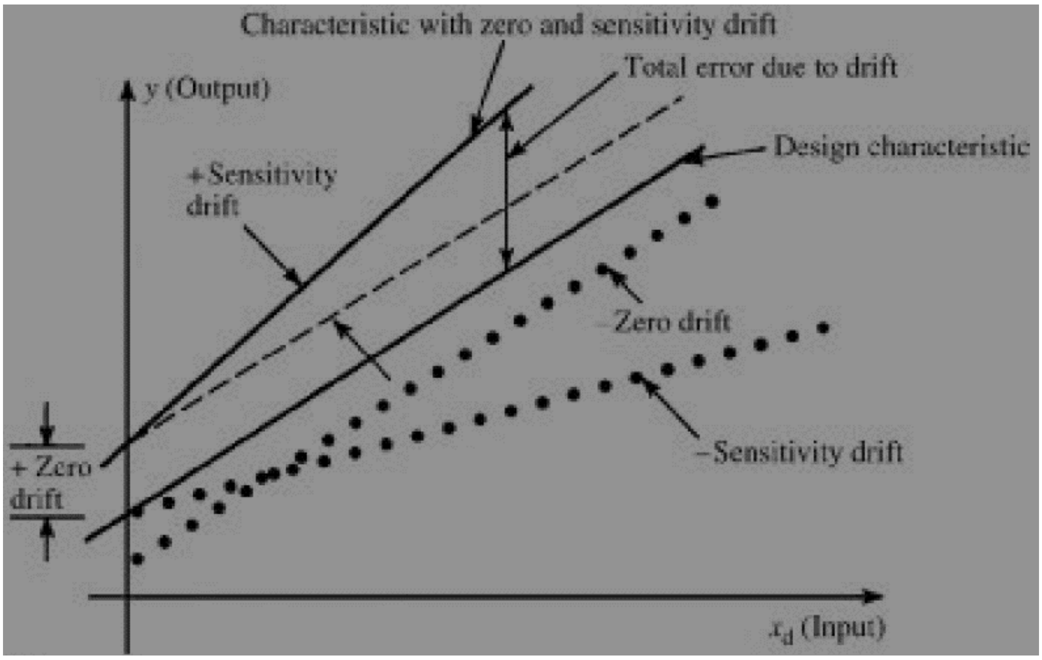
When the calibration curve's slope changes due to an interfering and/ or modifying input, a drift in sensitivity results. Sensitivity drift causes an error that is proportional to the magnitude of the input. Sensitivity drift can result from manufacturing tolerances, variations in power supply, nonlinearities, and ambient temperature and pressure changes. Variations in the ECG amplifier voltage gain due to fluctuations in dc power supply voltage or changes in temperature are examples of sensitivity drift.



(Fig) span drift

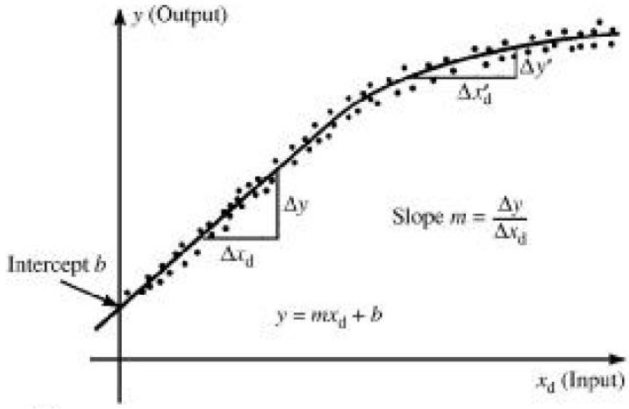


(fig) zero drif



STATIC SENSITIVITY

The static sensitivity of an instrument or system is the ratio of the incremental output quantity to the incremental input quantity. The sensitivity is expressed as the slope of the calibration curve if the ordinates are expressed in actual units. When a calibration curve is linear the slope of the calibration curve is constant. For this case the sensitivity is constant over the entire range of the instrument. However, if the curve is not a straight line, the sensitivity varies with the input.



$$m = \frac{n\sum x_d y \quad (\sum x_d)(\sum y)}{n\sum x_d^2 - (\sum x_d)^2}$$

$$b = \frac{(\sum y)(\sum x_d^2) - (\sum x_d y)(\sum x_d)}{n\sum x_d^2 \quad (\sum x_d)^2}$$

$$y = mx_d + b$$

The <u>static sensitivity for modulating sensors</u> is usually given per volt of excitation, because the output voltage is proportional to the excitation voltage. For example, the static sensitivity for a blood-pressure sensor containing a strain-gage bridge might be 50μV.V^{-1} mm Hg^{-1}. An instrument's sensitivity should be high; therefore, the instrument should not have a range greatly exceeding the value to be measured. However, some margin should be kept for any accidental overloads. It may be noted that

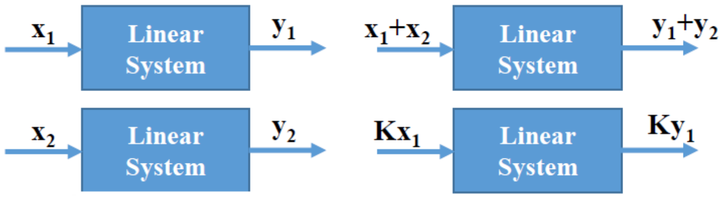
i) A sensitive instrument can quickly detect a slight change in measurement.

ii) Measuring instruments that have smaller scale parts are more sensitive.

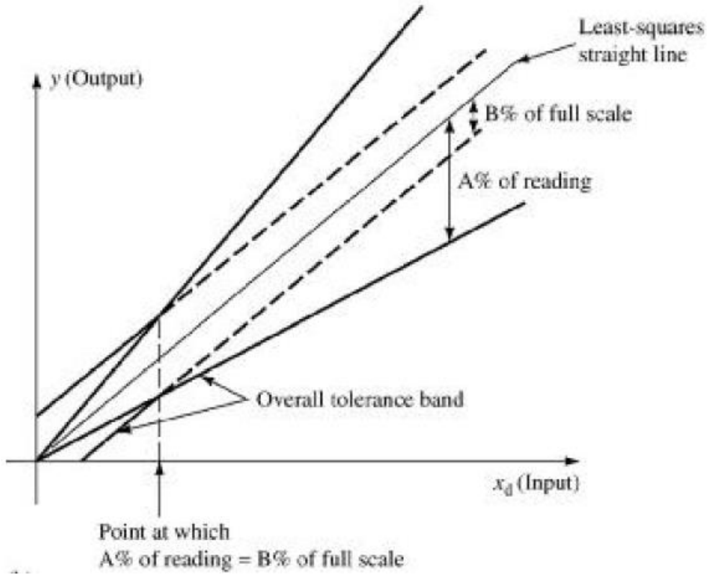
iii) Sensitive instruments need not necessarily be accurate.

Linearity

A system or element is considered linear if it has properties such that if y_1 is the response to x_1 and y_2 is the response to x_2, then $y_1 + y_2$ is the response to $x_1 + x_2$, and Ky_1 is the response to Kx_1.



__In practice__, no instrument has a perfectly linear response, so a measure of deviation from linearity is needed. Independent nonlinearity expresses the maximal deviation of points from the least squares fitted line as either ±A% of the reading or ±B% of full scale, whichever is greater (that is, whichever permits the more significant error).



Linearity of out-input relation is considered one of the best characteristics of the measurement system because of the convenience of scale reading. The non-linear relation does not lead to any inaccuracy, but it is better to keep the linearity as small as possible, by choosing the operating range instrument so that the input-output relation is linear. Lack of linearity thus does not necessarily degrade sensor performance. If the nonlinearity can be modeled and an appropriate correction applied to the measurement before it is used for monitoring and control, the effect of the non-linearity can be eliminated.

INPUT RANGES

Several maximal ranges of allowed input quantities are applicable for various conditions. Minimal resolvable inputs impose a lower bound on the quantity to be measured. The typical linear operating range specifies the maximal or near-maximal inputs that give linear outputs. The maximal operating range is the largest input that does not damage the instrument.

INPUT IMPEDANCE

Because biomedical sensors and instruments usually convert nonelectric quantities into voltage or current, we introduce a generalized concept of input impedance. This is necessary to properly evaluate the degree to which instruments disturb the quantity being measured. For every desired input X_{d1} that we seek to measure, there is another implicit input quantity X_{d2} such that the product $X_{d1}.X_{d2}$ has the dimensions of power. This product represents the instantaneous energy transfer rate across the tissue-sensor interface.

The generalized input impedance Z_x is the ratio of the phasor equivalent of a steady-state sinusoidal effort input variable (voltage, force, pressure) to the phasor equivalent of a steady-state sinusoidal flow input variable (current, velocity, flow).

$$Z_x = \frac{X_{d1}}{X_{d2}} = \frac{effort\ variable}{flow\ variable}$$

The power P is the time rate of energy transfer from the measurement medium.

$$P = X_{d1}X_{d2} = \frac{X_{d1}^2}{Z_x} = Z_x X_{d2}^2$$

To minimize P, when measuring effort variables X_{d1}, we should make the generalized *input impedance as large as possible*.

***Q:** What is the difference between precision and accuracy?*

***Q:** Suggest a solution for this problem: A high-precision instrument provides low-accurate readings.*

Q: Give an example of resolution in Medical Devices.