Ratiometric measurements in the context of LVDT-sensor signal conditioning

By Arun T Vemuri, *Systems Architect*
Matthew Sullivan, *Applications Engineer, Sensor Signal Conditioners*

Introduction

Ratiometricity is a common approach for measuring analog-sensor signals for the purpose of conditioning and standardizing the signal for proper operation with an industrial control system. In the context of linear-variable differential-transformer (LVDT) signal conditioning, ratiometric measurement has a specific meaning. In this article, ratiometric measurement is described in general and also in the context of LVDT-sensor signal conditioning in three different stages of the signal chain.

LVDT-sensor signal conditioning

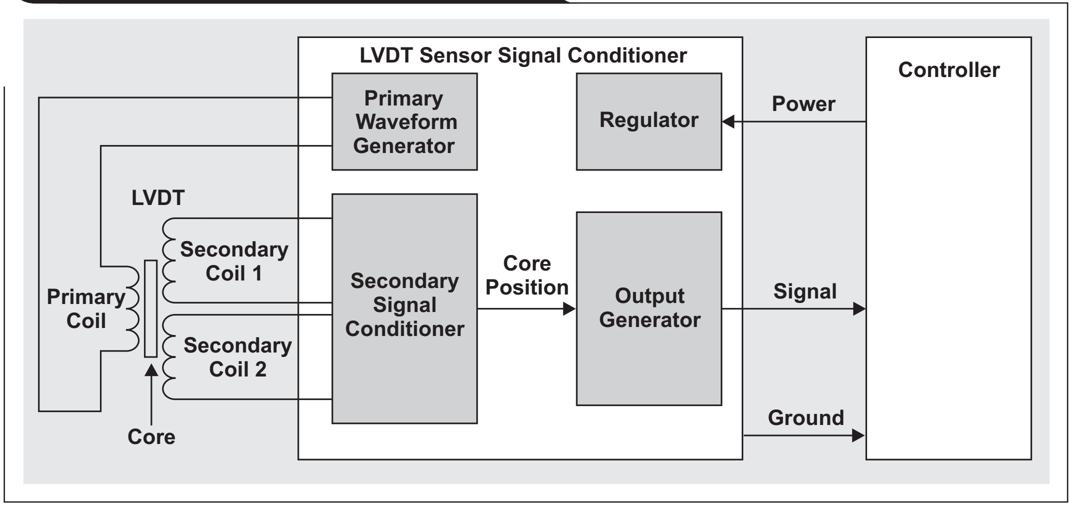
LVDT position sensors are commonly used to measure the position of the moving components in a machine, such as control valves in hydraulic systems and control surfaces in aircraft. LVDTs are popular for their robust, frictionless design, which makes these transformers a great fit for position measurement in harsh environmental conditions. Typically, a LVDT sensor consists of primary coils, secondary coils and a moving core. The core is moved by the object whose position is being measured.

As the core moves, the coupling between the primary and secondary coils changes proportionally. With knowledge of the characteristic nature of this proportion, the position of the core can then be inferred, and in turn, the position of the moving component attached to the core. This is often done through the use of algorithms and other signal processing found in a LVDT-sensor signal conditioner.

The LVDT-sensor signal conditioner excites the primary coil and measures the output voltage of the secondary coils. The PGA970 is a LVDT-sensor signal conditioner from Texas Instruments that has regulators to generate power to the various circuits in the signal conditioner, as well as circuits to generate the signal representing the position of LVDT. The LVDT signal conditioner receives power from an external controller, such as an industrial programmable-logic controller (PLC) or automotive electronic-control unit (ECU), and sends the position signal to the external controller.

Figure 1 shows the block diagram of a typical LVDT-sensor signal conditioner along with the LVDT sensor. Note that the signal conditioner may have additional circuits such as fault detection circuits and calibration circuits. In this article, the primary focus is on the blocks shown in Figure 1.

Figure 1. LVDT sensor signal conditioner



What is ratiometric measurement?

In today's systems, signals are measured for both monitoring and control purposes. One approach to measuring a signal is the absolute method. In this method, the signal of interest, say x, is measured directly. The measurement of x is independent of any other signal or reference, and can be affected by variances from outside conditions such as temperature, power supply variance, and many others.

In a ratiometric method of measurement, the signal of interest is measured with respect to a second signal as a ratio. That is, the ratio is measured. Note that the ratio of two signals is simply expressed mathematically using Equation 1:

$$\text{Ratio}_x = \frac{x}{y} \tag{1}$$

where x is the signal of interest and y is the second signal.

In the ratiometric system, both the signal of interest, x, and a reference signal, y, usually are proportionally similar. Any variance of one will proportionally affect the other. Hence, the ratio effectively remains the same.

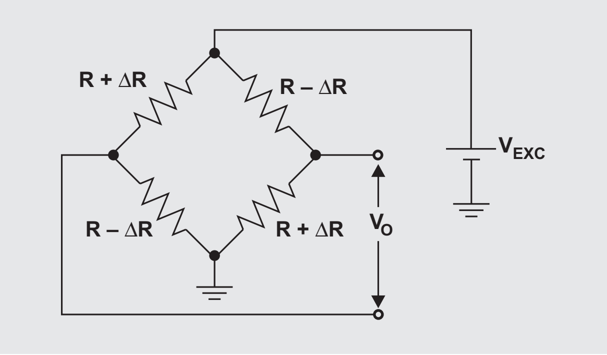
Advantages of ratiometric measurement

Ratiometric measurement may not be possible for in all signal measurements. For example, consider the measurement of thermocouple voltage. The thermocouple output voltage is a function of the junction temperature. In this case, the thermocouple output voltage has to be measured using the absolute method.

To help visualize the difference between the two methods, consider the measurement of the resistance ΔR in a Wheatstone bridge (Figure 2). The Wheatstone bridge is excited by voltage V_{EXC}, and the output voltage is calculated with Equation 2.

$$V_O = \frac{\Delta R}{R} \times V_{EXC} \tag{2}$$

Figure 2. Measurement of resistance in a Wheatstone bridge

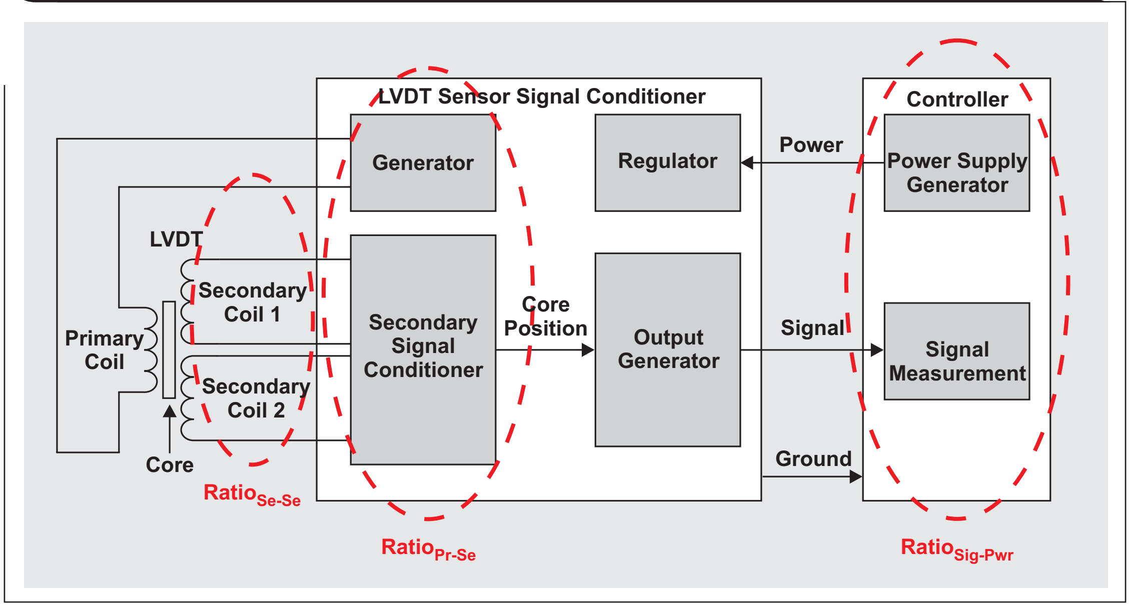


Now, the ratio of the output voltage of the bridge V_O and the excitation voltage V_{EXC} is calculated with Equation 3.

$$\text{Ratio}_O = \frac{\Delta R}{R} \times \frac{V_{EXC}}{V_{EXC}} = \frac{\Delta R}{R} \tag{3}$$

Clearly, one advantage of using ratiometric measurement in the context of a Wheatstone-bridge resistance measurement is that the ratiometric measurement yields the resistance value directly. Another key advantage, which is not obvious at first glance, is the effect of changes in the excitation voltage. If the excitation voltage to the Wheatstone bridge were to change—either due to part-to-part variation or with the system's operating temperature—the Wheatstone bridge's output voltage changes. However, Ratio_O does not change.

Figure 3. Ratiometric measurements in the context of LVDT-sensor signal conditioning



Ratiometricity in LVDT-sensor signal conditioning

In this section, ratiometricity is described in the following three contexts: 1) between primary waveform generator and secondary signal conditioner; 2) between the two secondary coil outputs; and 3) in power supply and signal output. Figure 3 provides a visual reference for the following descriptions.

1. Ratiometricity between primary waveform generator and secondary signal conditioner

The ideal output voltage of each LVDT and each secondary coil is given by Equation 4.

$$V_{SN} = \kappa_N \times V_P \tag{4}$$

where V_{SN} is the output voltage of secondary coil, N, and N = 1 or 2; V_P is the primary excitation voltage; and κ is the effective magnetic coupling between the primary and secondary coils.

This effective coupling between the two coils is a function of the position of the core. That is, for a given primary-voltage excitation level, as the core moves, the effective coupling represents the position of the core.

An alternative to measuring the secondary voltage in an absolute mode is to measure the ratio of the secondary output voltage to the primary excitation voltage. Now the ratio can be simplified to just the magnetic coupling coefficient according to Equation 5.

$$\text{Ratio}_{\text{Pr-Se}} = \frac{V_{SN}}{V_P} = \frac{\kappa_N \times V_P}{V_P} = \kappa_N \tag{5}$$

That is, by measuring the secondary voltage as a ratio of the primary voltage, the effect of variation in the primary voltage can be eliminated. This is a key advantage when using ratiometricity between a primary waveform generator and a secondary signal conditioner.

2. Ratiometricity between the two secondary coil outputs

Now consider an alternative method for ratiometric measurement that is commonly used in LVDT-sensor signal conditioning, "delta over sum." In this method, the ratio of the difference between the two secondary coil outputs and the sum of the two secondary coil outputs is measured (Equation 6).

$$\text{Ratio}_{\text{Se-Se}} = \frac{V_{S1} - V_{S2}}{V_{S1} + V_{S2}} \tag{6}$$

Equation 6 can be simplified to Equation 7.

$$\text{Ratio}_{\text{Se-Se}} = \frac{V_{S1} - V_{S2}}{V_{S1} + V_{S2}} = \frac{\kappa_1 V_P - \kappa_2 V_P}{\kappa_1 V_P + \kappa_2 V_P} = \frac{\kappa_1 - \kappa_2}{\kappa_1 + \kappa_2} \tag{7}$$

Equation 7 shows that the delta-over-sum method is equivalent to the ratio of difference in the coupling coefficients and sum of the coupling coefficients.

So, what is the advantage of measuring the two secondary output voltages using the delta-over-sum ratio? The key advantage is if the coupling coefficient in an LVDT changes with temperature, then the delta-over-sum ratio remains constant with respect to temperature—assuming that both coupling coefficients change similarly. In other words, the ratio automatically compensates for the variation of secondary output voltages related to temperature changes. This is the case in most LVDT configurations, where the coupling coefficients of the two coils changes in a similar way.

The delta-over-sum method also nullifies any changes in the primary excitation voltage. In other words, if $\text{Ratio}_{\text{Se-Se}}$ is used, then $\text{Ratio}_{\text{Pr-Se}}$ is not needed. It is advantageous to measure $\text{Ratio}_{\text{Pr-Se}}$ if the LVDT has only one secondary coil. In this case, compensation of the output voltage change due to temperature needs to use an alternate approach. These method types can be found in signal conditioners for other types of sense elements, such as look-up tables as in PGA309 or polynomials as in PGA300.

Note that for LVDTs with two secondary coils, processing $\text{Ratio}_{\text{Se-Se}}$ further by using look-up tables or polynomials can compensate for changes in $\text{Ratio}_{\text{Se-Se}}$ because of a mismatch in temperature-related changes in the two coupling coefficients.

3. Ratiometricity in power supply and signal output

The third type of ratiometricity in the context of LVDT-sensor signal conditioning is at the signal output. Instead of generating a signal that is an absolute voltage or current, the position signal is generated with respect to the power supply voltage to the signal conditioner. One way to generate such a signal is to multiply the position signal computed by the signal conditioner and the power supply voltage (Equation 8).

$$\text{Signal} = \text{Position} \times \text{Supply\_Voltage} \tag{8}$$

So why does the LVDT signal conditioner generate such a signal for the controller to measure? The reason can be readily seen by considering the signal given by Equation 8 from the context of the controller. Consider that the controller measures the position signal generated by the LVDT-sensor signal conditioner given by Equation 8 in a ratiometric method using Equation 9.

$$\text{Ratio}_{\text{Sig-Pwr}} = \frac{\text{Signal}}{\text{Supply\_Voltage}} \tag{9}$$

The $\text{Ratio}_{\text{Sig-Pwr}}$ can be simplified to the expression given by Equation 10.

$$\text{Ratio}_{\text{Sig-Pwr}} = \frac{\text{Position} \times \text{Supply\_Voltage}}{\text{Supply\_Voltage}} = \text{Position} \tag{10}$$

Clearly, in making a ratiometric measurement, the controller has nullified any effects due to changes in power-supply voltage and/or in the generation of position signal by the LVDT-sensor signal conditioner.

Conclusions

It was shown that the LVDT signal conditioner can utilize ratiometric measurements in several subsections of the overall system. Ratiometricity is used to eliminate variance from the excitation voltage when measuring LVDT signals, and also compensate for and eliminate drift and other variances of the LVDT. In addition, it helps to maintain an accurate output voltage that reflects any changes to the end system's supply voltage.

Ratiometricity can be easily applied in an environment featuring a digital core for signal conditioning. An example device is the PGA970, an LVDT-sensor signal conditioner with a fully-programmable ARM M0 core. The PGA970 can be programmed with a digital-compensation algorithm by utilizing the methods and equations described. The result is a simple, all-in-one solution to an LVDT-sensor transmitter system. Additionally, the methods presented can be applied to many other types of sensor environments, including RVDTs, resolvers, and pressure sensors.

Related Web sites

Product information:
PGA970
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