Electrical Sensors and Transducers

James R. Carstens

ELECTRICAL SENSORS AND TRANSDUCERS

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PREFACE

It is very difficult to find a text that treats transducers in a concentrated manner. That is, to find information on transducers, you usually have to refer to a related text dealing with automatic controls or process controls. There you may find a chapter or two devoted to the subject of sensing. This makes life especially difficult for those engineers, technicians, or people in general who are curious—who wish to find out something about how transducers work but cannot get their hands on solid information.

This book is an effort to comfort those people in their frustrating efforts. This book is meant to serve as a refresher course in the subject in addition to being a textbook. It is not meant to be a complete, highly technical dissertation on the subject. Using a book of this kind for that particular purpose can only serve "to confuse and cloud Man's mind" (to quote a childhood radio idol of mine, Lamont Kranston, "The Shadow"). Students in particular have difficulty at times sifting through the classroom rhetoric, not having the advantage that the instructor has had during years of accrued experience. Therefore, I hope that this book will be used not only for the purpose of gaining knowledge but also for refreshing old memories. The subject matter is suitable for a beginning course text for two-year and possibly for four-year students.

Much of the information given in this book is based on my experience in industry. Its style is based on my several years in the classroom transferring to my students what I know on the subject of sensors and transducers. Hopefully, I have succeeded in carrying on that effort in this book.

Naturally, a project like this is not the product of one person but is also the product of others who were present with their expertise when help was needed. These people gave unselfishly of their effort. My thanks to the School of Technology secretaries, Phylis and Pam, for handling all the necessary paperwork and documents associated with book writing; thanks also to my students, Kris Baldrica, Greg Powell, and Shawn Smith for producing most of this book's illustrations on AutoCad—a tremendous undertaking to say the least. The most thanks go to my wife, Sandy, for putting up with me during the pursuit of this project. I can only hope that she feels that it was worth it.

J.R.C.
Houghton, Michigan

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INTRODUCTION TO SENSORS AND TRANSDUCERS

CHAPTER OBJECTIVES

1. To define the sensor and transducer.
2. To review physics needed to understand sensor principles.
3. To define the measurands sensed by the transducer.
4. To discuss methods used to describe sensor performance.

1-1 BEFORE WE GET STARTED: SOME COMMENTS ABOUT UNITS

Confusion reigns as to which systems of units should be used in an engineering discussion or report. Despite the good intentions of many, the United States has done a questionable job in converting to the obviously superior metric system. What with the three most popular systems all coexisting in this country—the English (sometimes referred to as the British system), the CGS, and the MKS systems, not to mention a fourth, the SI or "System International" (from a translation from French)—many people have been led down the path of insanity in very short order. (If you are interested in obtaining more information on the SI system of measurements, contact the National Bureau of Standards, Washington D.C., and ask for NBS Special Publication 330, their latest edition.)

In an attempt to cope with this rather serious problem of unit indecisiveness, we will state both the English units and the SI units whenever both references are necessary or when space allows. Table 1-1 is a list of the four systems and some of

TABLE 1-1 COMPARISON OF THE ENGLISH AND METRIC SYSTEMS

		Metric		
	English	MKS	CGS	SI
Length	yard (0.914 m)	meter (39.37 in.)	centimeter (2.54 cm = 1 in.)	meter
Mass	slug (14.6 kg)	kilogram	gram	kilogram
Force	pound (4.45 N)	newton (100,000 dyn)	dyne	newton
Power	horsepower (746 W)	watt	watt	watt
Energy	ft-lb (1.336 J)	joule	erg	joule
Temperature	°F (1.8°C + 32)	°C	°C	kelvin (273.2 + °C)
Time	second	second	second	second
Volume	gallon (3.785 L)	liter	cubic centimeter (1000 cm^3 = 1 L)	liter

the more commonly used conversions needed to leap from one system to another. In addition, when the English units are stated, we will use the most appropriate units when more than one is possible. For instance, if a machining process is being discussed, rather than using feet for measuring the length of a small precision part, inches will be stated instead. Abbreviations for units used in this book will be stated as shown in Table 1-2. Other, more specialized units not listed in Table 1-2 will be pointed out and explained as they are encountered.

1-2 DEFINITIONS OF SENSOR AND TRANSDUCER

People who work with sensors and transducers every day tend to use these two words somewhat interchangeably in their speech. There is no hard and fast rule as to what distinguishes an electrical transducer from an electrical sensor. Ask any number of engineers or scientists for their definitions of these two terms and you will probably get that many different answers. For our purposes in this book I will make the following distinctions: An *electrical sensor* is a device that converts a quantity or an energy form into an electrical output signal. The form of that output signal, whether it is an ac or a dc signal, whether the output is a change in resistance or a change in capacitance, whether the signal is digital or analog, to name just a few, is determined by the sensor's electromechanical and/or chemical makeup. On the other hand, an *electrical transducer* is a device comprised of a sensor whose output signal is modified or conditioned to suit a particular application or need by its user. Furthermore, that transducer may have an onboard power source for its proper

TABLE 1-2 UNIT ABBREVIATIONS USED IN THIS BOOK

English units		SI units	
inch	in.	gram	g
foot	ft	centigram	cg
pound	lb	kilogram	kg
slug	slug	millimeter	mm
mile	mi	nanometer	nm
horsepower	hp	centimeter	cm
foot pound	ft-lb	kilometer	km
degrees Fahrenheit	°F	joule	J
second	s	second	s
gallon	gal	liter	L
		degrees Celsius	°C
		kelvin	K
		cubic centimeter	cm^3
		newton	N
		watt	W
		dyne	dyn
		mole	mol

operation. Figure 1-1 will help to illustrate this major difference. The transducer depicted uses a sensor as one of its many possible operating elements, whereas a sensor has no internal separate operating elements, just the sensing element itself. A transducer depends on the sensor to produce the quantity or energy conversion. It is also capable of modifying the sensor's output signal to convert that signal into a more desirable form. In Figure 1-1 the sensing element that is shown is what is referred to as a photo-resistive sensor whose electrical resistance varies with the light intensity that is striking this element. The sensor's output is in the form of a changing

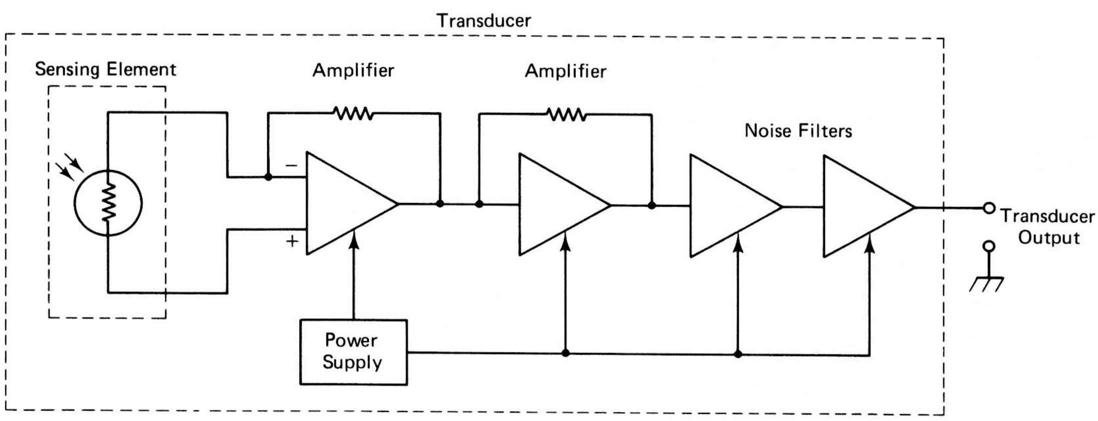

Figure 1-1 Typical transducer configuration. (From James R. Carstens, *Automatic Control Systems and Components,* copyright 1990, p. 86. Reprinted by permission of Prentice Hall, Englewood Cliffs, NJ.)

dc resistance, as already mentioned. However, because it is generally more desirable to work with changing voltages and currents instead of changing resistance, this particular transducer uses amplifiers to convert the resistance to these quantities. In addition, these amplifiers have the task of modifying the signal's amplitude to more desirable signal levels. The noise filters that are shown have the job of "stripping off" or diminishing any electrical noise that might be present on the modified signal coming from the sensor. Not all transducers have this elaborate provision or capability.

Now one might argue that a gasoline engine could also be classified as a transducer. After all, it does convert one form of energy, chemical energy, in the form of gasoline in this case, into another form, kinetic energy or motion. Therefore, we have to be a little more precise in our transducer definition. We have to qualify our statement by saying that a transducer has a very predictable output based on the energy or quantity input that it is converting. This output can be measured and quantified, usually in very precise amounts. In other words, the transducer can be calibrated. An engine is not considered that precise an instrument in terms of ready calibration. Also, many transducers can easily be transported and installed in systems or circuits. Although admittedly that in itself is a somewhat imprecise criterion, it is a simply applied criterion that may be useful in identifying transducers.

In summary, then, transducers are used to measure or sense certain quantities or energy forms. They can be precisely calibrated if desired and, for the most part, are easily transportable. In the material that follows, we discuss the types of outputs that are available from sensors and transducers.

1-3 FORMS OF TRANSDUCER OUTPUTS

Looking at the output terminals of a transducer, let's now see what varieties of electrical outputs can be obtained there. There is probably a transducer available from a manufacturer that can produce the signal that you may have in mind for your application. In the discussion that follows, we look at the three major categories of data signal forms that presently exist: (1) analog, (2) digital or pulse, and (3) carrier.

1-3.1 Analog Signal

Very simply stated, an analog signal is a continuous (not interrupted) data signal comprised of a flow of current or a voltage level whose amplitude, frequency, or phase relationship with some reference signal contains data information. This information represents a proportional relationship or analog of the input measurand that is controlling the signal. In Figure 1-2 we see an aneroid barometer that has a variable potentiometer attached. The variable-voltage output of this potentiometer is a direct representation of the varying air pressure being sensed by the aneroid. This output is an analog equivalent of the varying air pressure. As a matter of fact, the resultant voltage curve can easily be transformed into a pressure reading merely by noting how