LINEAR POSITION SENSORS

Theory and Application

DAVID S. NYCE

WILEY-INTERSCIENCE

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Published by John Wiley & Sons, Inc., Hoboken, New Jersey.
Published simultaneously in Canada.

Library of Congress Cataloging-in-Publication Data:

Nyce, David S.
Linear position sensors: theory and application / David S. Nyce.
p. cm.
Includes bibliographical references and index.
ISBN 0-471-23326-9 (cloth)
1. Transducers. 2. Detectors. I. Title.
TK7872.T6N93 2003
681′.2—dc21

2003053455

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

To Gwen, and our children Timothy, Christopher, and Megan,
whose love and support helped me complete this project

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PREFACE

Society and industry worldwide continue to increase their reliance on the availability of accurate and current measurement information. Timely access to this information is critical to effectively meet the indication and control requirements of industrial processes, manufacturing equipment, household appliances, onboard automotive systems, and consumer products. A variety of technologies are used to address the specific sensing parameters and configurations needed to meet these requirements.

Sensors are used in cars to measure many safety- and performance-related parameters, including throttle position, temperature, composition of the exhaust gas, suspension height, pedal position, transmission gear position, and vehicle acceleration. In clothes-washing machines, sensors measure water level and temperature, load size, and drum position variation. Industrial process machinery requires the measurement of position, velocity, and acceleration, in addition to chemical composition, process pressure, temperature, and so on. Position measurement comprises a large portion of the worldwide requirement for sensors. In this book we explain the theory and application of the technologies used in sensors and transducers for the measurement of linear position.

There is often some hesitation in selecting the proper word, *sensor* or *transducer*, since the meanings of the terms are somewhat overlapping in normal use. In Chapter 1 we present working definitions of these and other, sometimes confusing, terms used in the field of sensing technology. In Chapter 2 we explain how the performance of linear position transducers is specified. In the remaining chapters we present the theory supporting an understanding of the prominent technologies in use in linear position transducer products. Application guidance and examples are included.

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CHAPTER 1

SENSOR DEFINITIONS AND CONVENTIONS

1.1 IS IT A SENSOR OR A TRANSDUCER?

A *transducer* is generally defined as a device that converts a signal from one physical form to a corresponding signal having a different physical form [29, p. 2]. Energy can be converted from one form into another for the purpose of transmitting power or information. Mechanical energy can be converted into electrical energy, or one form of mechanical energy can be converted into another form of mechanical energy. Examples of transducers include a loudspeaker, which converts an electrical input into an audio wave output; a microphone, which converts an audio wave input into an electrical output; and a stepper motor, which converts an electrical input into a rotary position change.

A *sensor* is generally defined as an input device that provides a usable output in response to a specific physical quantity input. The physical quantity input that is to be measured, called the *measurand*, affects the sensor in a way that causes a response represented in the output. The output of many modern sensors is an electrical signal, but alternatively, could be a motion, pressure, flow, or other usable type of output. Some examples of sensors include a thermocouple pair, which converts a temperature difference into an electrical output; a pressure sensing diaphragm, which converts a fluid pressure into a force or position change; and a linear variable differential transformer (LVDT), which converts a position into an electrical output.

Linear Position Sensors: Theory and Application, by David S. Nyce
ISBN 0-471-23326-9

Obviously, according to these definitions, a transducer can sometimes be a sensor, and vice versa. For example, a microphone fits the description of both a transducer and a sensor. This can be confusing, and many specialized terms are used in particular areas of measurement. (An audio engineer would seldom refer to a microphone as a sensor, preferring to call it a transducer.) Although the general term *transducer* refers to both input and output devices, in this book we are concerned only with sensing devices. Accordingly, we will use the term *transducer* to signify an input transducer (unless specified as an output transducer).

So, for the purpose of understanding sensors and transducers in this book, we will define these terms more specifically as they are used in developing sensors for industrial and manufacturing products, as follows:

An *input transducer* produces an electrical output, which is representative of the input measurand. Its output is conditioned and ready for use by the receiving electronics.

The receiving electronics can be an indicator, controller, computer, programmable logic controller, or other. The terms *input transducer* and *transducer* can be used interchangeably, as we do in this book.

A *sensor* is an input device that provides a usable output in response to the input measurand.

The sensing part of a transducer can also be called the *sensing element*, *primary transducer*, or *primary detector*. A sensor is often one of the components of a transducer.

Sometimes, common usage will have to override our theoretical definition in order to result in clear communication among engineers in a specific industry. The author has found, for instance, that automotive engineers refer to any measuring device providing information to the onboard controller, as a sensor. In the case of a position measurement, this includes the combination of sensing element, conditioning electronics, power supply, and so on. That is, the term *sensor* is used to name exactly what our definition strives to call a transducer. In automotive terminology, the word *sender* is also commonly used to name a sensor or transducer. In any case, we rely on the definition presented here, because it applies to most industrial uses.

An example of a sensor as part of a transducer may help the reader understand our definition. The metal diaphragm shown in Figure 1.1*a* is a sensor that changes pressure into a linear motion. The linear motion can be changed into an electrical signal by an LVDT, as in Figure 1.1*b*. The combination of the diaphragm, LVDT, and signal conditioning electronics would comprise a pressure transducer. A pressure transducer of this description, designed by the author, is shown in Figure 1.2.

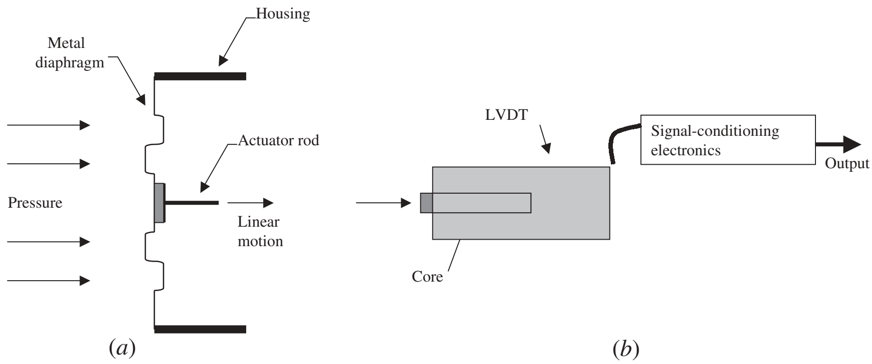

Figure 1.1 (*a*) The circular diaphragm (shown edgewise, cutaway) changes pressure into linear motion. (*b*) An LVDT changes linear motion to an electrical signal, comprising a transducer with the addition of signal-conditioning electronics.

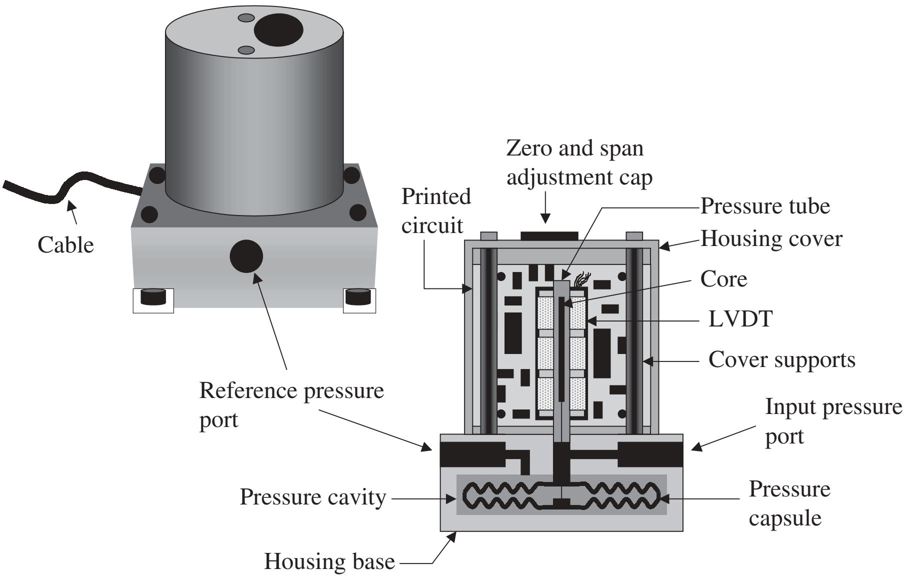

Figure 1.2 Commercially available pressure transducer according to Figure 1.1. Cutaway view with diaphragm in the lower cavity, and LVDT, core, and signal-conditioning electronics in the upper cavity.

1.2 POSITION VERSUS DISPLACEMENT

Since linear position sensors and transducers are presented in this work and many manufacturers confuse the terms *position* and *displacement*, the difference between position and displacement should be understood by the reader.

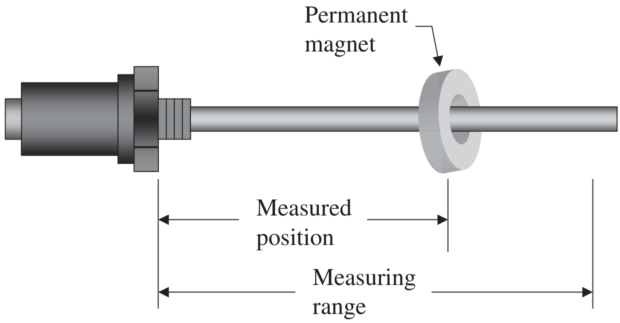

Figure 1.3 Magnetostrictive linear position transducer with position magnet. (Courtesy of MTS Systems Corporation.)

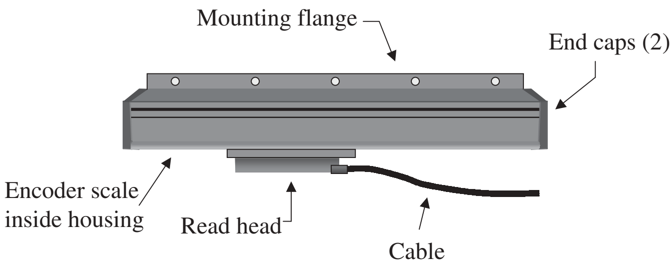

Figure 1.4 Incremental magnetic linear encoder.

A *position transducer* measures the distance between a reference point and the present location of the target. The word *target* is used in this case to mean that element of which the position or displacement is to be determined. The reference point can be one end, the face of a flange, or a mark on the body of the position transducer (such as a fixed reference datum in an absolute transducer), or it can be a programmable reference datum. As an example, consider Figure 1.3, which shows the components of the measuring range of a magnetostrictive absolute linear position transducer. This transducer measures the location of a permanent magnet with reference to a fixed point on the transducer. (More details on the magnetostrictive position transducer are presented in Chapter 9.)

Conversely, a *displacement transducer* measures the distance between the present position of the target and the position recorded previously. An example of this would be an incremental magnetic encoder (see Figure 1.4). Position transducers can be used as displacement transducers by adding circuitry to remember the previous position and subtract the new position, yielding the difference as the displacement. Alternatively, the data from a position transducer may be recorded into memory by a microcontroller, and differences calculated as needed to indicate displacement. Unfortunately, and constituting another assault against clarity, it is common for many manufacturers of position transducers to call their products displacement transducers.

To summarize, *position* refers to a measurement with respect to a constant reference datum; *displacement* is a relative measurement.

1.3 ABSOLUTE OR INCREMENTAL READING

An absolute-reading position transducer indicates the measurand with respect to a constant datum. This reference datum is usually one end, the face of a flange, or a mark on the body of a position transducer. For example, an absolute linear position transducer may indicate the number of millimeters from one end of the sensor, or a datum mark, to the location of the target (the item to be measured by the transducer). If power is interrupted, or the position changes repeatedly, the indication when normal operation is restored will still be the number of millimeters from one end of the sensor, or a datum mark, to the location of the target. If the operation of the transducer is disturbed by an external influence, such as by an especially strong burst of electromagnetic interference (EMI), the correct reading will be restored once normal operating conditions return.

To the contrary, an incremental-reading transducer indicates only the changes in the measurand as they occur. An electronic circuit is used to keep track of the sum of these changes (the count) since the last time that a reading was recorded and the count was zeroed. If the count is lost due to a power interruption, or the sensing element is moved during power-down, the count when normal operating conditions are restored will not represent the present magnitude of the measurand. For example, if an incremental encoder is first zeroed, then moved upscale 25 counts, followed by moving downscale 5 counts, the resulting position would be represented by a count of 20. If there are 1000 counts per millimeter, the displacement is 0.02 mm. If power is lost and regained, the position would probably be reported as 0.00 mm. Also, if the count is corrupted by an especially strong burst of EMI, the incorrect count will remain when normal operation is restored.

1.4 CONTACT OR CONTACTLESS SENSING AND ACTUATION

One classification of a position transducer pertains to whether it utilizes a *contact* or *noncontact* (also called *contactless*) type of sensing element. With contactless sensing, another aspect is whether or not the transducer also uses contactless actuation. In a contact type of linear position sensor, the device making the conversion between the measurand and the sensor output incorporates a sliding electrical and/or mechanical contact. The primary example is the linear potentiometer, (see Figure 1.5). The actuator rod is connected internally to a wiper arm. The wiper arm incorporates one or more