Semiconductor Sensors:

Ch3: Electromagnetic Sensors cont.

Lecturer: Dr. N. A. Sheini
Shahid Chamran University of Ahvaz

حسگرهای اثر هال با خروجی آنالوگ و دیجیتال:

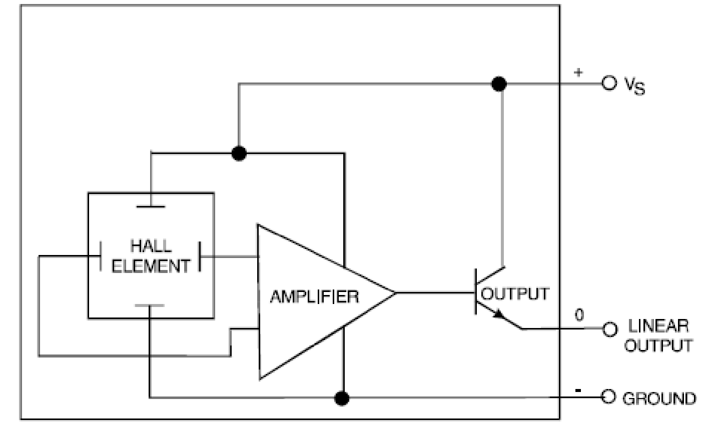


Figure 2-6 Simple analog output sensor (SS49/SS19 types)

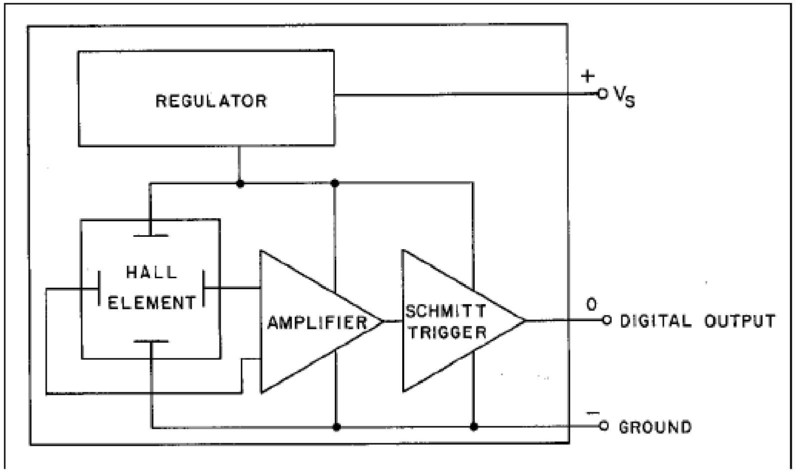


Figure 2-10 Digital output Hall effect sensor

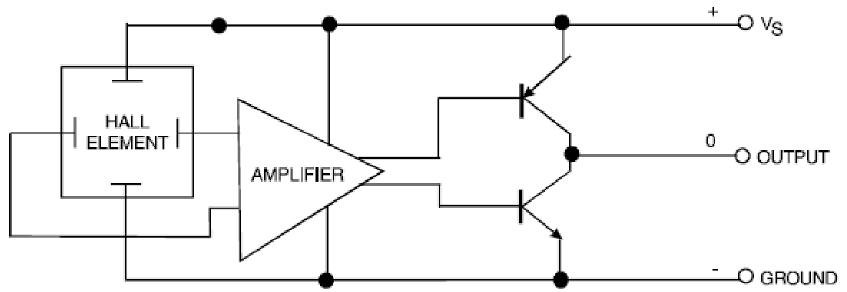


Figure 2-7 Ratiometric linear output sensor

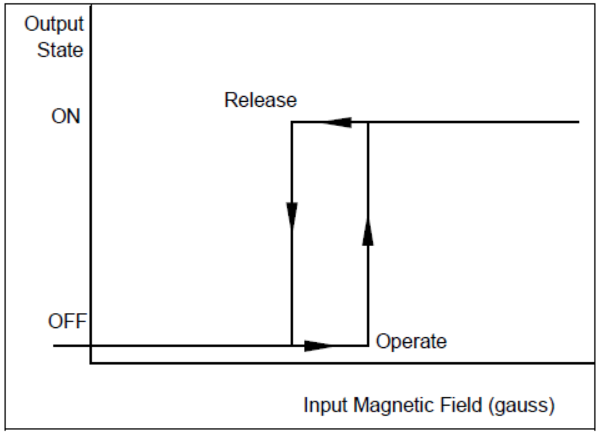


**Figure 2-11 Transfer function hysteresis . . .
Digital output sensor**

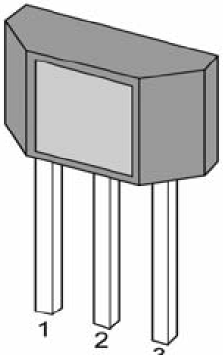
https://sensing.honeywell.com/hallbook.pdf

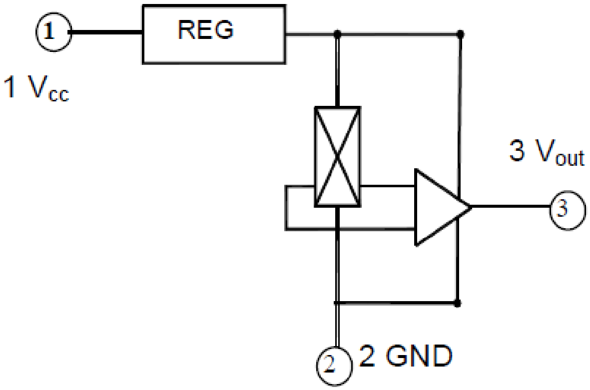
حسگرهای اثر هال با خروجی آنالوگ :

SS49E

Linear Hall Effect Sensor

3 pin SIP (suffix UA)





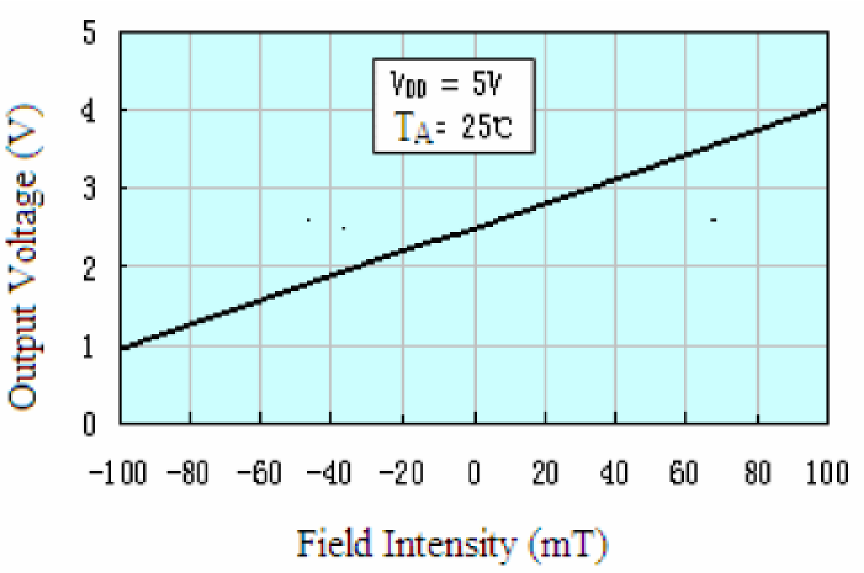
Electrical Characteristics（TA =25℃，VCC =5.0V）

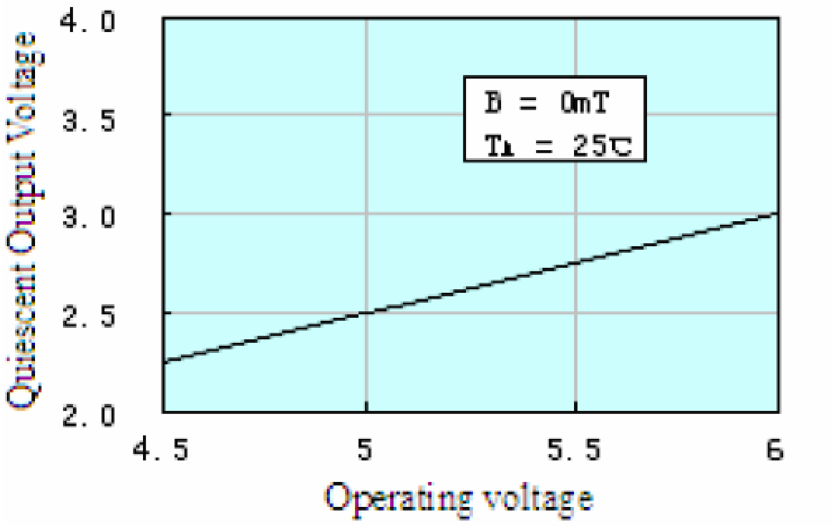
Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
Operating voltage	V_{CC}	Operating	3.0		6.5	V
Supply current	I_{CC}	Average		4.2	8.0	mA
Output Current	I_{OUT}		1.0	1.5		mA
Response Time	Tack			3		uS
Quiescent Output Voltage	Vo	B=0G	2.25	2.5	2.75	V
Sensitivity	△Vout	TA=25℃	1.6	1.8	2.0	mV/G
Min Output Voltage		B=-1500G		0.86		V
Max Output Voltage		B=1500G		4.21		V

http://pdf1.alldatasheet.com/datasheet-pdf/view/473135/SECELECTRONICS/SS49E.html

حسگرهای اثر هال با خروجی آنالوگ :

SS49E





TCS11NLU

حسگر اثر هال با خروجی دیجیتال:

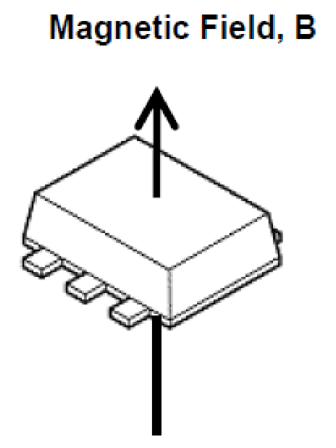
Digital Output Magnetic Sensor

TOSHIBA CMOS Digital Integrated Circuit Silicon Monolithic

Features

Open-Drain Output with Inverted Logic

North-Pole Detection



DC Characteristics (Ta = 25°C)

Characteristics		Symbol	Condition	V_{CC} (V)	Min	Typ.	Max	Unit
Output Voltage	Low- Level	V_{OL}	I_{OL} = 1.0 mA	2.3 to 3.6	—	—	V_{CC} x 10%	V
Output Leakage Current		I_{OFF}	V_{OUT} = 5.5V	0	—	0.5	1	μA
Supply Current	Average Current	I_{CC}	Current at pulse driving (Note 5, Fig. A)	2.3 to 2.7	—	5.5	9.5	μA
				3.0 to 3.6	—	8.7	13.2	
	Operating Current	I_{CC} ON	Peak current (Note 5, Fig. A)	2.3 to 3.6	—	0.7	1.3	mA
Operating Frequency		f_{opr}	(Fig. A)	2.3 to 3.6	—	25	—	Hz

Note 5: I_{CC} is pulsed periodically.

http://pdf1.alldatasheet.com/datasheet-pdf/view/356287/TOSHIBA/TCS11NLU.html

حسگر اثر هال با خروجی دیجیتال:

TCS11NLU

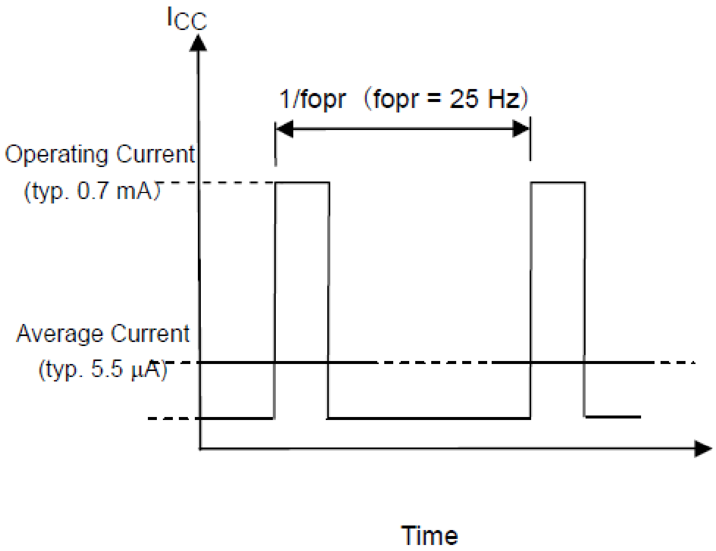
Magnetic Characteristics (Ta = 25°C)

Characteristics		Symbol	Condition (Note 6, Fig. B)	V_{CC} (V)	Min	Typ.	Max	Unit
Magnetic Flux Density	Operating Point	B_{ON}	$V_{OUT} = Z$ (Note 7)	2.3 to 3.6	-2.5	-1.8	—	mT
	Releasing Point	B_{OFF}	$V_{OUT} = V_{OL}$	2.3 to 3.6	—	-0.8	-0.3	
	Hysteresis	B_H	$\lvert B_{ON} - B_{OFF} \rvert$	2.3 to 3.6	—	1.0	—	

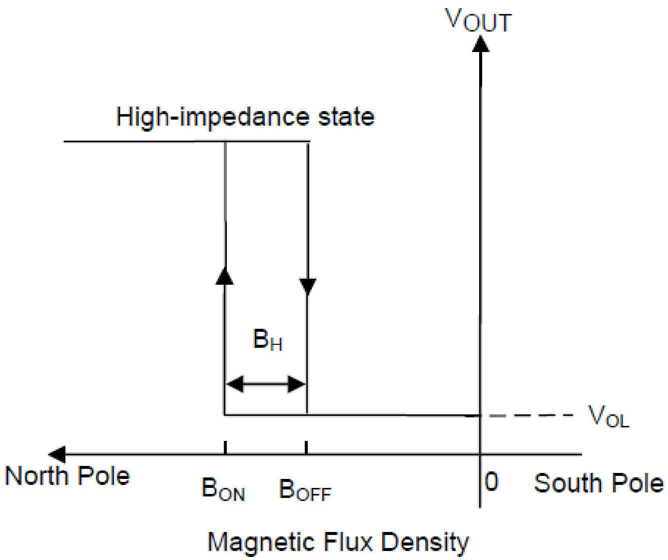
Note 6: Uniform magnetic field perpendicularly to the magnetic sensor.

Note 7: In the high-impedance state.

(Fig. A): I_{CC} Characteristics



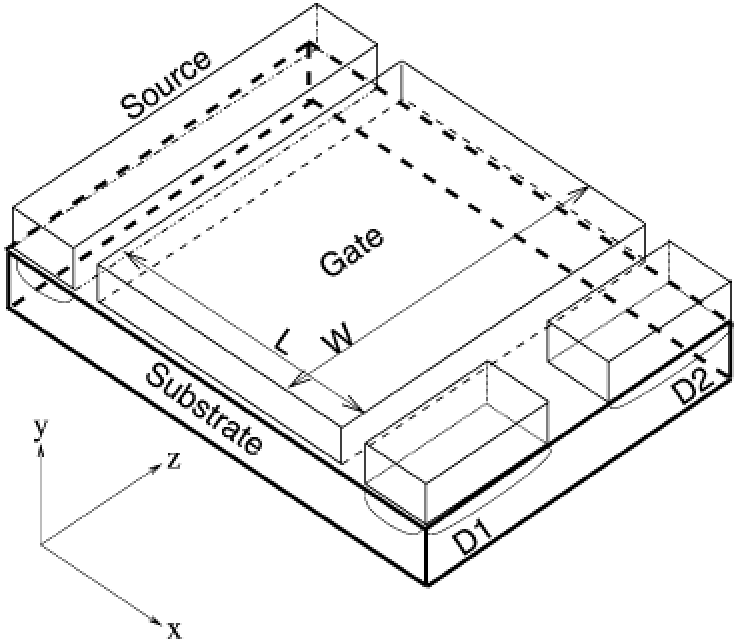
(Fig. B): Operating Characteristics



http://pdf1.alldatasheet.com/datasheet-pdf/view/356287/TOSHIBA/TCS11NLU.html

حسگر هال از نوع FET:

مشخصه بدون اعمال میدان مغناطیسی:



View of the simulated two-drain MAGFET structure.

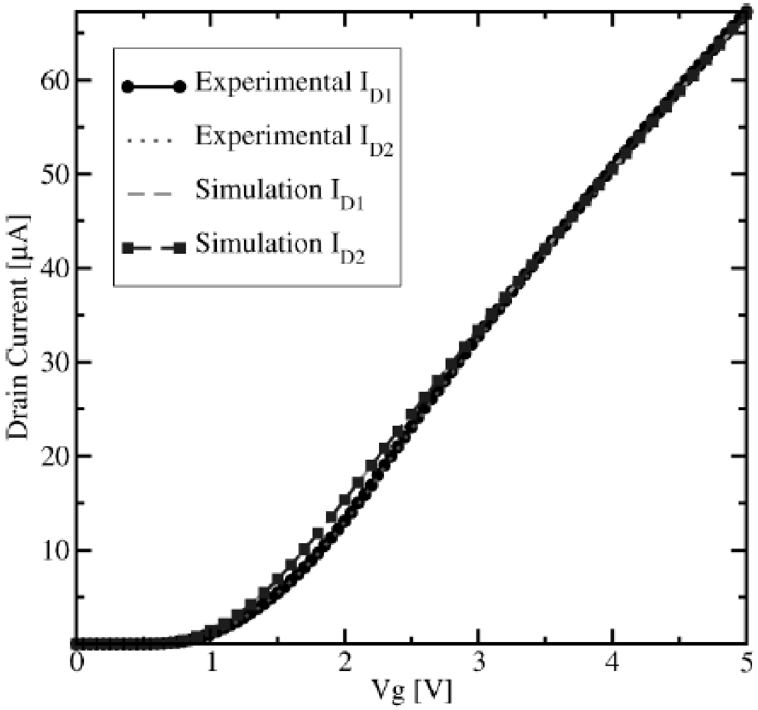
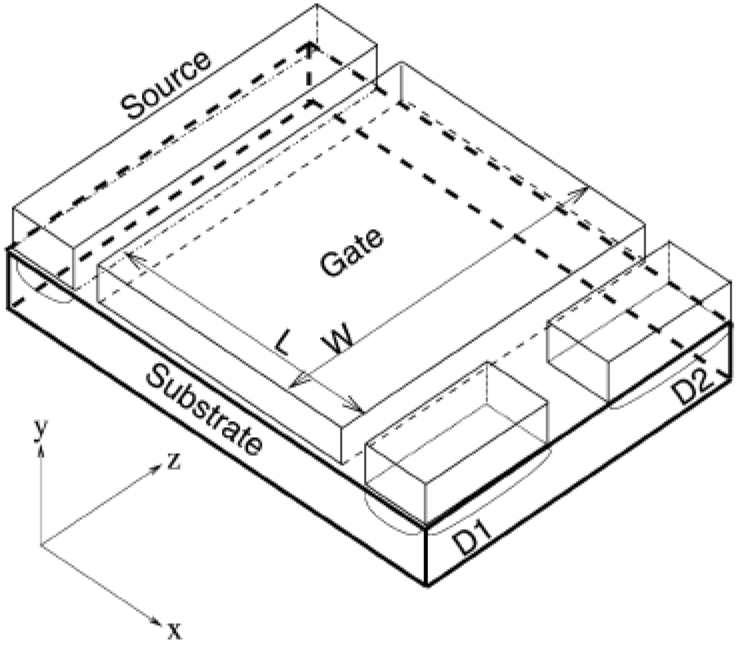


Fig. 2. Drain currents as a function of the gate voltage at 300 K.

R.T.Rodrigo, et al. "Analysis of split-drain MAGFETs." *IEEE Transactions on Electron Devices* (2004).

حسگر هال از نوع FET:



View of the simulated two-drain MAGFET structure.

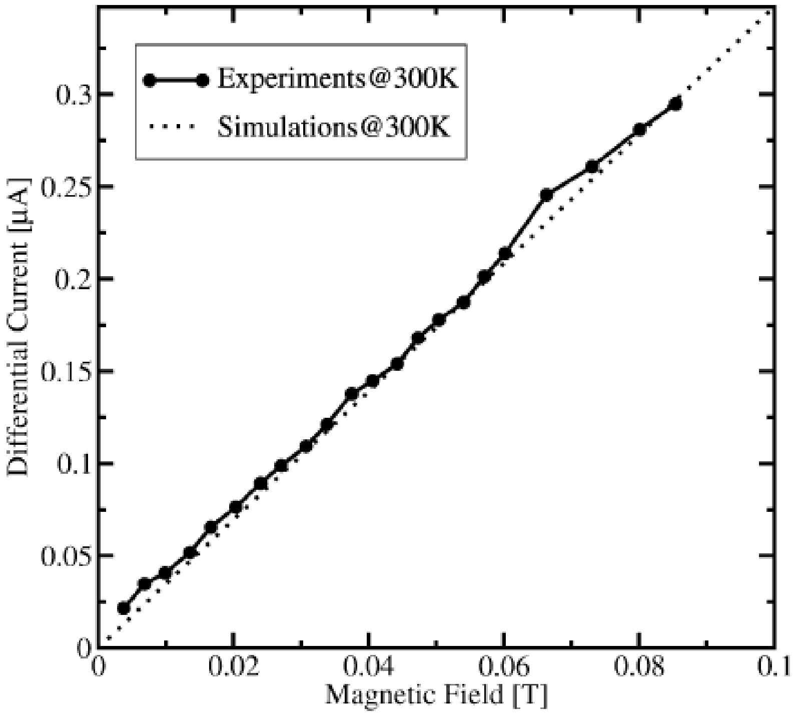


Fig. 3. Differential currents versus magnetic field at 300 K.

Fig. 3 shows the experimental and simulated differential current for the structure of Fig. 1 at 300 K. The voltage at the drains is 1.0 V, the gate voltage is 4.95 V, and the bulk voltage is 0.0 V.

R.T.Rodrigo, et al. "Analysis of split-drain MAGFETs." *IEEE Transactions on Electron Devices* (2004).

حسگر هال از نوع FET:

حساسیت نسبی:

$$S = \frac{|I_{D1} - I_{D2}|}{(I_{D1} + I_{D2})|\mathbf{B}|} \qquad (1)$$

where I_{D1} and I_{D2} are the currents at Drain 1 and Drain 2, and $|\mathbf{B}|$ is the magnetic field strength.

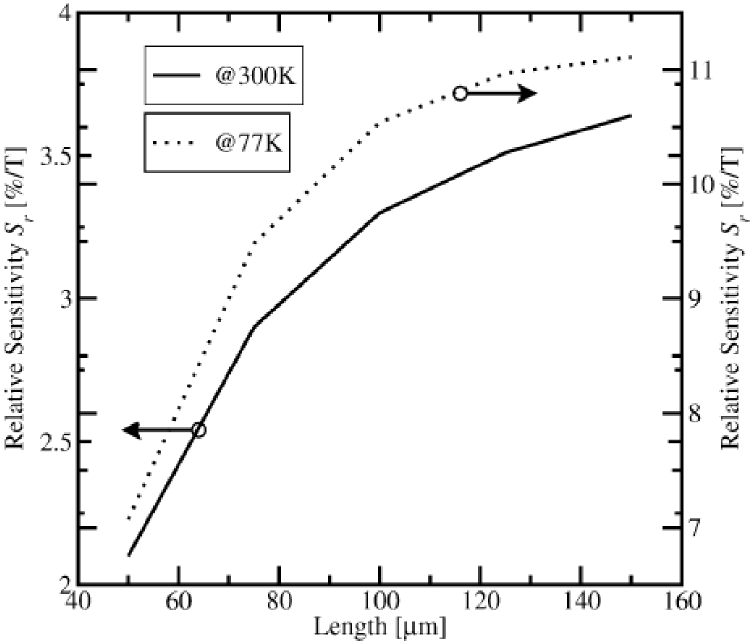


Fig. 6. Simulated relative sensitivity for different lengths.

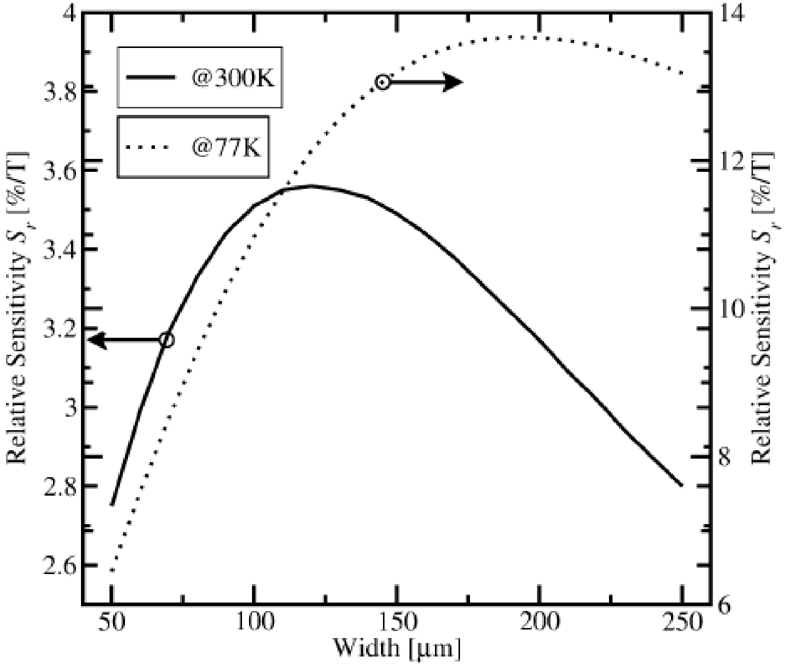


Fig. 7. Simulated relative sensitivity for different widths.

R.T.Rodrigo, et al. "Analysis of split-drain MAGFETs." *IEEE Transactions on Electron Devices* (2004).

حسگر هال از نوع FET:

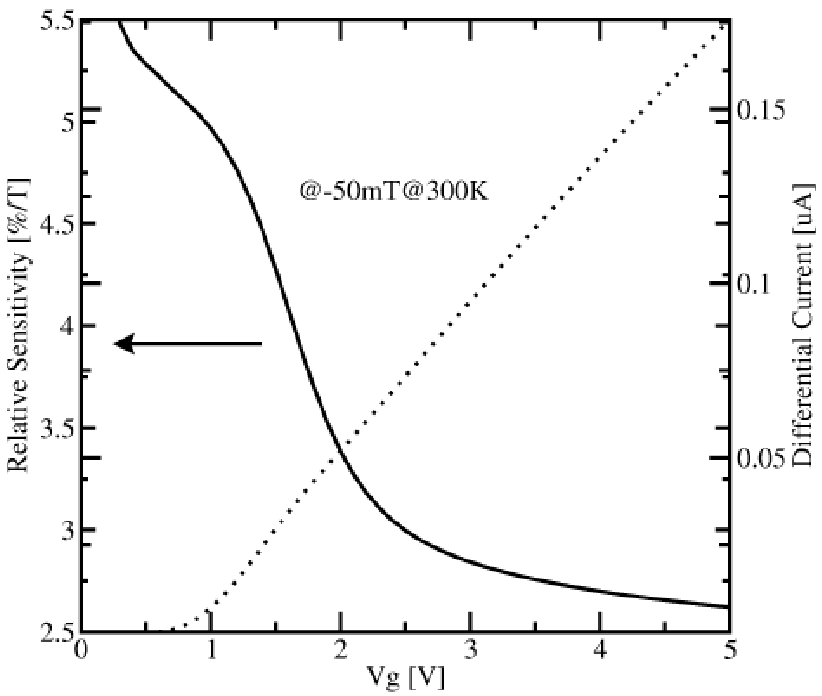


Fig. 8. S_r and Δ as a function of V_G. V_{D1} and V_{D2} are set to 1.0 V.

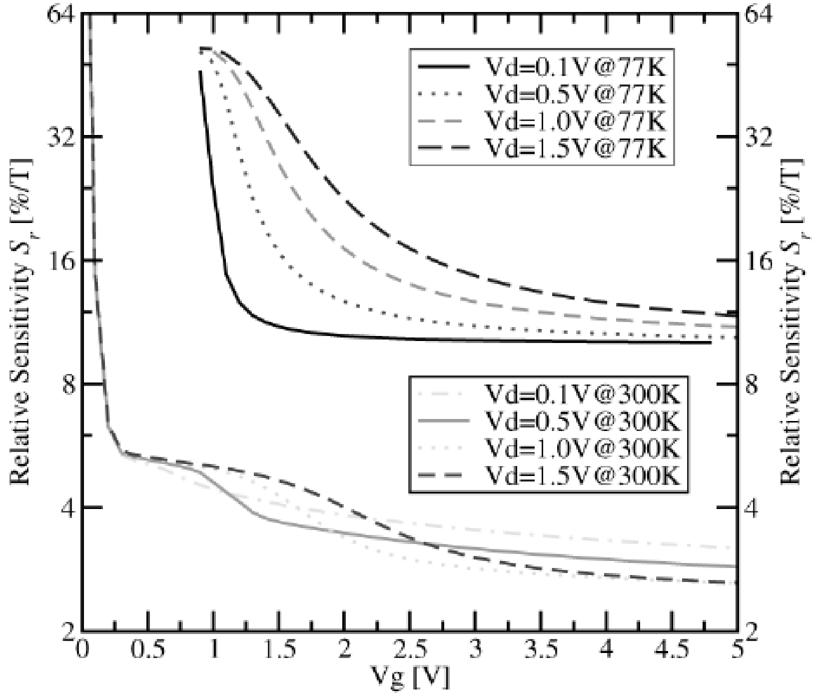


Fig. 9. S_r as a function of the gate voltage at $B = -50$ mT.

R.T.Rodrigo, et al. "Analysis of split-drain MAGFETs." *IEEE Transactions on Electron Devices* (2004).

کاربردهای حسگرهای هال :

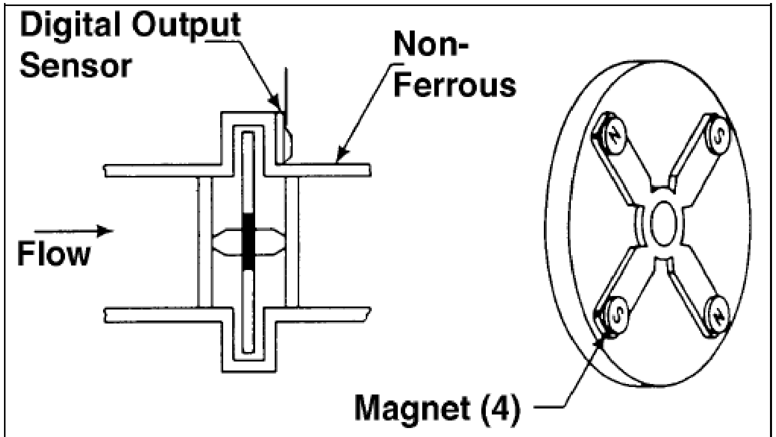


Figure 7-1 Flow rate sensor

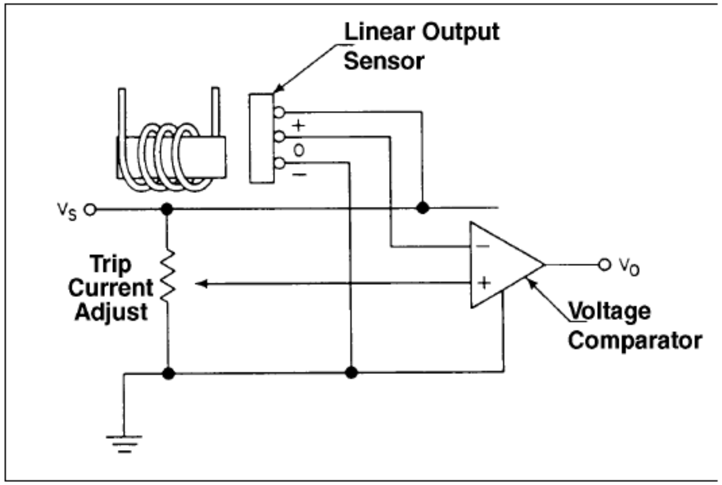


Figure 7-7 Adjustable current sensor

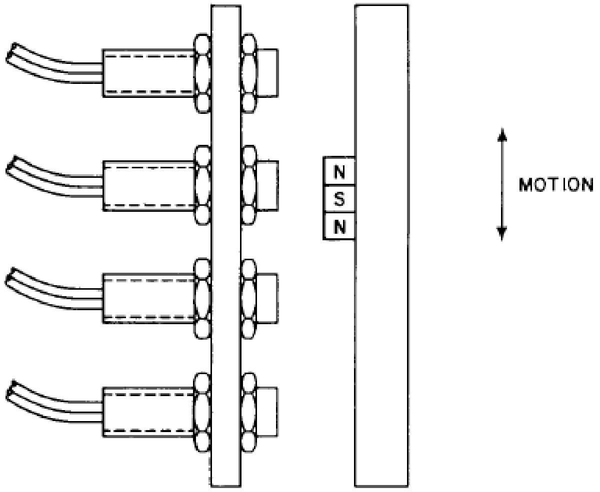


Figure 7-3B Proximity sensors

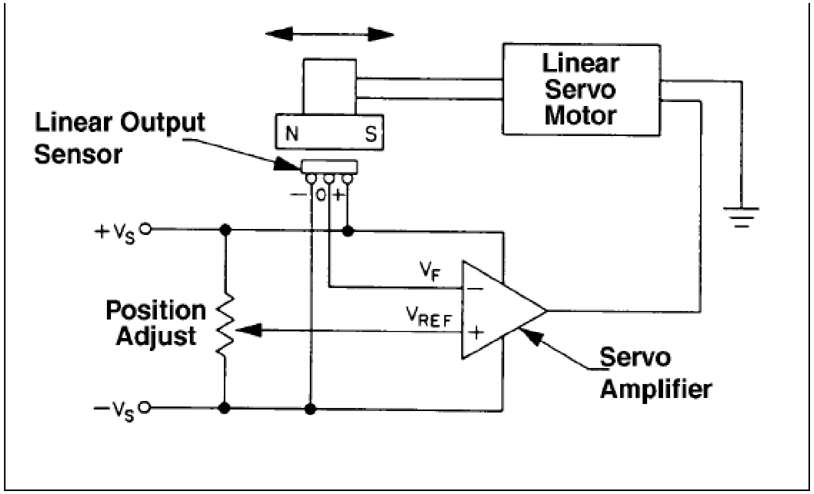


Figure 7-8 Linear feedback sensor for analog control systems

https://sensing.honeywell.com/hallbook.pdf

کاربردهای حسگرهای هال :

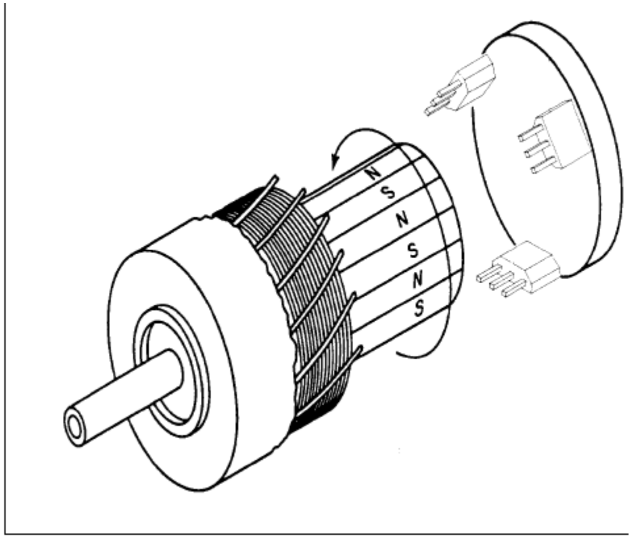


Figure 7-17 Brushless DC motor sensors

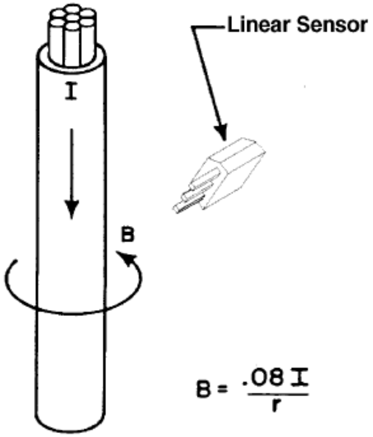


Figure 7-21 Simple current sensor

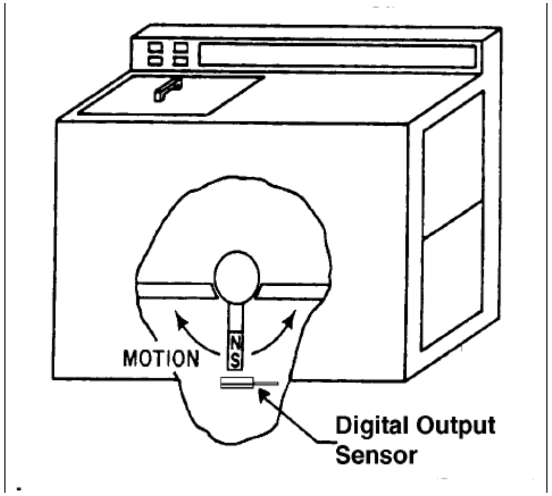


Figure 7-16 Level/tilt sensor

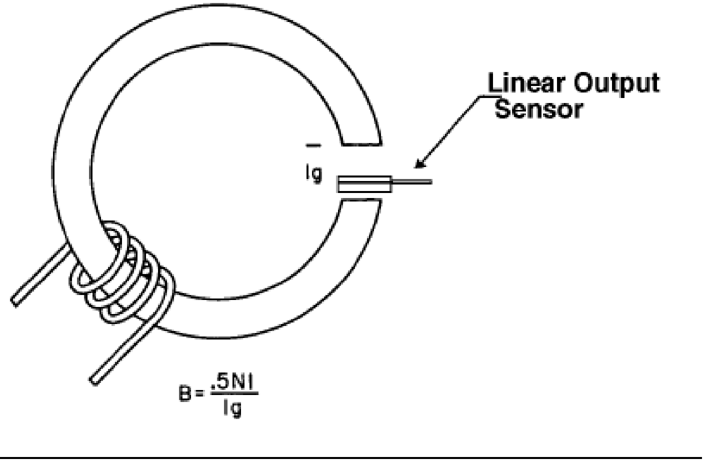


Figure 7-22 Low level current sensor

https://sensing.honeywell.com/hallbook.pdf

حسگرهای مغناطیسی از نوع القایی:

- Nearly infinite resolution
- Fast response
- Large operating temperature range
- High reliability
- Robustness
- Easy handling

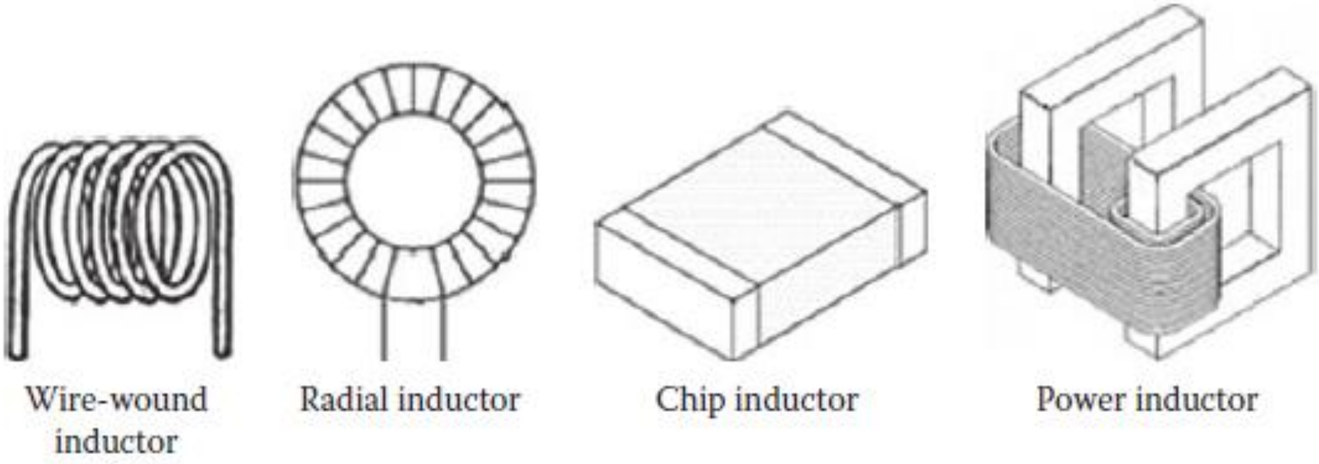


FIGURE 4.1 Types of inductors.

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

حسگرهای القایی:

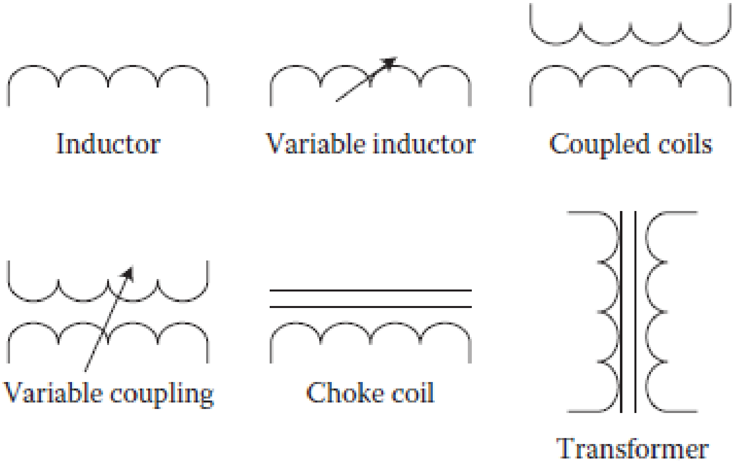
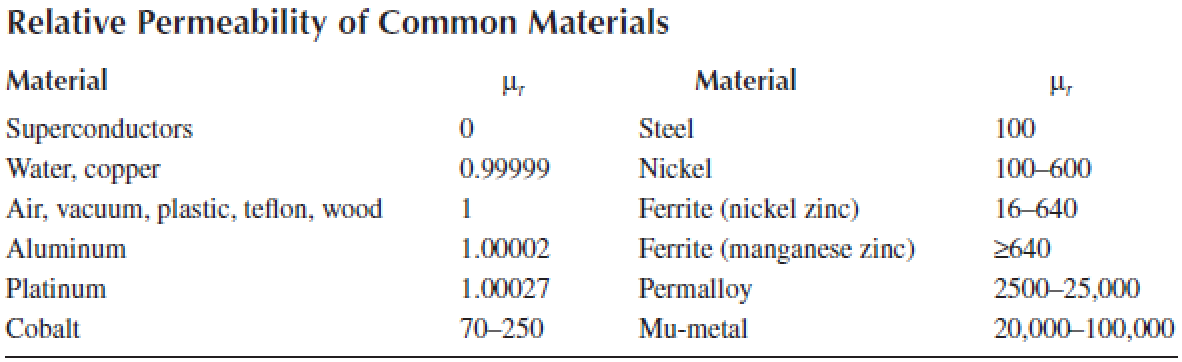


FIGURE 4.3 Circuit symbols for various inductors.



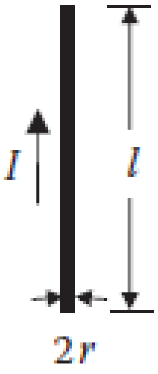
Relative Permeability of Common Materials

Material	μ_r	Material	μ_r
Superconductors	0	Steel	100
Water, copper	0.99999	Nickel	100–600
Air, vacuum, plastic, teflon, wood	1	Ferrite (nickel zinc)	16–640
Aluminum	1.00002	Ferrite (manganese zinc)	≥640
Platinum	1.00027	Permalloy	2500–25,000
Cobalt	70–250	Mu-metal	20,000–100,000

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

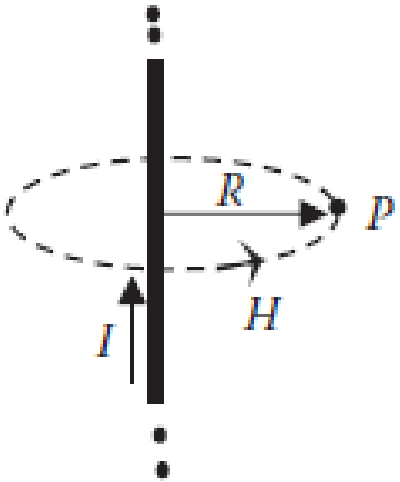
حسگرهای القایی:

Inductance and Magnetic Field for Various Configurations



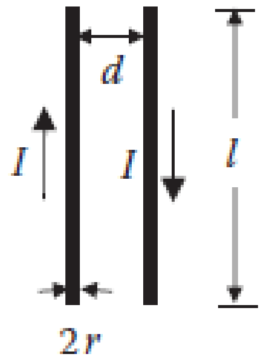
$$L = 200l\left(\ln\frac{2l}{r} - 1\right) \times 10^{-19}$$

where r is the radius of the wire (in m) and I is the current (in A).



$$H = \frac{I}{2\pi R}$$

$$B = \frac{\mu_0\mu_r I}{2\pi R}$$



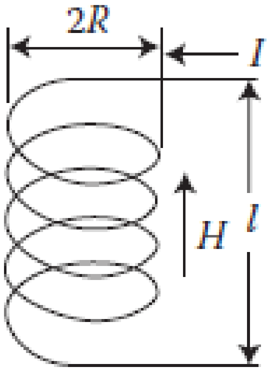
$$L = \frac{\mu l}{\pi}\ln\left(\frac{d-r}{r}\right)$$

$$H = \frac{2I}{\pi d}$$

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

حسگرهای القایی:

Inductance and Magnetic Field for Various Configurations



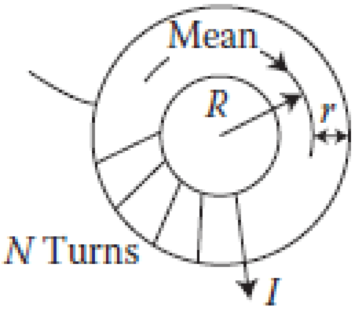
Infinite cylindrical coil helix:

$$L = \mu N^2 I A_{\text{coil}}$$

$$H = NI \text{ (for } l \gg R\text{)}$$

where N is the number of turns of the coil and A_{coil} is the area of the coil (m^2).

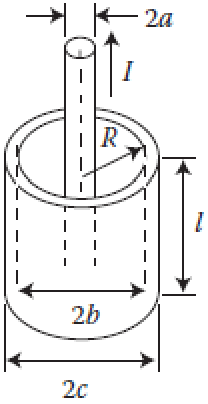
Torus (toroidal coil):



$$L = \frac{\mu N^2 r^2}{2R}$$

$$H = \frac{NI}{2\pi R}\left(\text{for } r \ll R\right)$$

Coaxial cable (high frequencies):



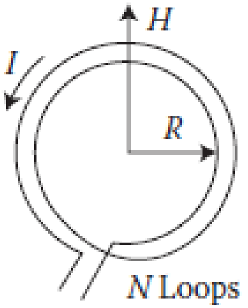
$$L = \frac{\mu I}{2\pi}\ln\left(\frac{b}{a}\right)$$

$$H = \frac{I}{2\pi R} \quad \left(a < R < b\right)$$

حسگرهای القایی:

Inductance and Magnetic Field for Various Configurations

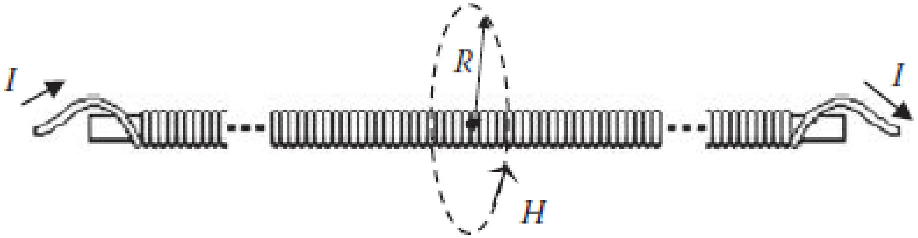
An N-turn circular conductive loop (r—radius of the wire):



$$L = \frac{R^2N^2}{(2R + 5.6r) \times 10^5}$$

$$H = \frac{NI}{2R}$$ (at the center of the coil)

A long and thin coil (length of the coil $l \gg R$):



The magnetic flux density B within the coil:

$$B = \mu_0\mu_r NI/l \qquad (4.18)$$

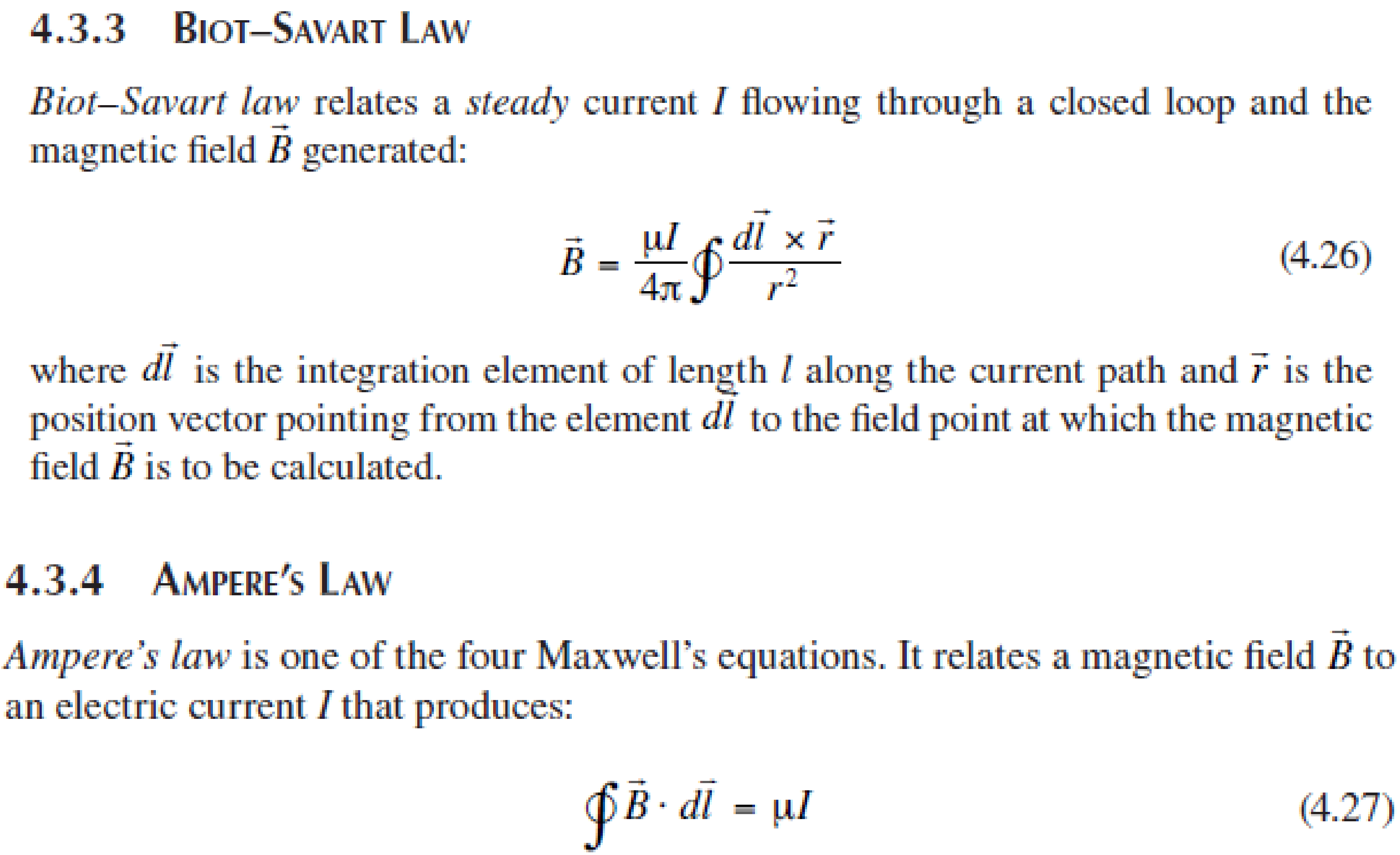
A circular conductive loop (single turn coil):

$$L = \mu_0\mu_r R[\ln(8R/r) - 2 + Y] \qquad (4.19)$$

where R is the radius of the loop, r is the radius of the conductor, and Y is a constant ($Y = 1/4$ when the current is homogeneous across the wire; $Y = 0$ when the current flows on the surface of the wire).

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

حسگرهای القایی- معادلات فیزیکی:



4.3.3 BIOT–SAVART LAW

Biot–Savart law relates a *steady* current I flowing through a closed loop and the magnetic field $\vec{B}$ generated:

$$\vec{B} = \frac{\mu I}{4\pi}\oint \frac{d\vec{l} \times \vec{r}}{r^2} \tag{4.26}$$

where $d\vec{l}$ is the integration element of length l along the current path and $\vec{r}$ is the position vector pointing from the element $d\vec{l}$ to the field point at which the magnetic field $\vec{B}$ is to be calculated.

4.3.4 AMPERE'S LAW

Ampere's law is one of the four Maxwell's equations. It relates a magnetic field $\vec{B}$ to an electric current I that produces:

$$\oint \vec{B} \cdot d\vec{l} = \mu I \tag{4.27}$$

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

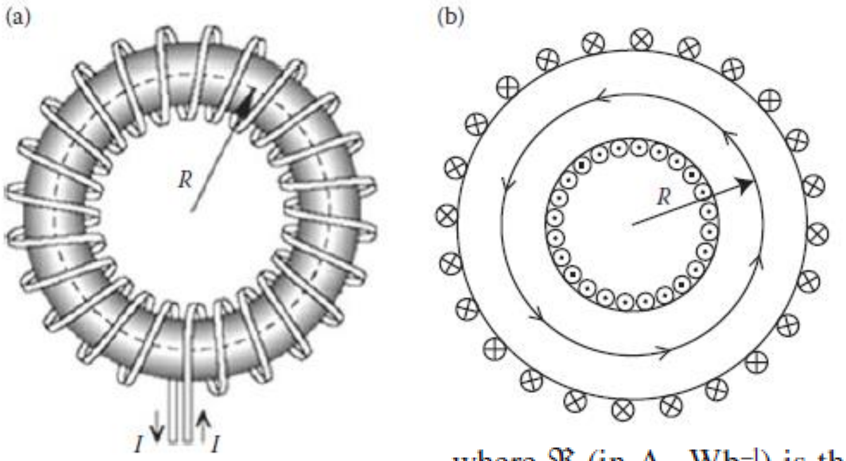
حسگرهای القایی- معادلات فیزیکی:

4.3.5 MAGNETOMOTIVE FORCE

Any physical cause that produces magnetic flux is called *magnetomotive force* (MMF).

The total MMF $\Im$ along a closed path encircling a current-carrying coil is proportional to the ampere-turns NI in its winding:

$$\Im = \oint H dl = NI \tag{4.30}$$



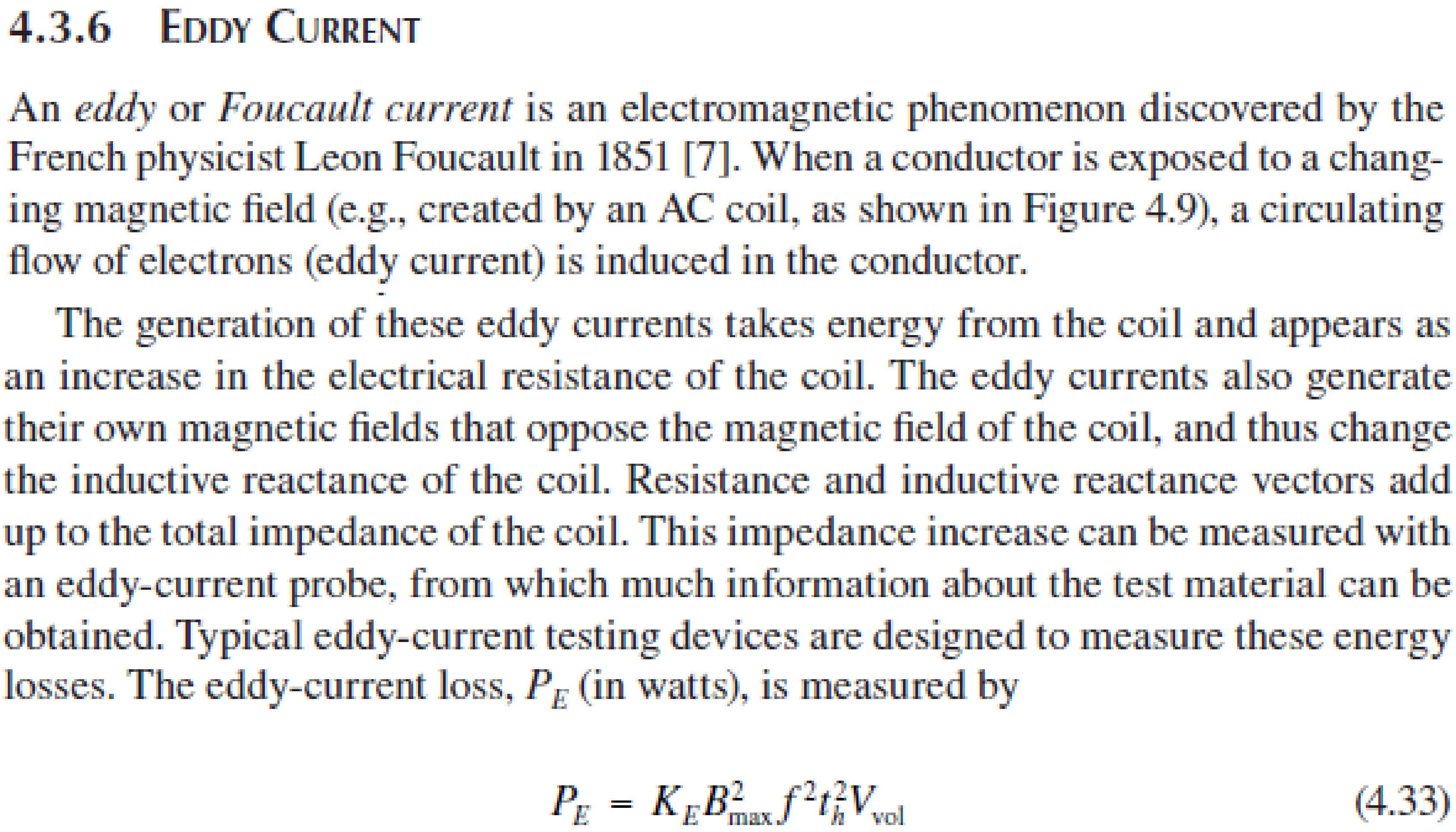
$$\Im = NI = \Phi \Re$$

$$\Re = \frac{l}{\mu A}$$

where $\Re$ (in $A \cdot Wb^{-1}$) is the reluctance of the magnetic circuit. $\Re$ is analogous to electrical resistance and it depends on the path area A, length l, and permeability μ:

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

حسگرهای القایی- معادلات فیزیکی:



4.3.6 EDDY CURRENT

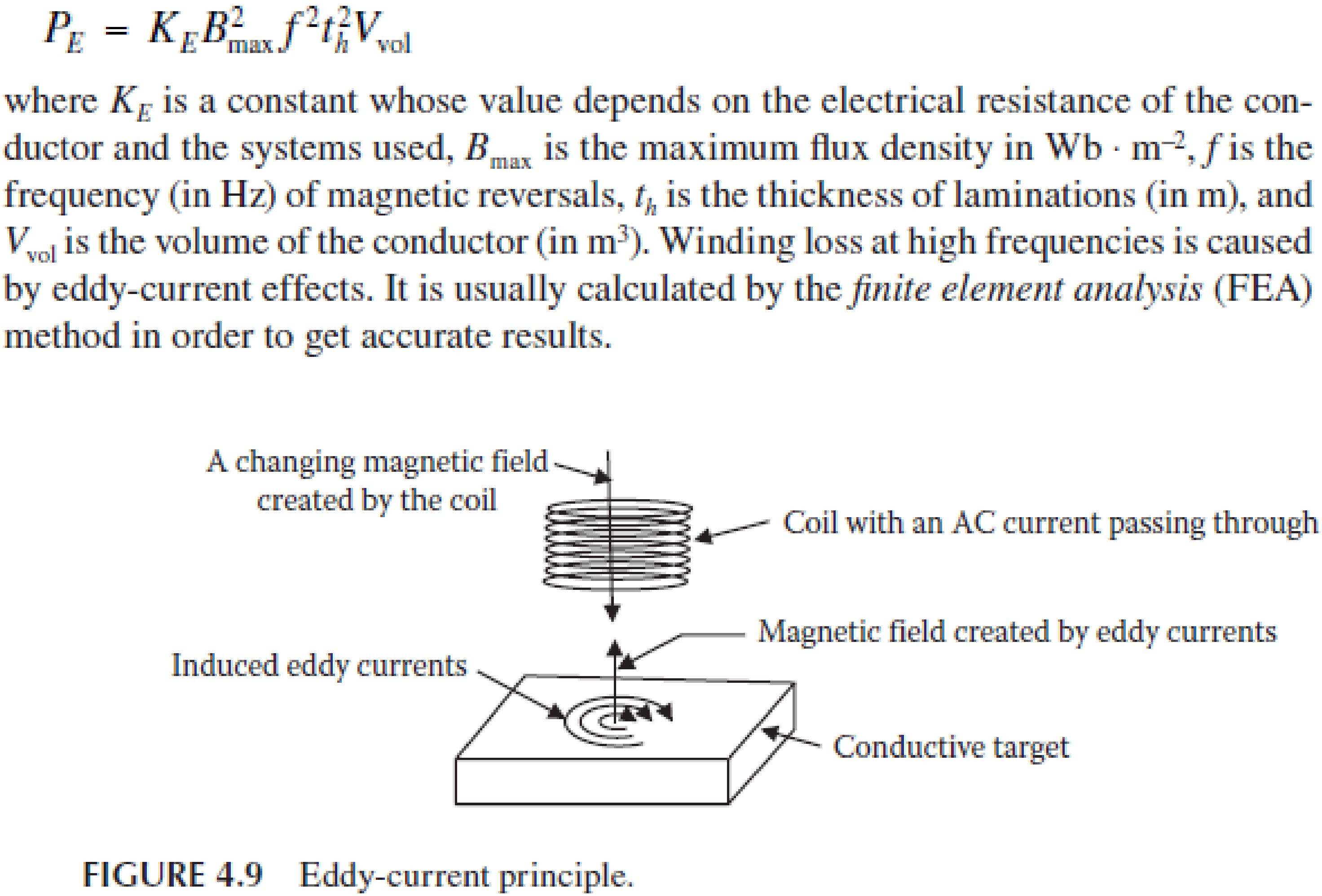
An *eddy* or *Foucault current* is an electromagnetic phenomenon discovered by the French physicist Leon Foucault in 1851 [7]. When a conductor is exposed to a changing magnetic field (e.g., created by an AC coil, as shown in Figure 4.9), a circulating flow of electrons (eddy current) is induced in the conductor.

The generation of these eddy currents takes energy from the coil and appears as an increase in the electrical resistance of the coil. The eddy currents also generate their own magnetic fields that oppose the magnetic field of the coil, and thus change the inductive reactance of the coil. Resistance and inductive reactance vectors add up to the total impedance of the coil. This impedance increase can be measured with an eddy-current probe, from which much information about the test material can be obtained. Typical eddy-current testing devices are designed to measure these energy losses. The eddy-current loss, P_E (in watts), is measured by

$$P_E = K_E B_{\max}^2 f^2 t_h^2 V_{\text{vol}} \tag{4.33}$$

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

حسگرهای القایی- معادلات فیزیکی:



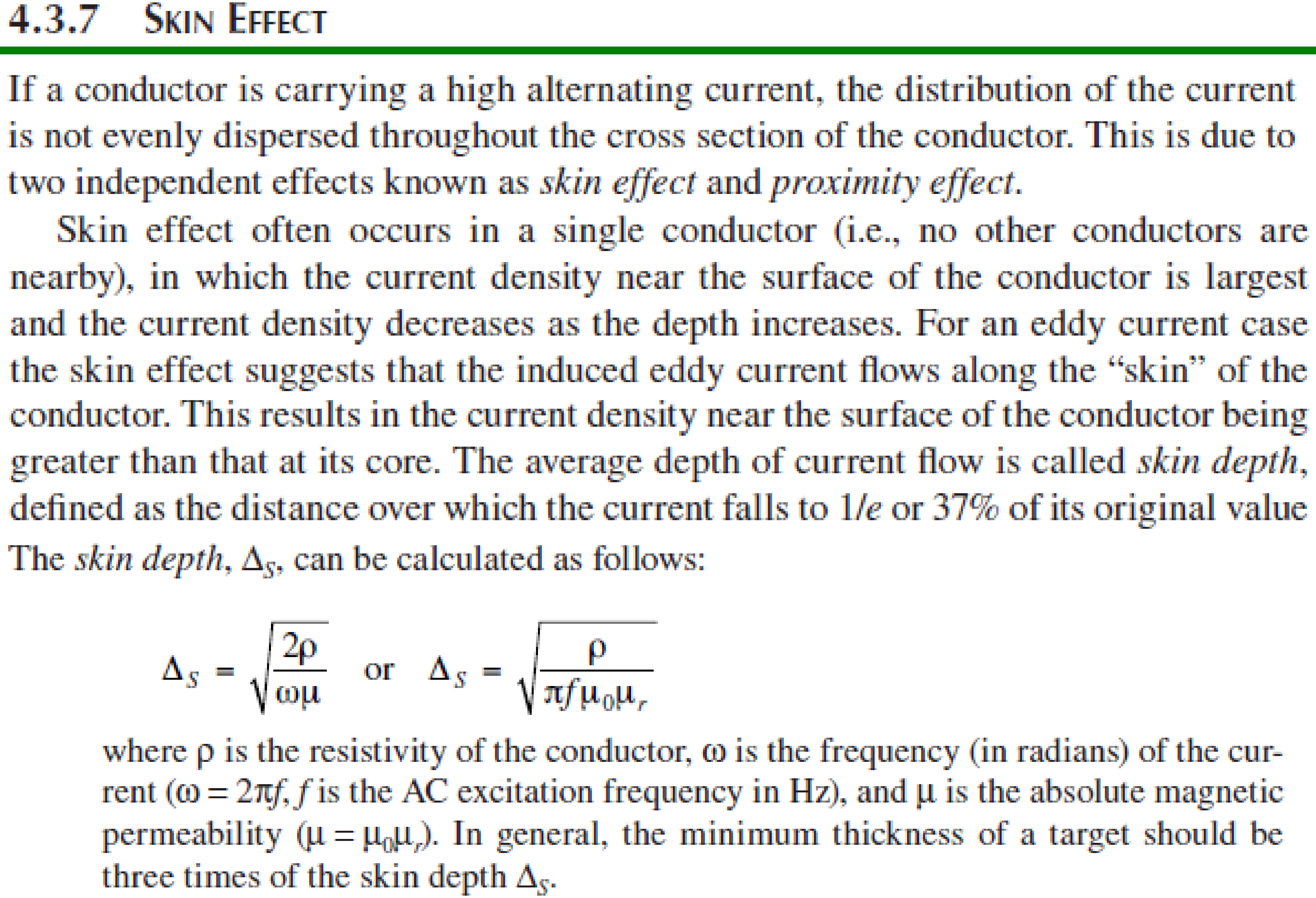
$$P_E = K_E B_{\max}^2 f^2 t_h^2 V_{\mathrm{vol}}$$

where K_E is a constant whose value depends on the electrical resistance of the conductor and the systems used, $B_{\max}$ is the maximum flux density in $\mathrm{Wb \cdot m^{-2}}$, f is the frequency (in Hz) of magnetic reversals, t_h is the thickness of laminations (in m), and V_{vol} is the volume of the conductor (in $\mathrm{m^3}$). Winding loss at high frequencies is caused by eddy-current effects. It is usually calculated by the *finite element analysis* (FEA) method in order to get accurate results.

FIGURE 4.9 Eddy-current principle.

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

حسگرهای القایی- معادلات فیزیکی:



4.3.7 SKIN EFFECT

If a conductor is carrying a high alternating current, the distribution of the current is not evenly dispersed throughout the cross section of the conductor. This is due to two independent effects known as *skin effect* and *proximity effect*.

Skin effect often occurs in a single conductor (i.e., no other conductors are nearby), in which the current density near the surface of the conductor is largest and the current density decreases as the depth increases. For an eddy current case the skin effect suggests that the induced eddy current flows along the "skin" of the conductor. This results in the current density near the surface of the conductor being greater than that at its core. The average depth of current flow is called *skin depth*, defined as the distance over which the current falls to $1/e$ or 37% of its original value

The *skin depth*, Δ_S, can be calculated as follows:

$$\Delta_S = \sqrt{\frac{2\rho}{\omega\mu}} \quad \text{or} \quad \Delta_S = \sqrt{\frac{\rho}{\pi f \mu_0 \mu_r}}$$

where ρ is the resistivity of the conductor, ω is the frequency (in radians) of the current ($\omega = 2\pi f$, f is the AC excitation frequency in Hz), and μ is the absolute magnetic permeability ($\mu = \mu_0\mu_r$). In general, the minimum thickness of a target should be three times of the skin depth Δ_S.

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

حسگرهای القایی- معادلات فیزیکی:

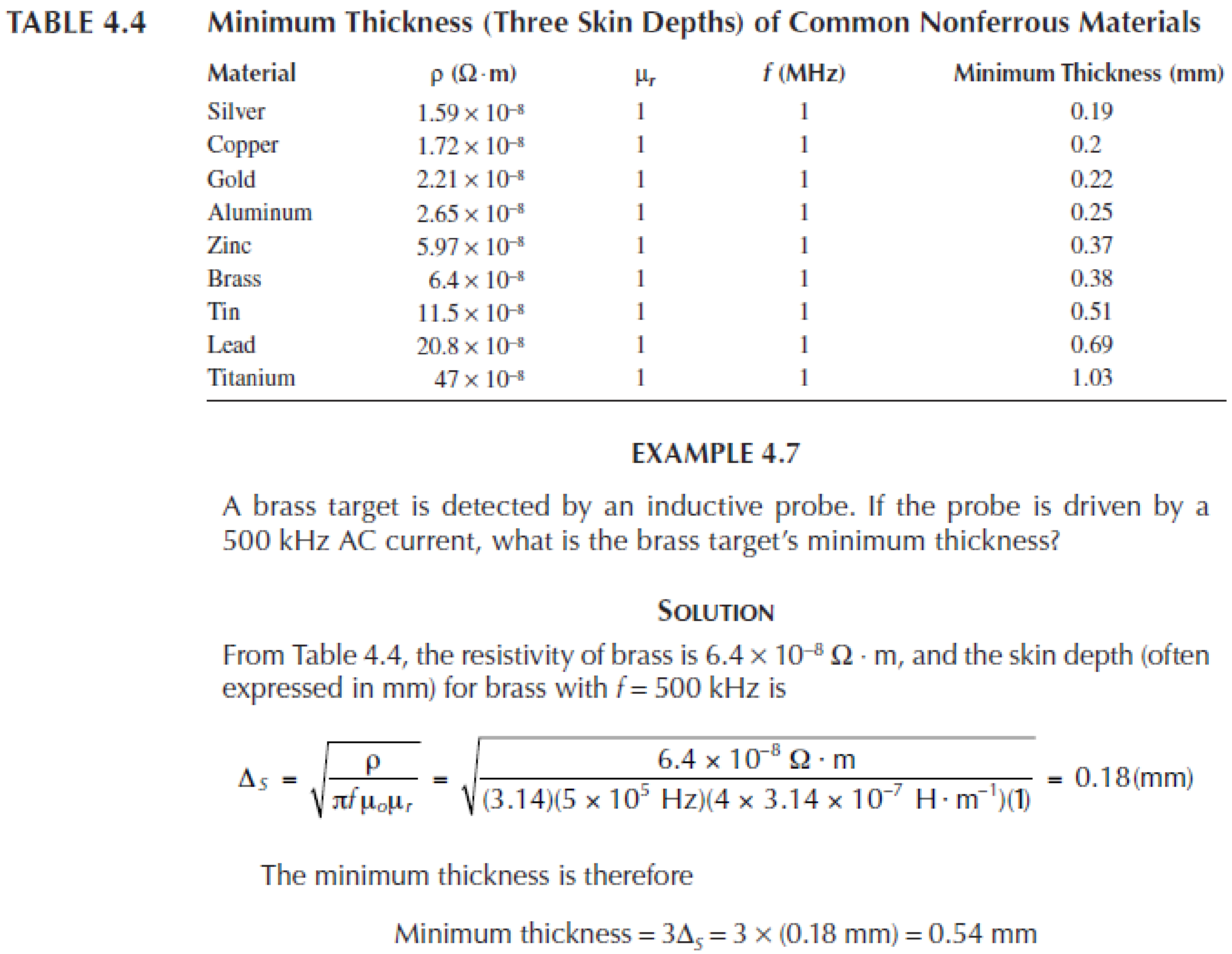


TABLE 4.4 Minimum Thickness (Three Skin Depths) of Common Nonferrous Materials

Material	ρ ($\Omega \cdot$m)	μ_r	f (MHz)	Minimum Thickness (mm)
Silver	1.59×10^{-8}	1	1	0.19
Copper	1.72×10^{-8}	1	1	0.2
Gold	2.21×10^{-8}	1	1	0.22
Aluminum	2.65×10^{-8}	1	1	0.25
Zinc	5.97×10^{-8}	1	1	0.37
Brass	6.4×10^{-8}	1	1	0.38
Tin	11.5×10^{-8}	1	1	0.51
Lead	20.8×10^{-8}	1	1	0.69
Titanium	47×10^{-8}	1	1	1.03

EXAMPLE 4.7

A brass target is detected by an inductive probe. If the probe is driven by a 500 kHz AC current, what is the brass target's minimum thickness?

SOLUTION

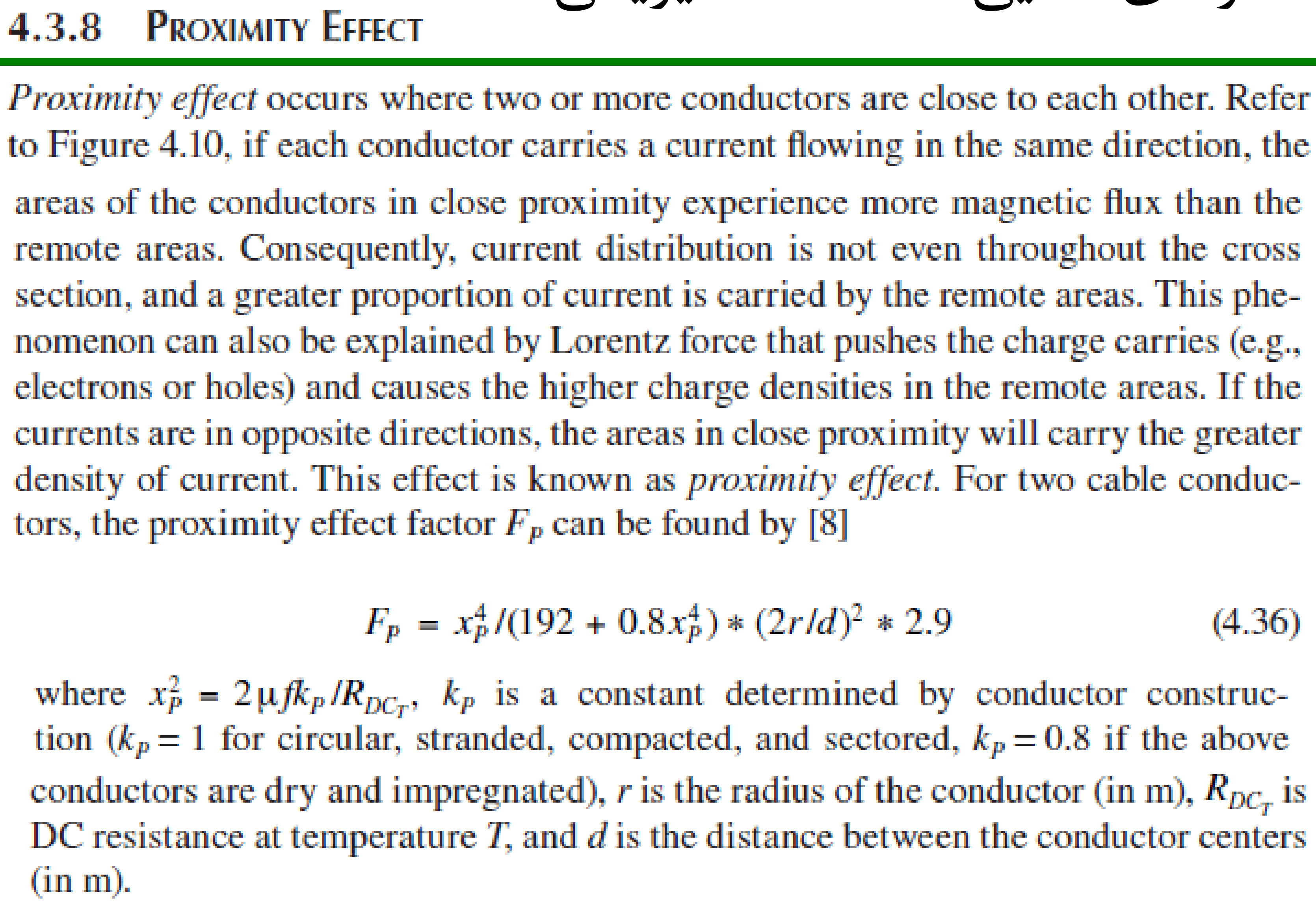
From Table 4.4, the resistivity of brass is $6.4 \times 10^{-8}\ \Omega \cdot$ m, and the skin depth (often expressed in mm) for brass with $f = 500$ kHz is

$$\Delta_S = \sqrt{\frac{\rho}{\pi f \mu_o \mu_r}} = \sqrt{\frac{6.4 \times 10^{-8}\ \Omega \cdot \mathrm{m}}{(3.14)(5 \times 10^{5}\ \mathrm{Hz})(4 \times 3.14 \times 10^{-7}\ \mathrm{H} \cdot \mathrm{m}^{-1})(1)}} = 0.18(\mathrm{mm})$$

The minimum thickness is therefore

$$\text{Minimum thickness} = 3\Delta_S = 3 \times (0.18\ \text{mm}) = 0.54\ \text{mm}$$

حسگرهای القایی- معادلات فیزیکی:



4.3.8 PROXIMITY EFFECT

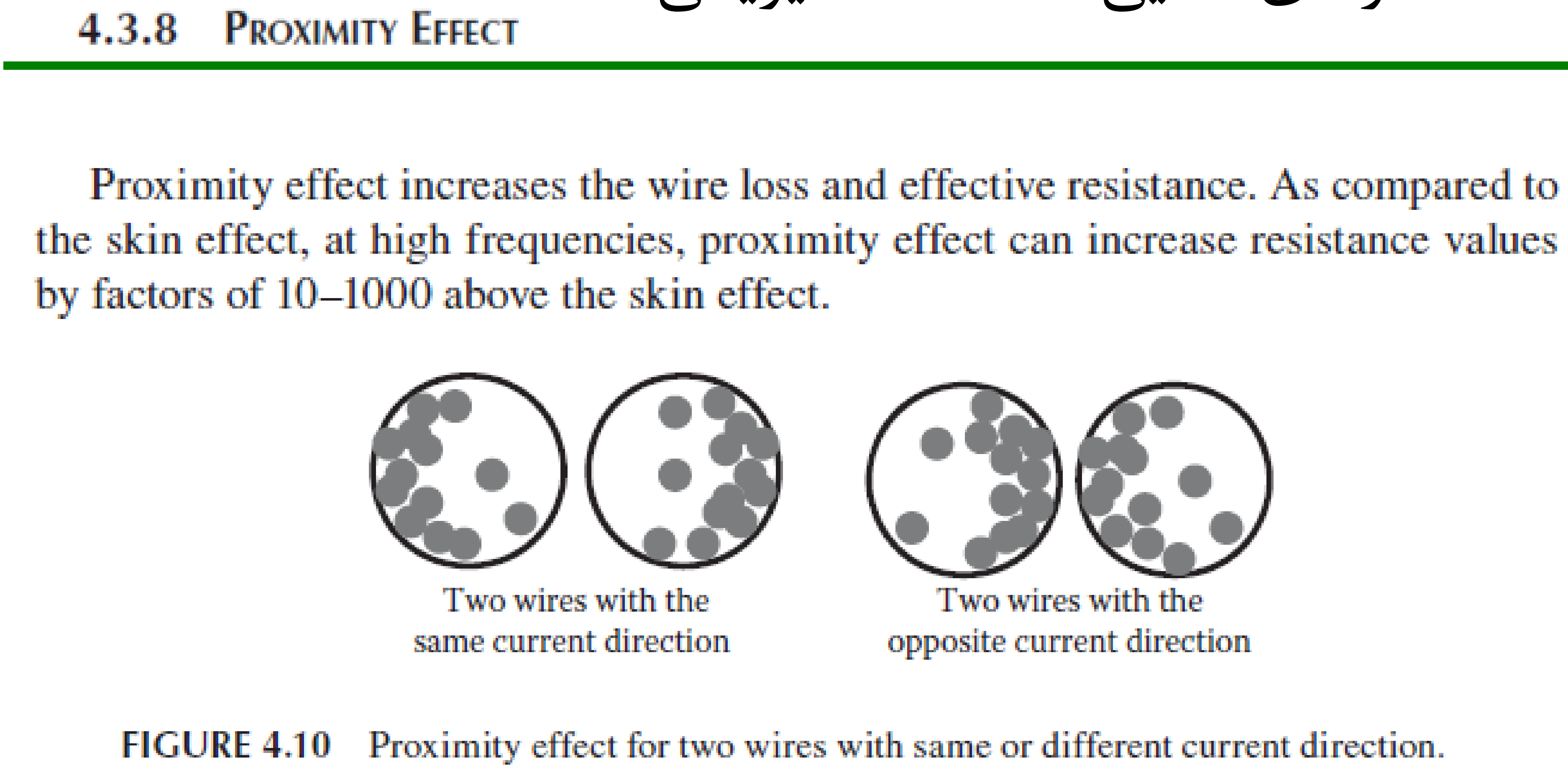
Proximity effect occurs where two or more conductors are close to each other. Refer to Figure 4.10, if each conductor carries a current flowing in the same direction, the areas of the conductors in close proximity experience more magnetic flux than the remote areas. Consequently, current distribution is not even throughout the cross section, and a greater proportion of current is carried by the remote areas. This phenomenon can also be explained by Lorentz force that pushes the charge carries (e.g., electrons or holes) and causes the higher charge densities in the remote areas. If the currents are in opposite directions, the areas in close proximity will carry the greater density of current. This effect is known as *proximity effect*. For two cable conductors, the proximity effect factor F_p can be found by [8]

$$F_p = x_p^4/(192 + 0.8x_p^4) * (2r/d)^2 * 2.9 \tag{4.36}$$

where $x_p^2 = 2\mu f k_p / R_{DC_T}$, k_p is a constant determined by conductor construction ($k_p = 1$ for circular, stranded, compacted, and sectored, $k_p = 0.8$ if the above conductors are dry and impregnated), r is the radius of the conductor (in m), R_{DC_T} is DC resistance at temperature T, and d is the distance between the conductor centers (in m).

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

حسگرهای القایی- معادلات فیزیکی:



4.3.8 PROXIMITY EFFECT

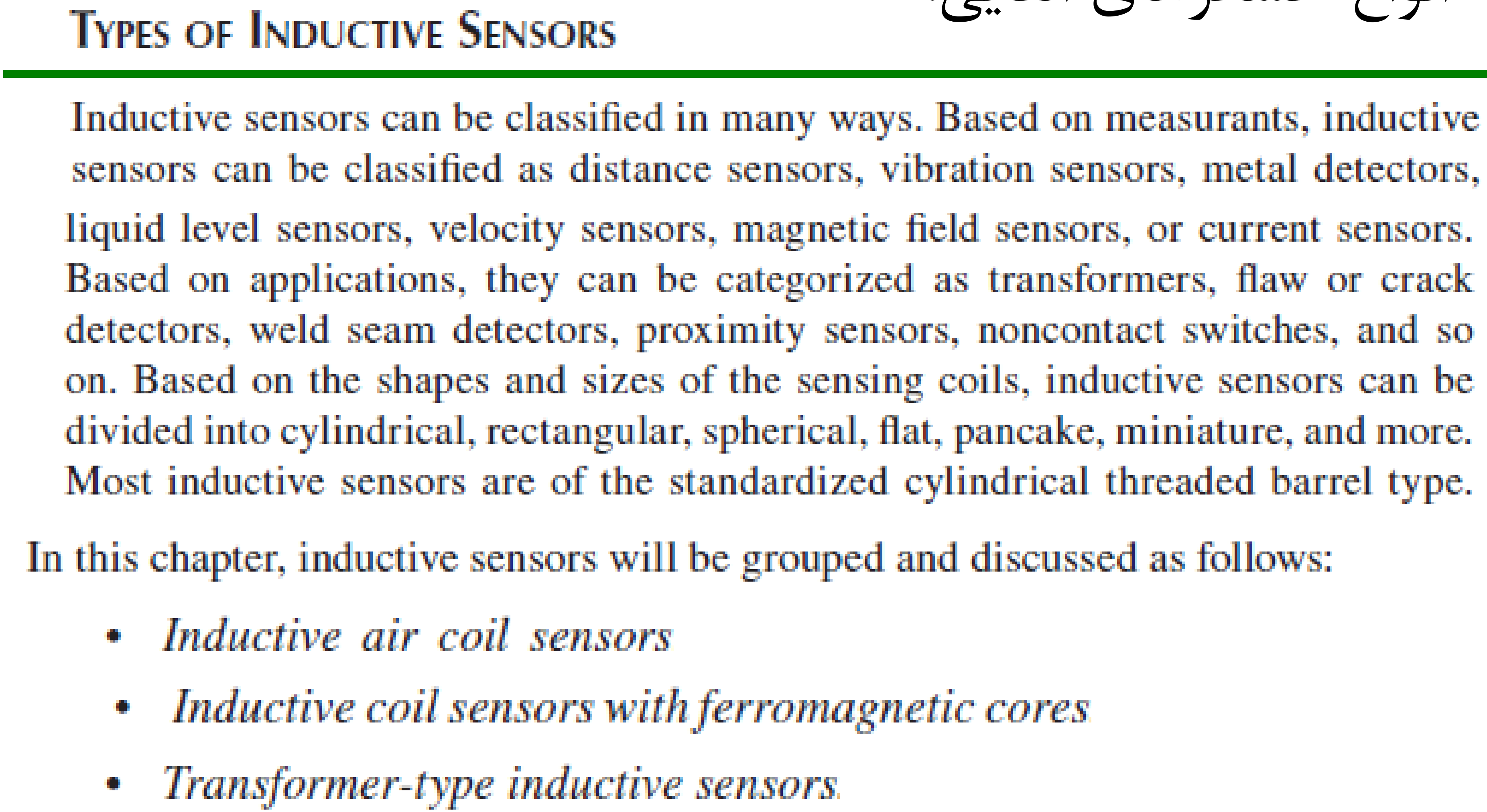
Proximity effect increases the wire loss and effective resistance. As compared to the skin effect, at high frequencies, proximity effect can increase resistance values by factors of 10–1000 above the skin effect.

Two wires with the same current direction

Two wires with the opposite current direction

FIGURE 4.10 Proximity effect for two wires with same or different current direction.

انواع حسگرهای القایی:



TYPES OF INDUCTIVE SENSORS

Inductive sensors can be classified in many ways. Based on measurants, inductive sensors can be classified as distance sensors, vibration sensors, metal detectors, liquid level sensors, velocity sensors, magnetic field sensors, or current sensors. Based on applications, they can be categorized as transformers, flaw or crack detectors, weld seam detectors, proximity sensors, noncontact switches, and so on. Based on the shapes and sizes of the sensing coils, inductive sensors can be divided into cylindrical, rectangular, spherical, flat, pancake, miniature, and more. Most inductive sensors are of the standardized cylindrical threaded barrel type.

In this chapter, inductive sensors will be grouped and discussed as follows:

- *Inductive air coil sensors*
- *Inductive coil sensors with ferromagnetic cores*
- *Transformer-type inductive sensors*

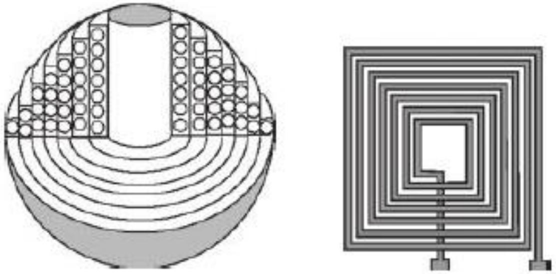
انواع حسگرهای القایی- نوع سیم پیچ هوایی:

- *Inductive air coil sensors:* In this type of sensor, there is no magnetic core—either no core at all (air coil sensors) or has a non-magnetic core (made of wood or plastics).

(a) Single magnetic loop antenna

(b) Single-coil sensor

(c) Three mutually perpendicular coils



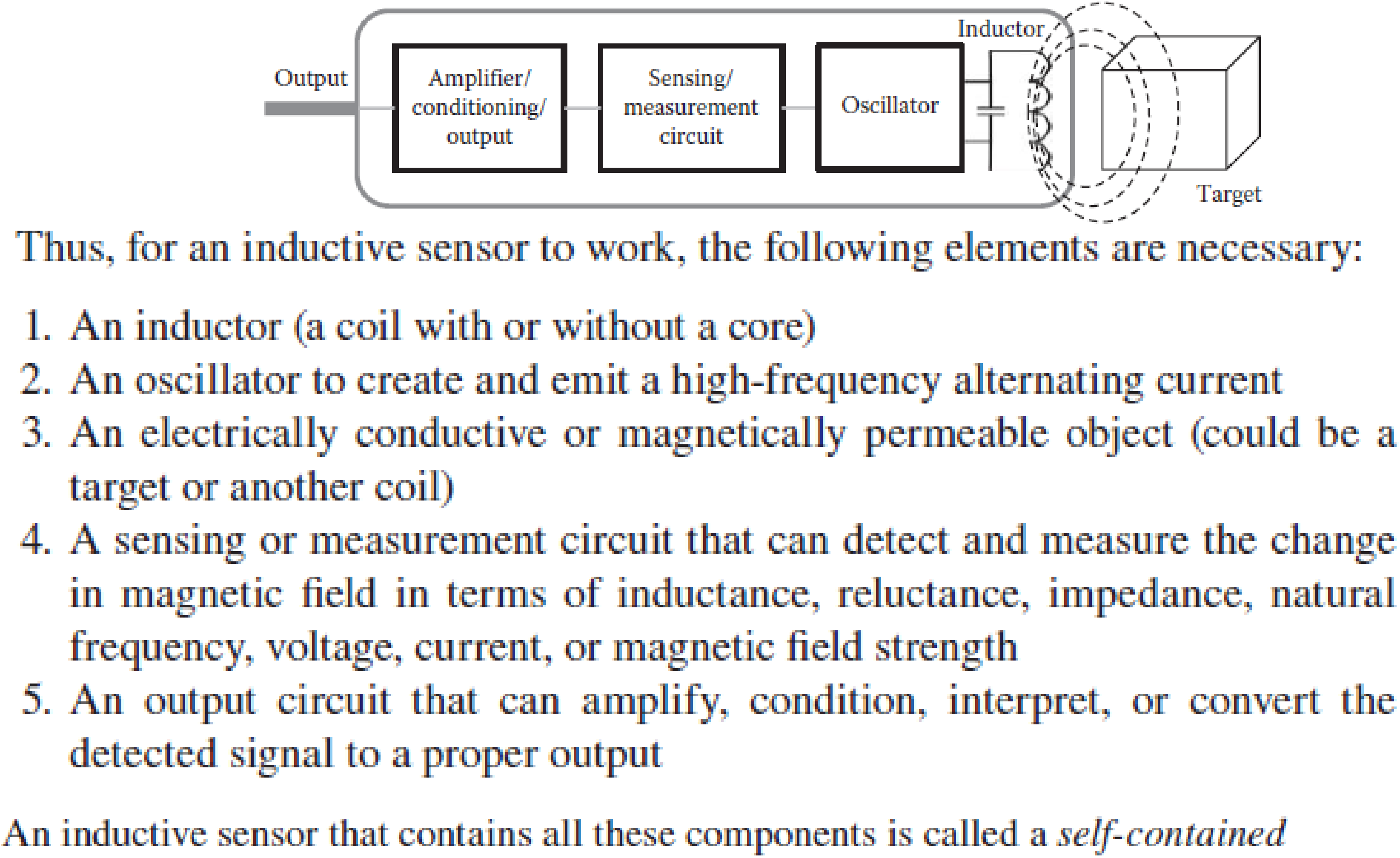
(d) Spherical coil

(e) Planar thin-film coil

$$Q = \frac{\omega L}{R} \tag{4.39}$$

Cores with an air gap have the highest Q *factor* and temperature stability.

انواع حسگرهای القایی- نوع سیم پیچ هوایی:



Thus, for an inductive sensor to work, the following elements are necessary:

1. An inductor (a coil with or without a core)
2. An oscillator to create and emit a high-frequency alternating current
3. An electrically conductive or magnetically permeable object (could be a target or another coil)
4. A sensing or measurement circuit that can detect and measure the change in magnetic field in terms of inductance, reluctance, impedance, natural frequency, voltage, current, or magnetic field strength
5. An output circuit that can amplify, condition, interpret, or convert the detected signal to a proper output

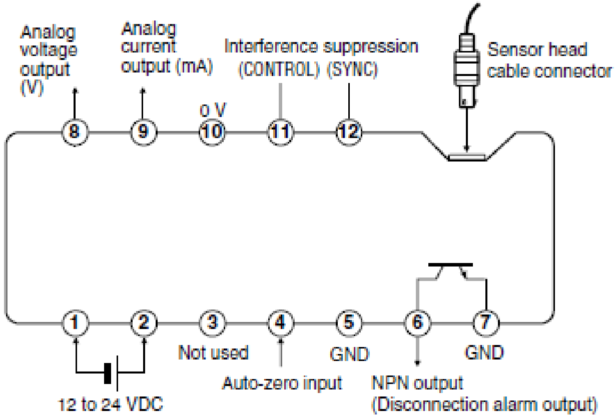
An inductive sensor that contains all these components is called a *self-contained*

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

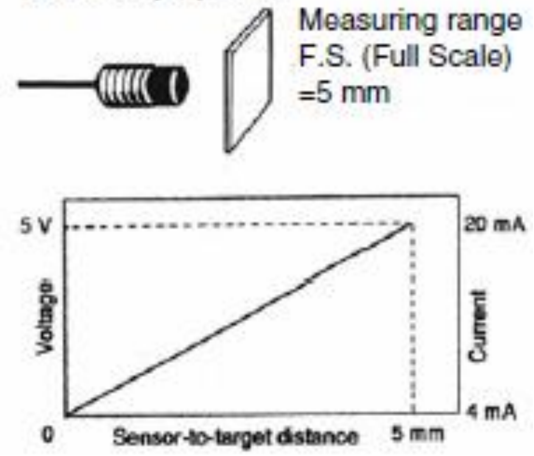
Inductive Gauging Sensor

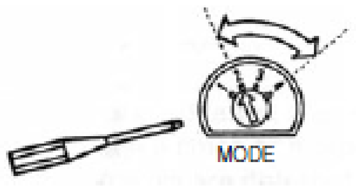
EX-500(W) Series

مثال از حسگر سیم پیچ هوایی:



EX-505(W)/016





MODE	2	3	4
Reference metal	Aluminum (A5052)	Stainless steel (SUS304)	Iron (S45C)
Other metals	Copper (C1100) Brass (C3560)	——	Iron (SS41) Stainless steel (SUS410) Stainless steel (SUS430)
Metal-plated*	——	Zinc-plated Chromium -plated	Nickel-plated

* Base material: Iron (SS41),
Plating thickness: 50 µm

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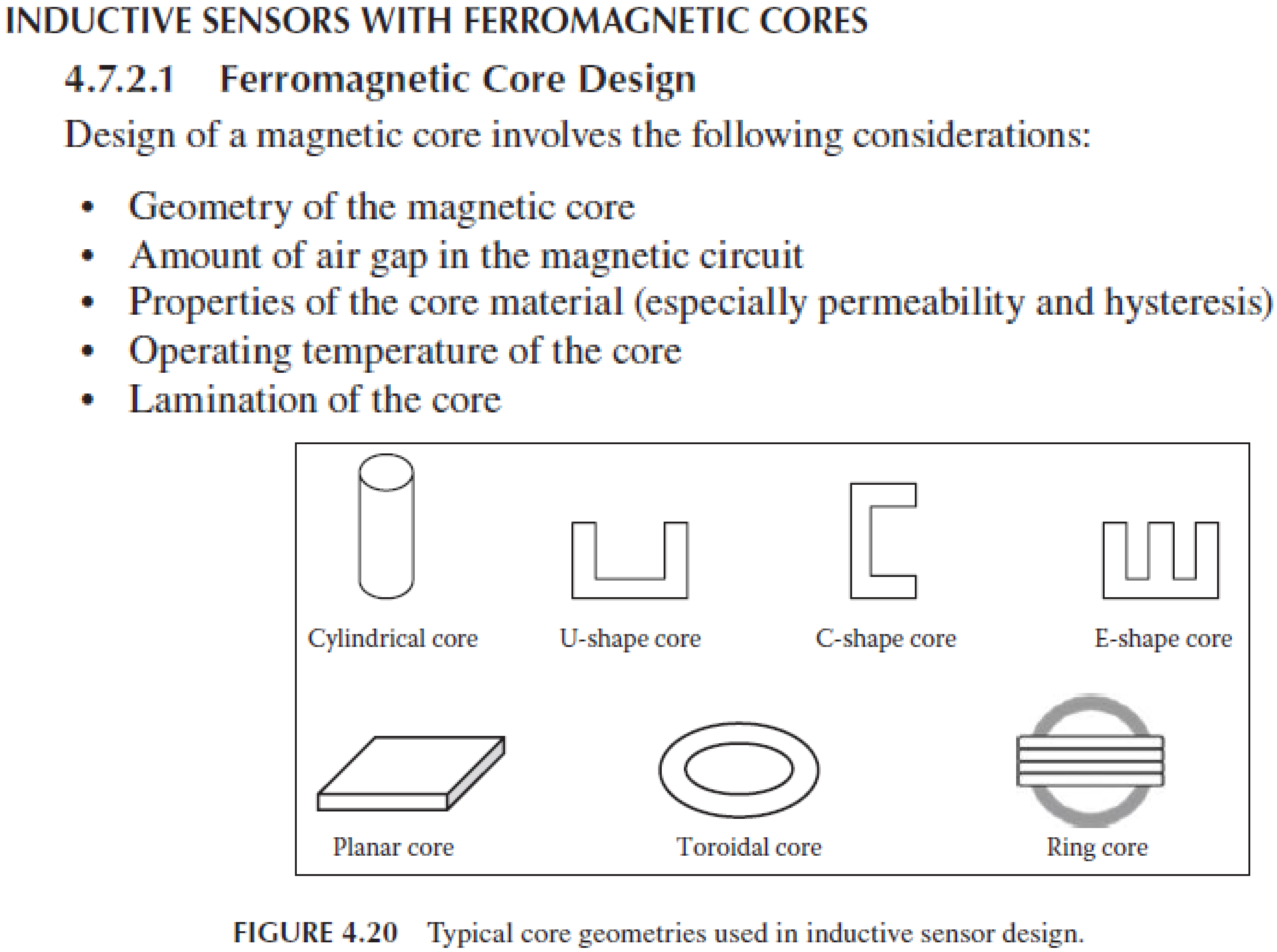

INDUCTIVE SENSORS WITH FERROMAGNETIC CORES

4.7.2.1 Ferromagnetic Core Design

Design of a magnetic core involves the following considerations:

- Geometry of the magnetic core
- Amount of air gap in the magnetic circuit
- Properties of the core material (especially permeability and hysteresis)
- Operating temperature of the core
- Lamination of the core

Cylindrical core
U-shape core
C-shape core
E-shape core
Planar core
Toroidal core
Ring core

FIGURE 4.20 Typical core geometries used in inductive sensor design.

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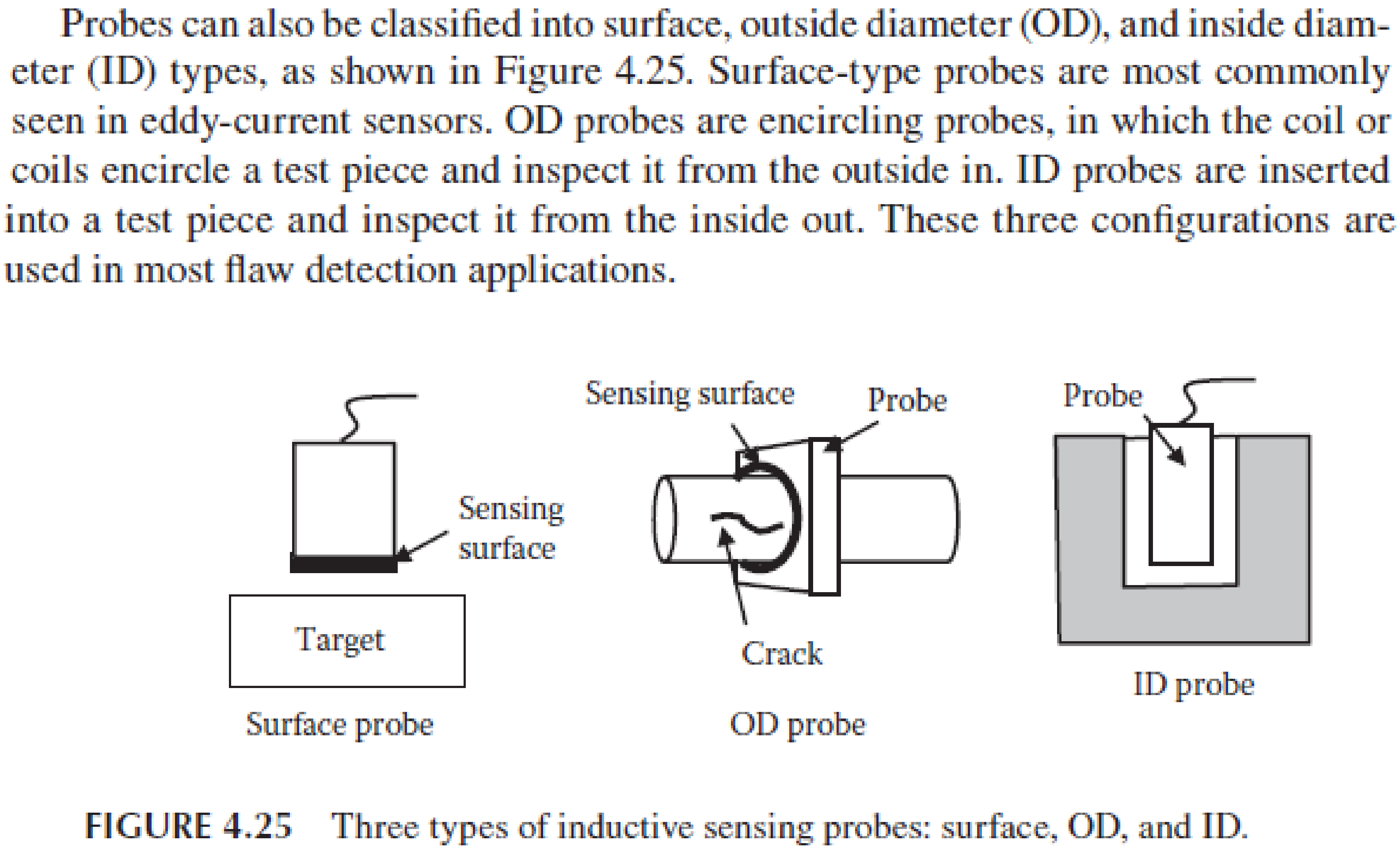
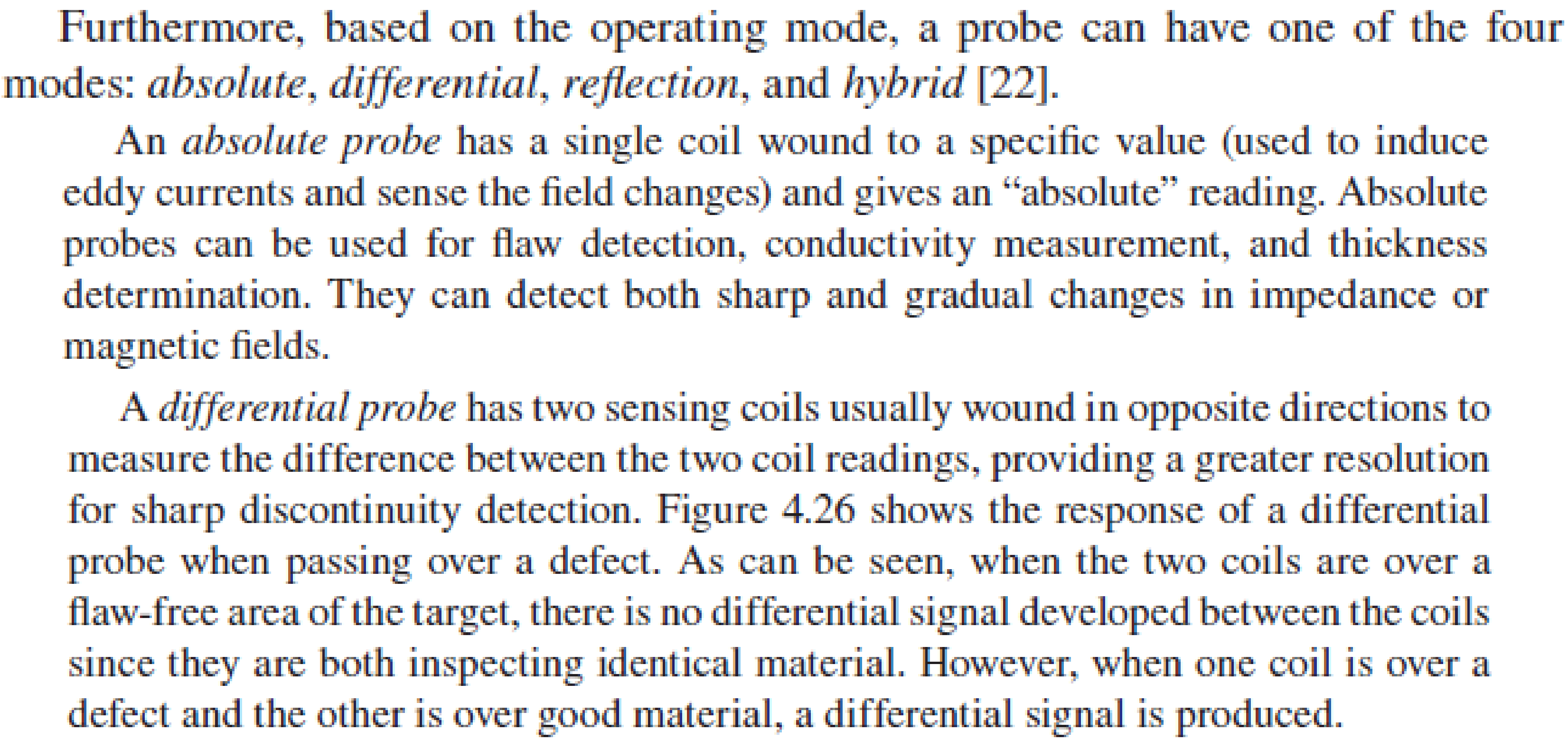


Probes can also be classified into surface, outside diameter (OD), and inside diameter (ID) types, as shown in Figure 4.25. Surface-type probes are most commonly seen in eddy-current sensors. OD probes are encircling probes, in which the coil or coils encircle a test piece and inspect it from the outside in. ID probes are inserted into a test piece and inspect it from the inside out. These three configurations are used in most flaw detection applications.

FIGURE 4.25 Three types of inductive sensing probes: surface, OD, and ID.

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

حسگرهای القایی با هسته فرومغناطیس:



Furthermore, based on the operating mode, a probe can have one of the four modes: *absolute*, *differential*, *reflection*, and *hybrid* [22].

An *absolute probe* has a single coil wound to a specific value (used to induce eddy currents and sense the field changes) and gives an "absolute" reading. Absolute probes can be used for flaw detection, conductivity measurement, and thickness determination. They can detect both sharp and gradual changes in impedance or magnetic fields.

A *differential probe* has two sensing coils usually wound in opposite directions to measure the difference between the two coil readings, providing a greater resolution for sharp discontinuity detection. Figure 4.26 shows the response of a differential probe when passing over a defect. As can be seen, when the two coils are over a flaw-free area of the target, there is no differential signal developed between the coils since they are both inspecting identical material. However, when one coil is over a defect and the other is over good material, a differential signal is produced.

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

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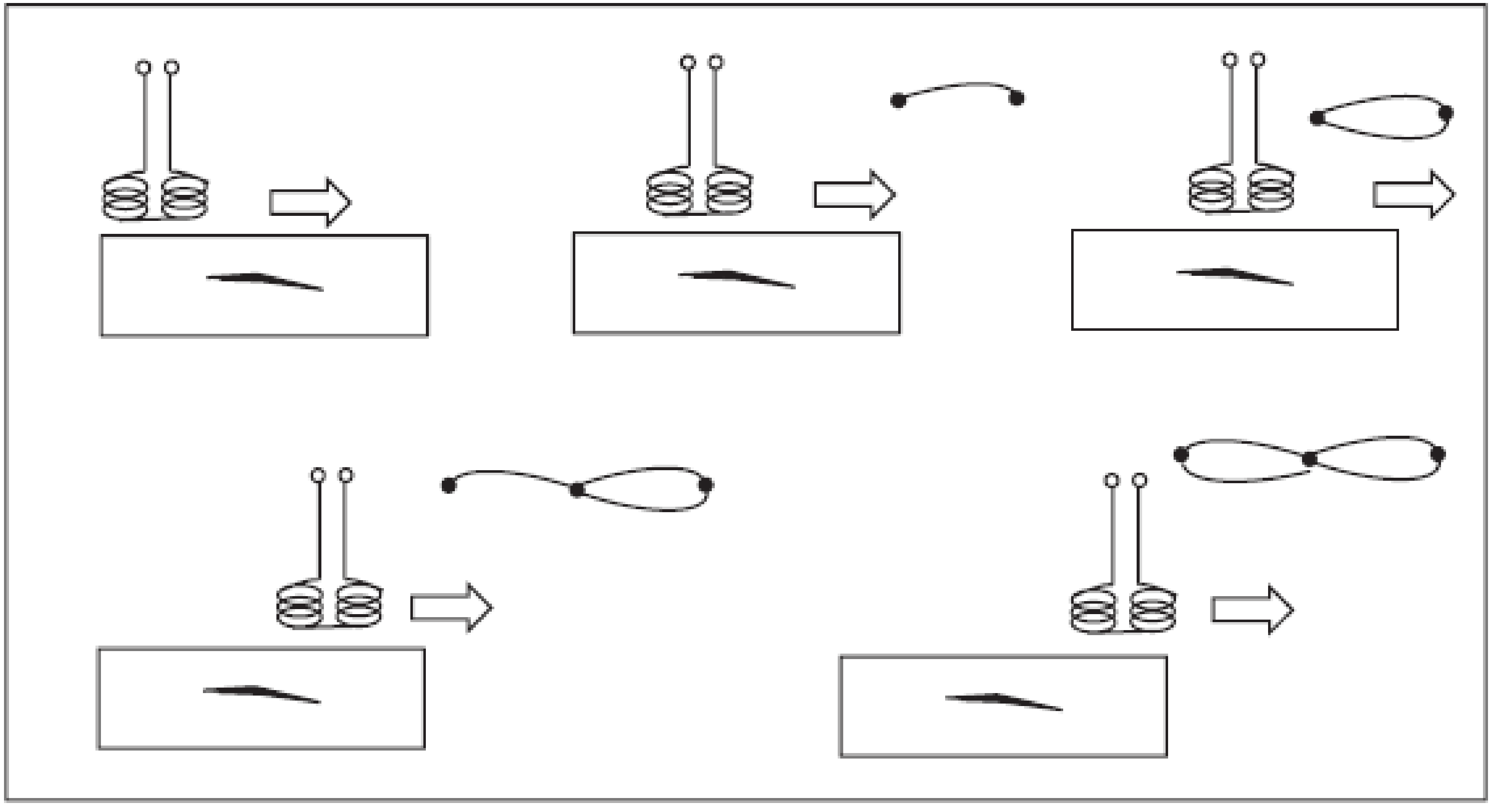

FIGURE 4.26 Response of a differential probe passing over a defect. (From Probes—mode of operation, NSF-NDT Resource Center. Available at: www.ndt-ed.org/EducationResources/CommunityCollege/EddyCurrents/ProbesCoilDesign/ProbesModeOp.htm.)

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

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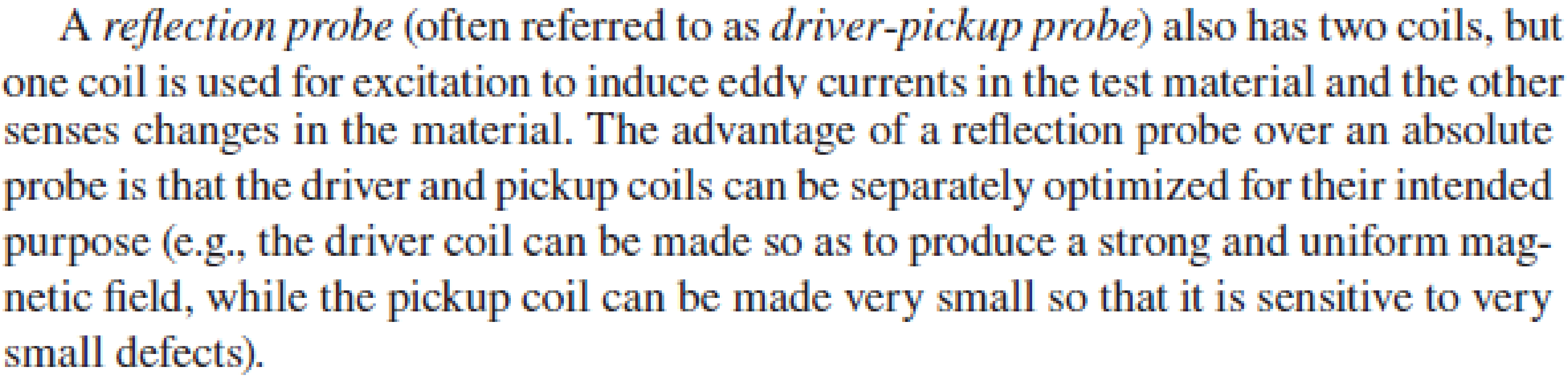
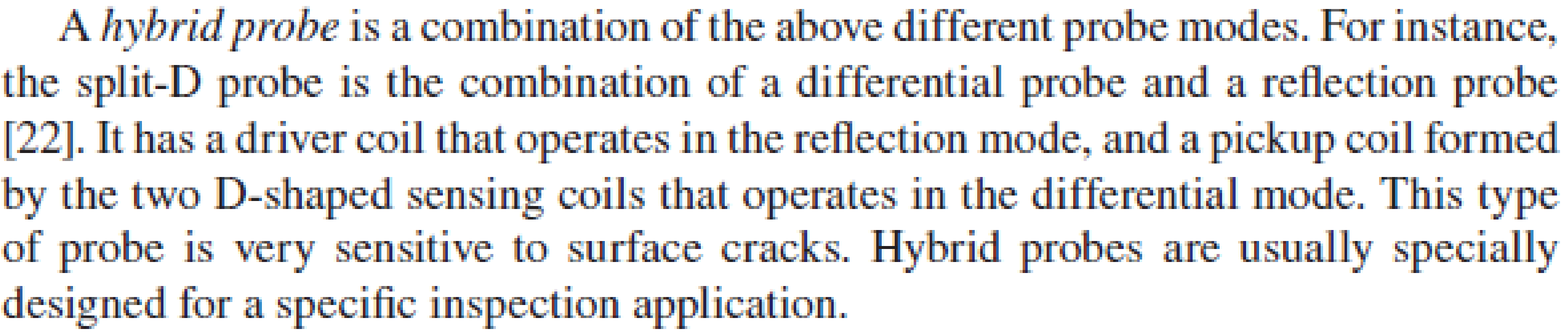


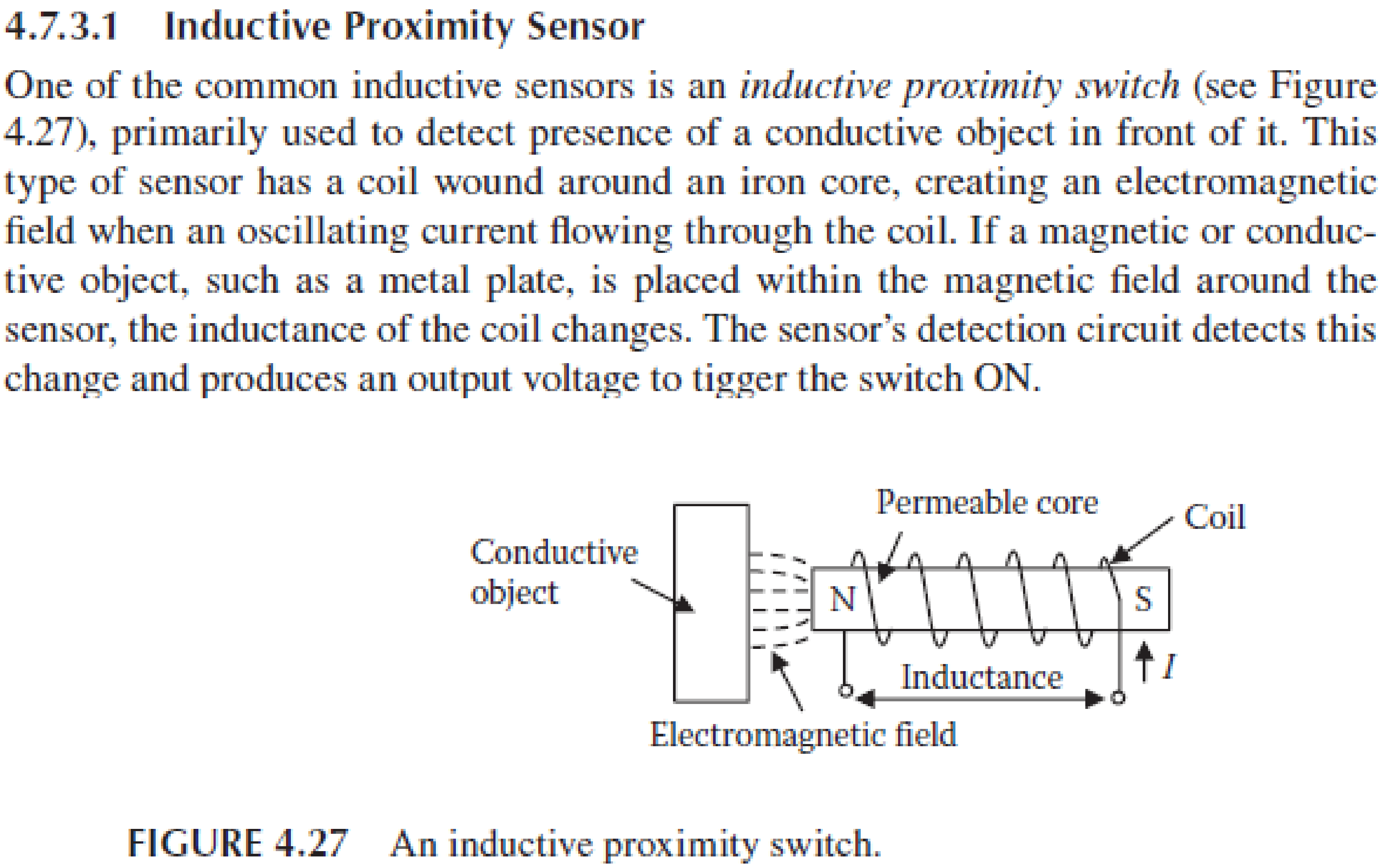
A *reflection probe* (often referred to as *driver-pickup probe*) also has two coils, but one coil is used for excitation to induce eddy currents in the test material and the other senses changes in the material. The advantage of a reflection probe over an absolute probe is that the driver and pickup coils can be separately optimized for their intended purpose (e.g., the driver coil can be made so as to produce a strong and uniform magnetic field, while the pickup coil can be made very small so that it is sensitive to very small defects).



A *hybrid probe* is a combination of the above different probe modes. For instance, the split-D probe is the combination of a differential probe and a reflection probe [22]. It has a driver coil that operates in the reflection mode, and a pickup coil formed by the two D-shaped sensing coils that operates in the differential mode. This type of probe is very sensitive to surface cracks. Hybrid probes are usually specially designed for a specific inspection application.

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

حسگرهای القایی با هسته فرومغناطیس- کاربردها:



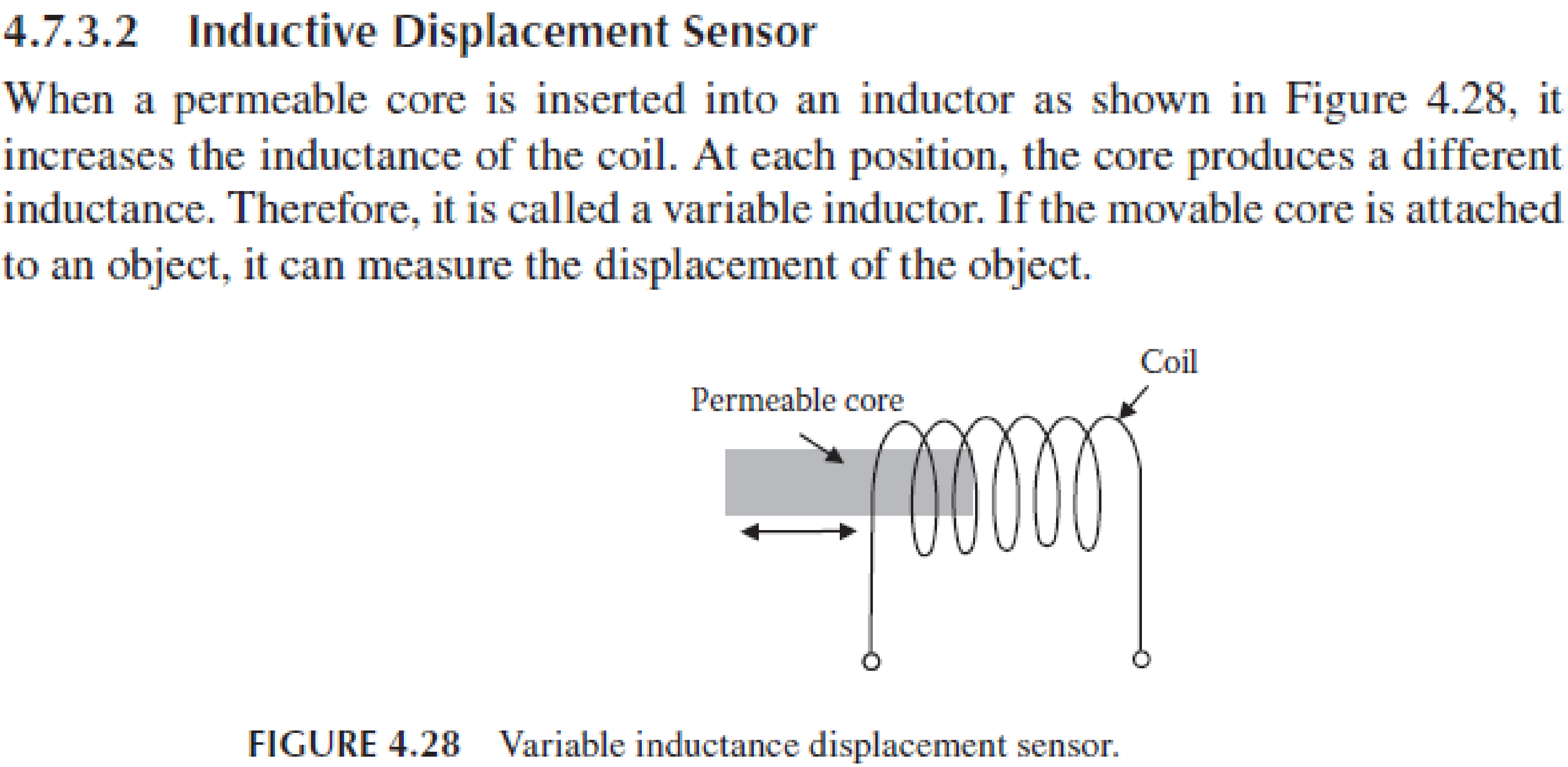
4.7.3.1 Inductive Proximity Sensor

One of the common inductive sensors is an *inductive proximity switch* (see Figure 4.27), primarily used to detect presence of a conductive object in front of it. This type of sensor has a coil wound around an iron core, creating an electromagnetic field when an oscillating current flowing through the coil. If a magnetic or conductive object, such as a metal plate, is placed within the magnetic field around the sensor, the inductance of the coil changes. The sensor's detection circuit detects this change and produces an output voltage to tigger the switch ON.

FIGURE 4.27 An inductive proximity switch.

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

حسگرهای القایی با هسته فرومغناطیس- کاربردها:



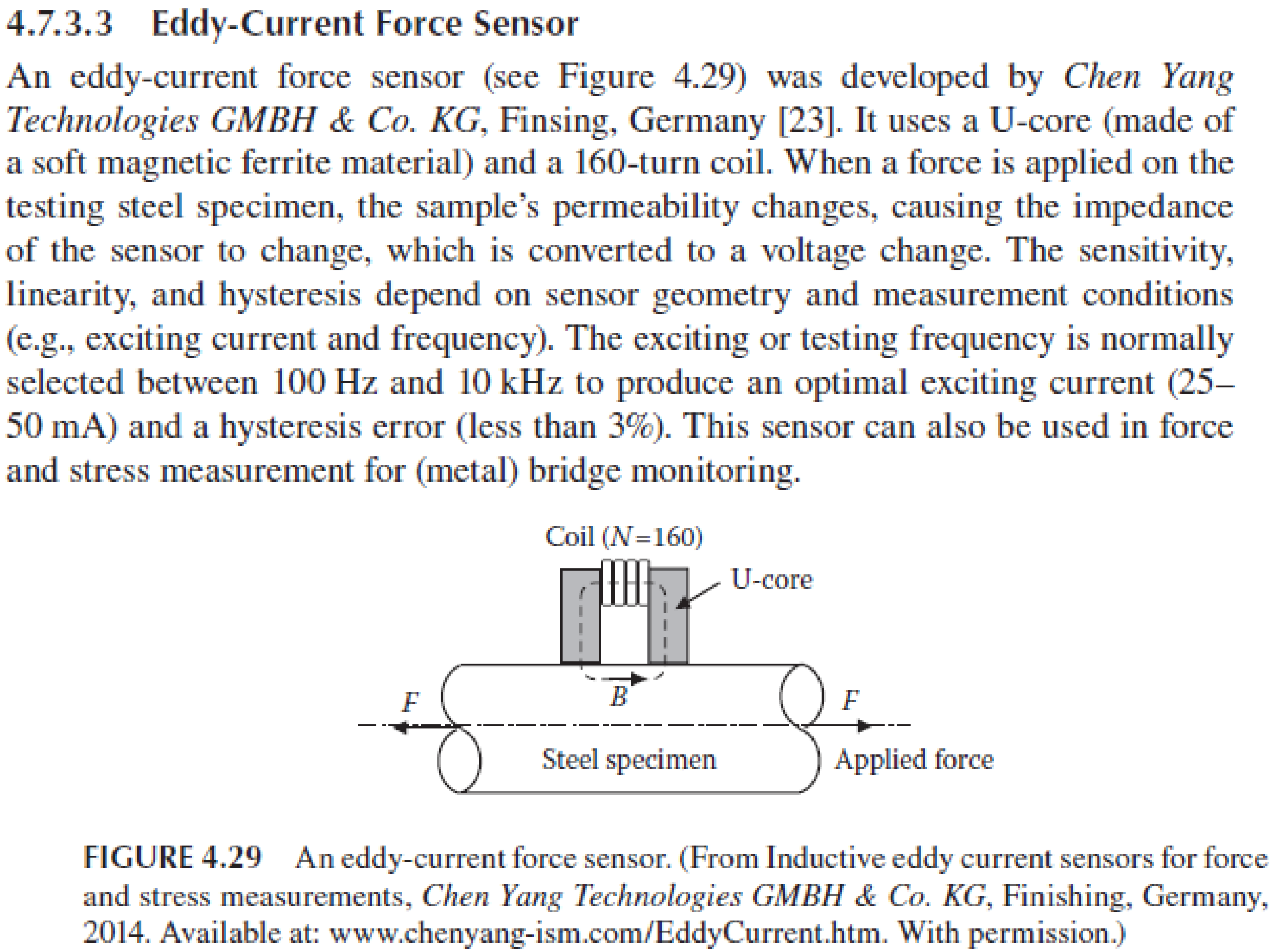
4.7.3.2 Inductive Displacement Sensor

When a permeable core is inserted into an inductor as shown in Figure 4.28, it increases the inductance of the coil. At each position, the core produces a different inductance. Therefore, it is called a variable inductor. If the movable core is attached to an object, it can measure the displacement of the object.

FIGURE 4.28 Variable inductance displacement sensor.

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

حسگرهای القایی با هسته فرومغناطیس- کاربردها:



4.7.3.3 Eddy-Current Force Sensor

An eddy-current force sensor (see Figure 4.29) was developed by *Chen Yang Technologies GMBH & Co. KG*, Finsing, Germany [23]. It uses a U-core (made of a soft magnetic ferrite material) and a 160-turn coil. When a force is applied on the testing steel specimen, the sample's permeability changes, causing the impedance of the sensor to change, which is converted to a voltage change. The sensitivity, linearity, and hysteresis depend on sensor geometry and measurement conditions (e.g., exciting current and frequency). The exciting or testing frequency is normally selected between 100 Hz and 10 kHz to produce an optimal exciting current (25–50 mA) and a hysteresis error (less than 3%). This sensor can also be used in force and stress measurement for (metal) bridge monitoring.

FIGURE 4.29 An eddy-current force sensor. (From Inductive eddy current sensors for force and stress measurements, *Chen Yang Technologies GMBH & Co. KG*, Finishing, Germany, 2014. Available at: www.chenyang-ism.com/EddyCurrent.htm. With permission.)

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

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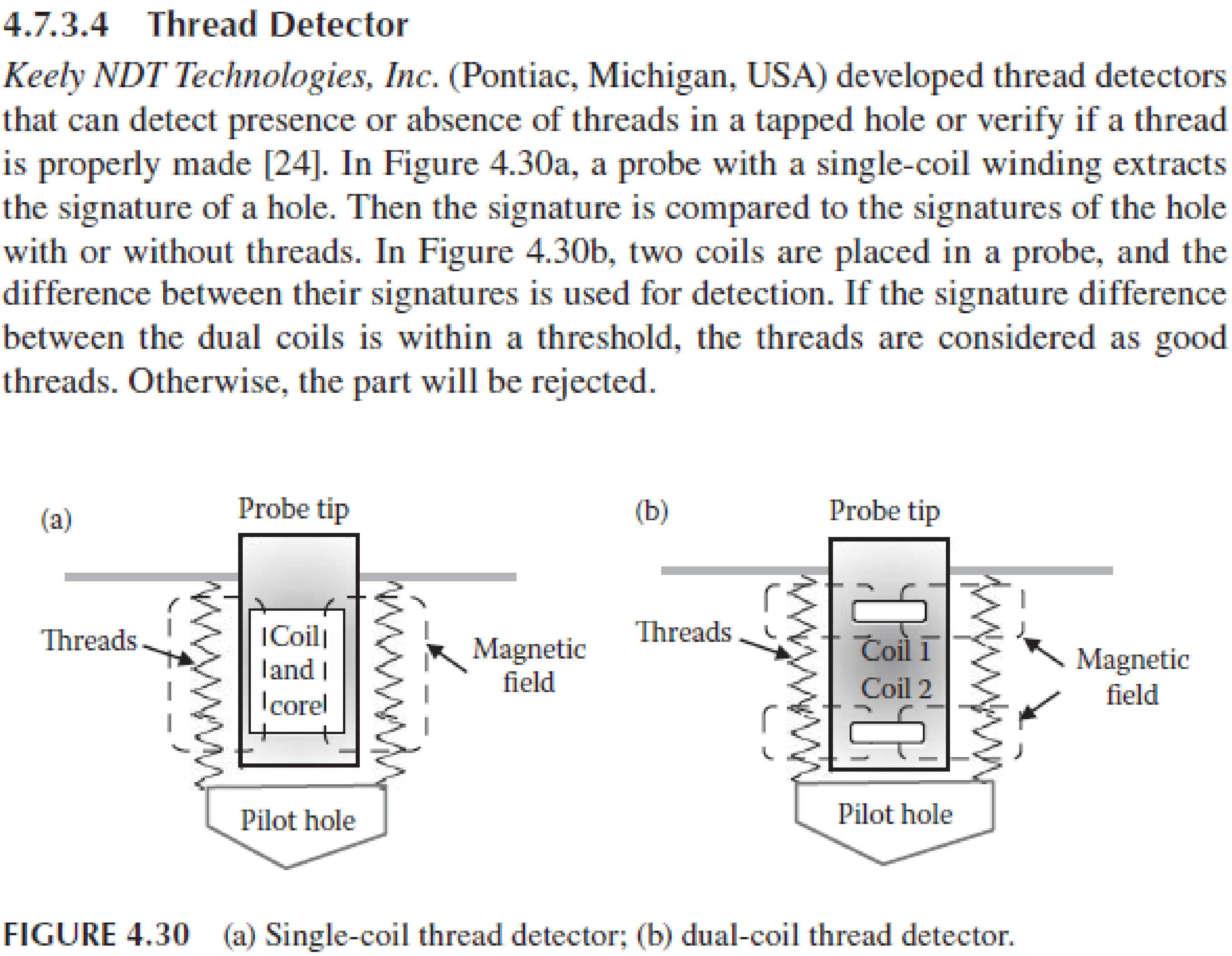


4.7.3.4 Thread Detector

Keely NDT Technologies, Inc. (Pontiac, Michigan, USA) developed thread detectors that can detect presence or absence of threads in a tapped hole or verify if a thread is properly made [24]. In Figure 4.30a, a probe with a single-coil winding extracts the signature of a hole. Then the signature is compared to the signatures of the hole with or without threads. In Figure 4.30b, two coils are placed in a probe, and the difference between their signatures is used for detection. If the signature difference between the dual coils is within a threshold, the threads are considered as good threads. Otherwise, the part will be rejected.

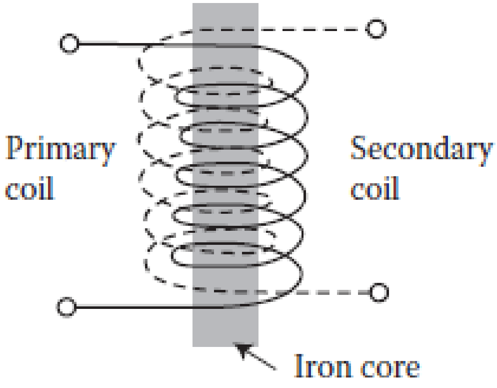
FIGURE 4.30 (a) Single-coil thread detector; (b) dual-coil thread detector.

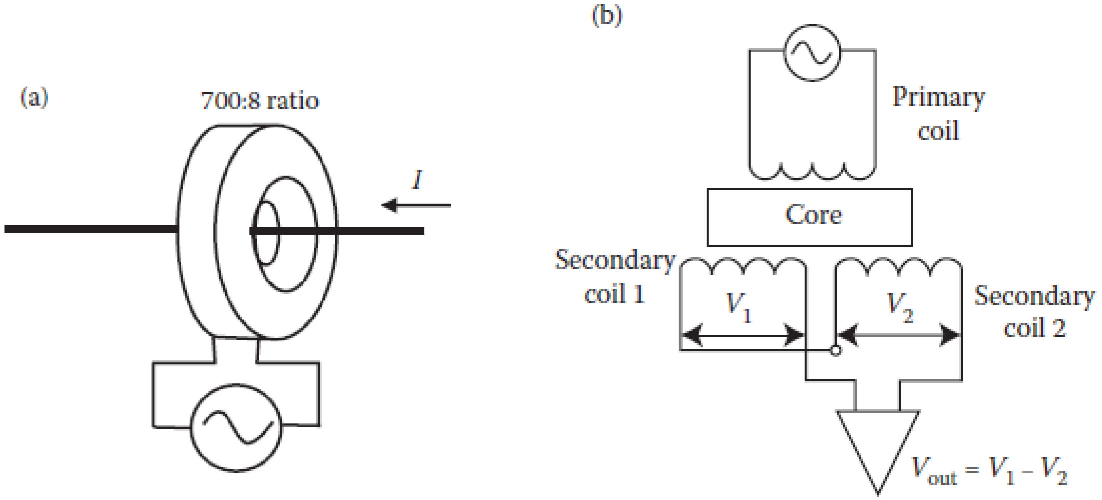
Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

حسگرهای القایی نوع ترانسفورماتوری:

4.8.1 INTRODUCTION

A transformer is an inductive device that transfers energy by inductive coupling between its primary winding and secondary winding. In transformer-type inductive sensors, the primary coil is driven by an AC excitation current, which creates a varying magnetic field. This changing field induces an AC voltage or current in the secondary coil (usually two or three windings) that can be measured and sent to an output circuit.



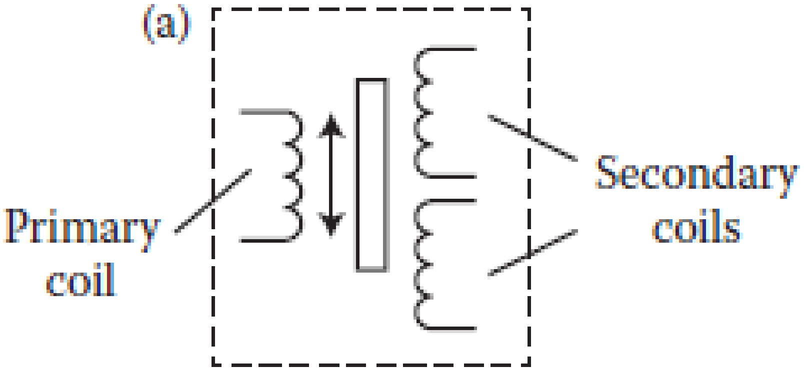


Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

حسگرهای القایی نوع ترانسفورماتوری:

Based on the type of the motion mechanism and the coil/core configurations, transformer-type inductive sensors can be categorized as :

- *Linear variable differential transformer*: Has a primary coil, two secondary coils, and a linearly movable core (see Figure 4.31a), and can measure linear displacement, force, acceleration, and pressure.

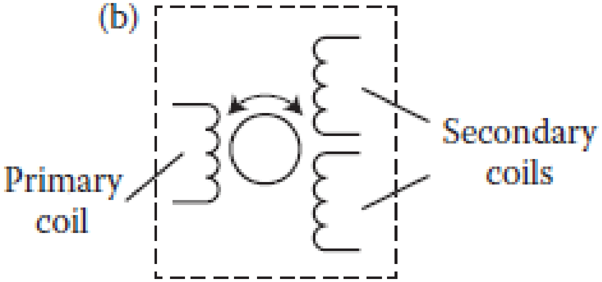


Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

حسگرهای القایی نوع ترانسفورماتوری:

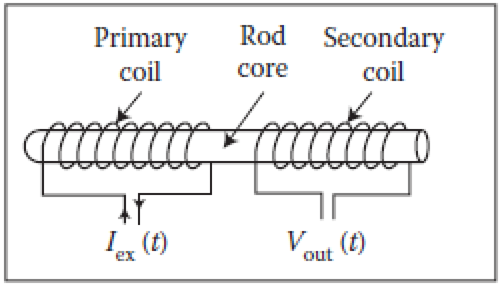
- *Rotary variable differential transformer*: Has a rotating core (Figure 4.31b) and can measure angular position.

(b)



- *Fluxgate sensor*: Uses a high-permeability ferromagnetic core (motionless) and operates at its saturation (gating) state (Figure 4.31c and d). The periodic saturation of the core due to the alternating current flowing through the excitation coil causes the permeability of the core to drop and a nearby DC magnetic field to decrease. The sensor output will be proportional to the intensity of the external magnetic field.

(c)



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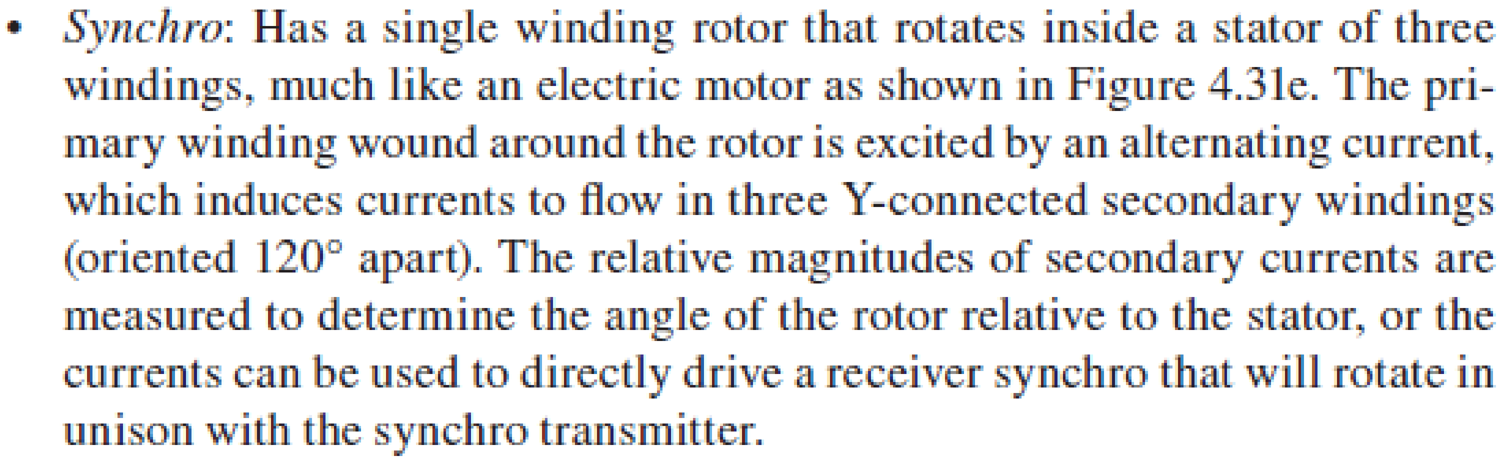
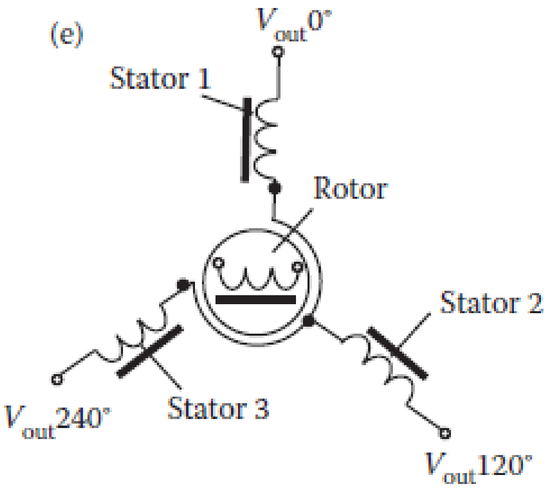


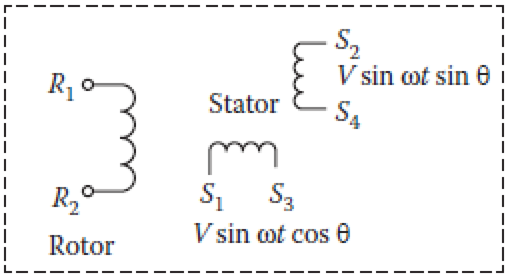
- *Synchro*: Has a single winding rotor that rotates inside a stator of three windings, much like an electric motor as shown in Figure 4.31e. The primary winding wound around the rotor is excited by an alternating current, which induces currents to flow in three Y-connected secondary windings (oriented 120° apart). The relative magnitudes of secondary currents are measured to determine the angle of the rotor relative to the stator, or the currents can be used to directly drive a receiver synchro that will rotate in unison with the synchro transmitter.



حسگرهای القایی نوع ترانسفورماتوری:

- *Resolver*: Has a single-winding rotor that rotates inside a stator of two windings (oriented 90° apart, see Figure 4.31f) and provides accurate angular and rotational information.

(f)



Ebook: W. Y. Du ”*Resistive, capacitive, inductive, and magnetic sensor technologies*”, CRC Press, 2014.

حسگرهای القایی نوع ترانسفورماتوری – LVDT:

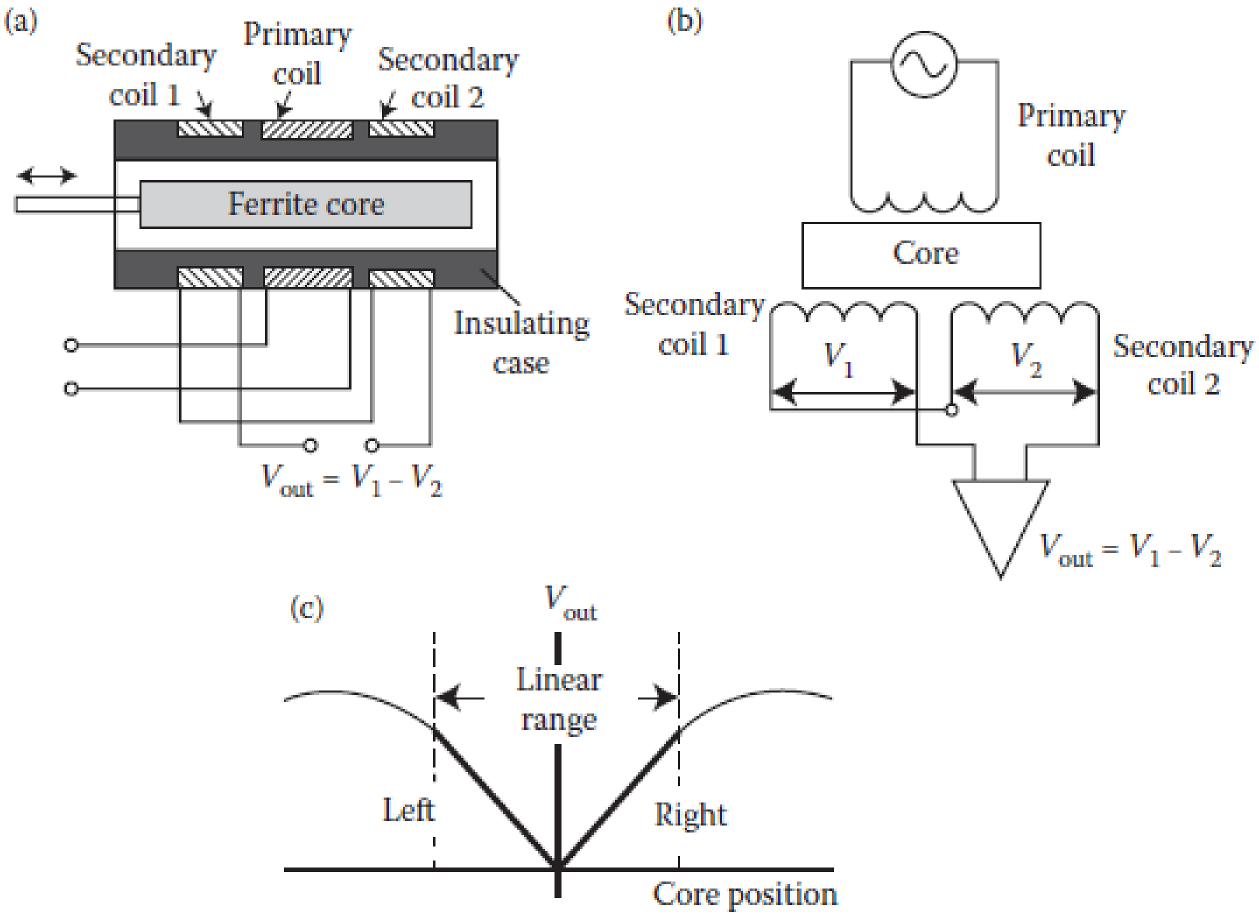


FIGURE 4.35 (a) Internal structure of an LVDT sensor, (b) its schematic diagram, and (c) its output.

حسگرهای القایی نوع ترانسفورماتوری – LVDT:

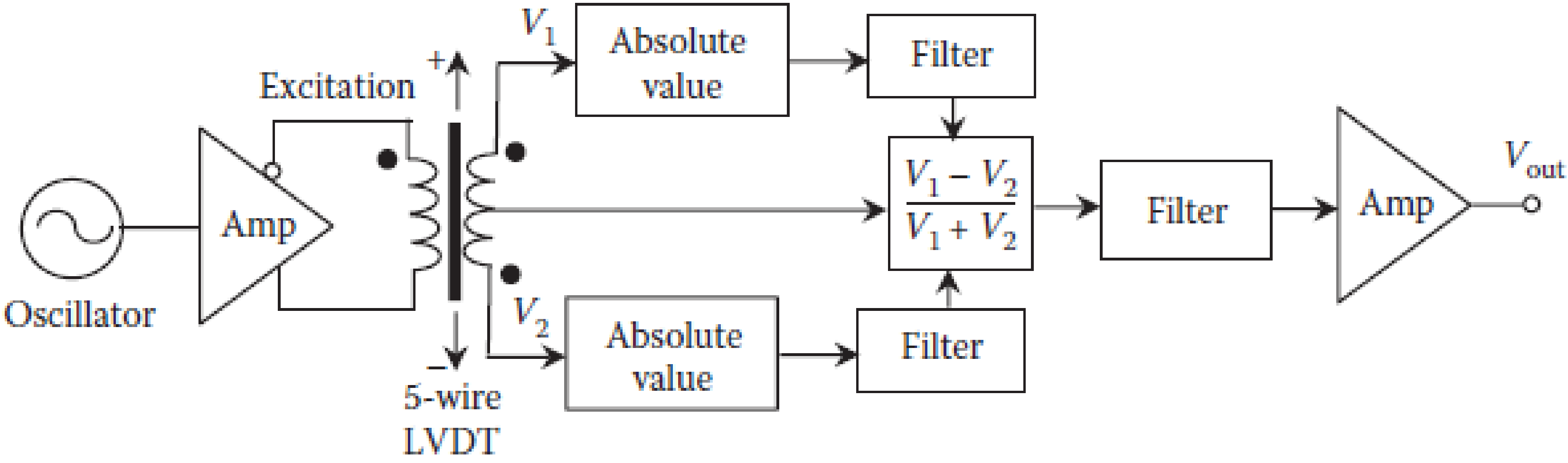
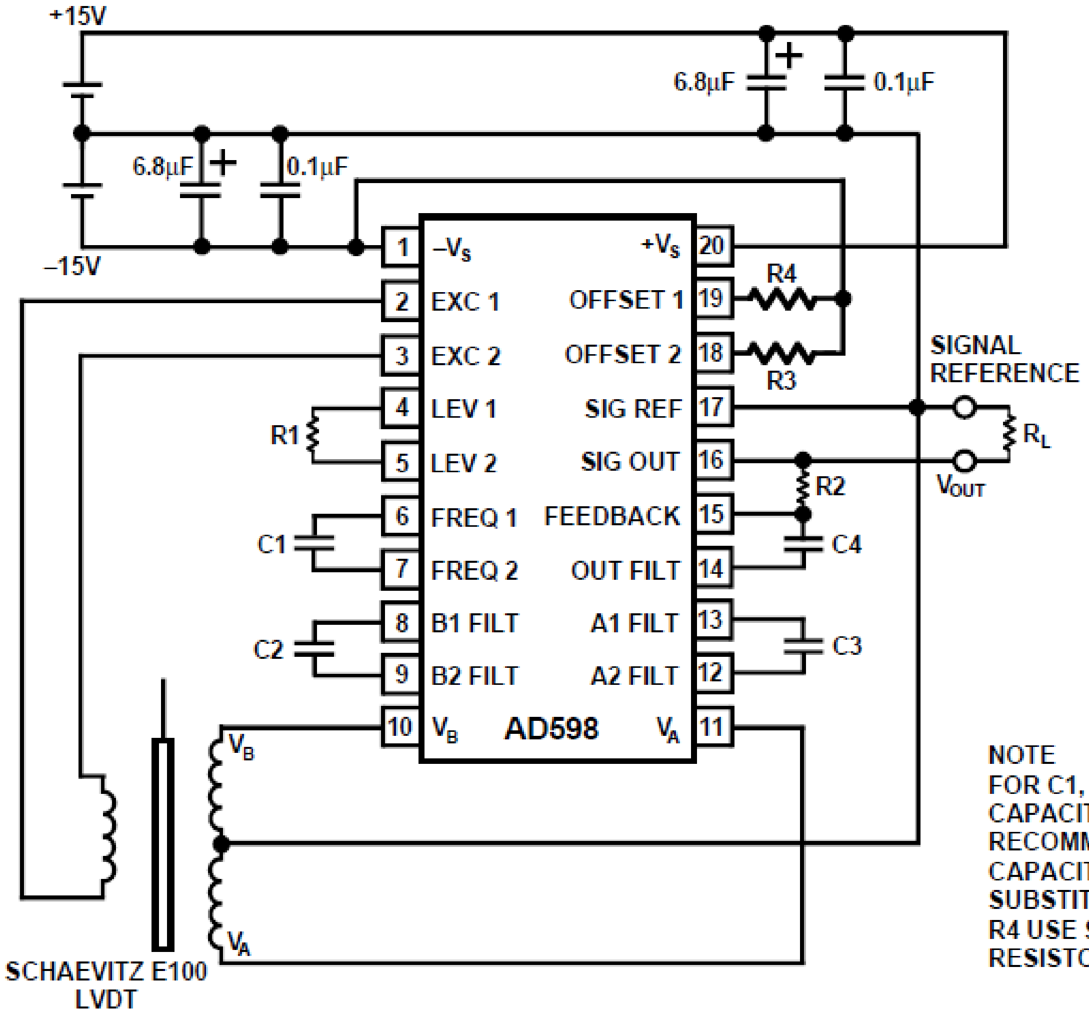


FIGURE 4.36 A simplified AD598 LVDT signal conditioner.

Ebook: W. Y. Du "*Resistive, capacitive, inductive, and magnetic sensor technologies*", CRC Press, 2014.

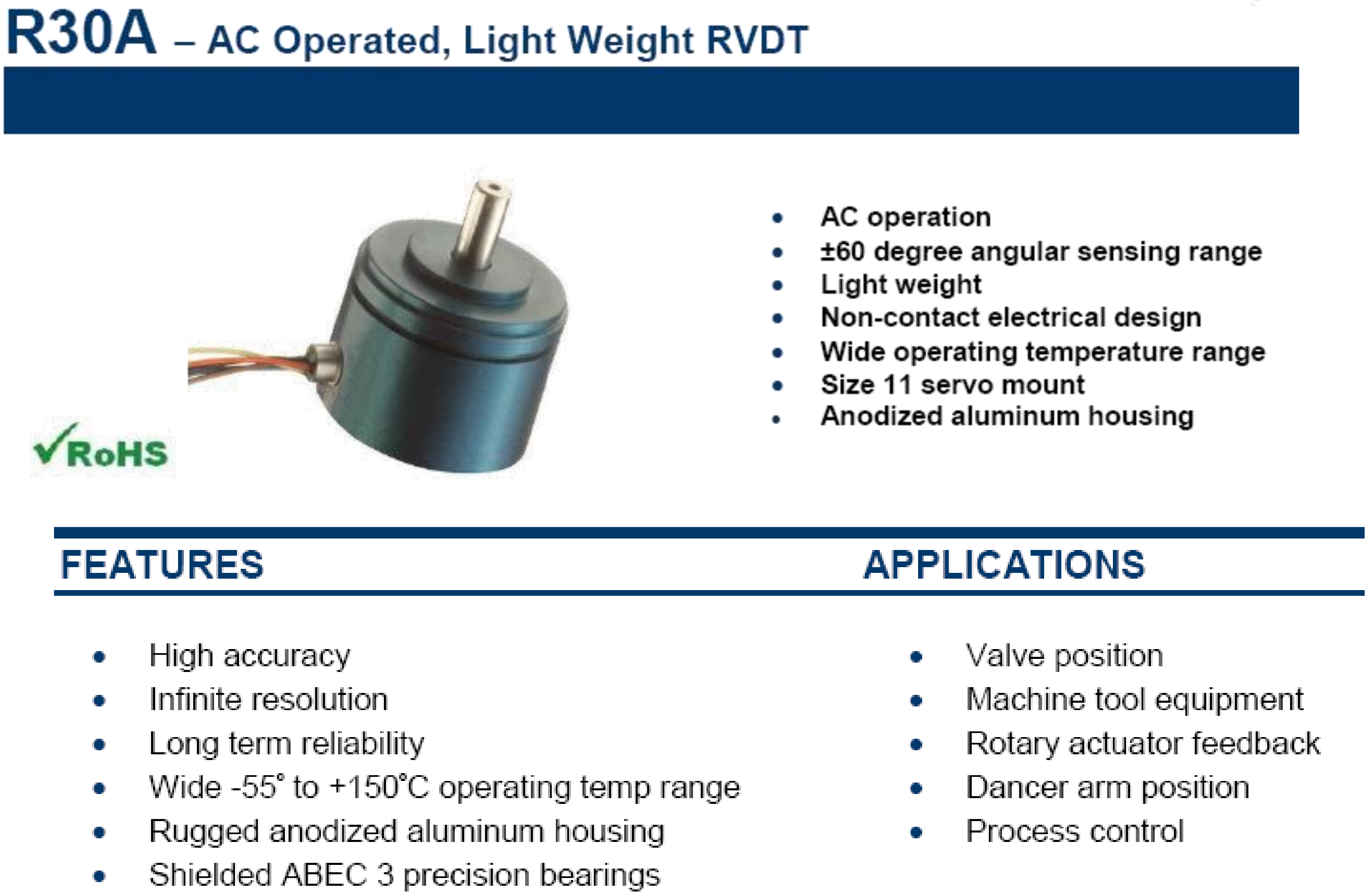
حسگرهای القایی نوع ترانسفورماتوری - LVDT:



NOTE
FOR C1, C2, C3 AND C4 MYLAR CAPACITORS ARE RECOMMENDED. CERAMIC CAPACITORS MAY BE SUBSTITUTED. FOR R2, R3 AND R4 USE STANDARD 1% RESISTORS.

http://pdf1.alldatasheet.com/datasheet-pdf/view/48082/AD/AD598A.html

حسگر القایی نوع ترانسفورماتوری - RVDT:



R30A – AC Operated, Light Weight RVDT

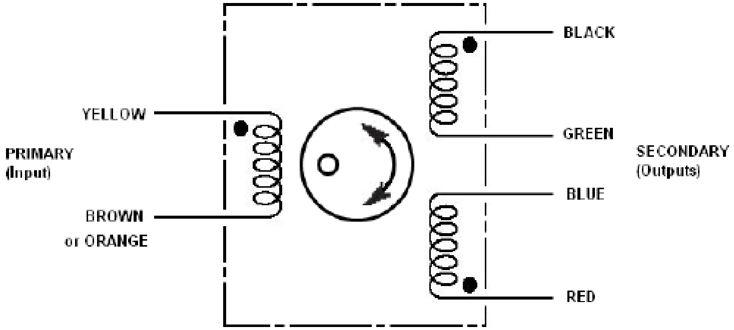
✓RoHS

- AC operation
- ±60 degree angular sensing range
- Light weight
- Non-contact electrical design
- Wide operating temperature range
- Size 11 servo mount
- Anodized aluminum housing

FEATURES	APPLICATIONS
High accuracy	Valve position
Infinite resolution	Machine tool equipment
Long term reliability	Rotary actuator feedback
Wide -55° to +150°C operating temp range	Dancer arm position
Rugged anodized aluminum housing	Process control
Shielded ABEC 3 precision bearings	

www.mouser.com/ds/2/418/R30A-710398.pdf

حسگر القایی نوع ترانسفورماتوری – RVDT:



Connect Green to Blue for differential output

ELECTRICAL SPECIFICATIONS						
Parameter	**@10kHz Input Frequency** *(recommended)*			**@2.5kHz Input Frequency**		
Angular range, degrees	±30º	±40º	±60º	±30º	±40º	±60º
Non-linearity, % of FR	±0.25%	±1%	±2%	±0.25%	±1%	±2%
Output at range ends (*)	87mV/V	116mV/V	174mV/V	69 mV/V	92 mV/V	138 mV/V
Sensitivity	2.9 mV/V/degree			2.3 mV/V/degree		
Temp coefficient of sensitivity	0.02%/ºF [0.036%/ºC], 20 to +160ºF [-7 to +71ºC]			Not specified		
Input / Output impedances	370Ω / 1300Ω			135Ω / 600Ω		
Phase shift	+3º			+35º		
Input voltage and frequency	3 VRMS @ 2.5 to 10 kHz (10kHz recommended)					
Null voltage	0.5% of FRO, maximum					

Notes:

All values are nominal unless otherwise noted

(*): Unit for output at range ends is millivolt per volt of excitation (input voltage)

FR (Full Range) is the angular range, end to end; 2xAº for ±Aº angular range

FRO (Full Range Output): Algebraic difference in outputs measured at the ends of the range

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