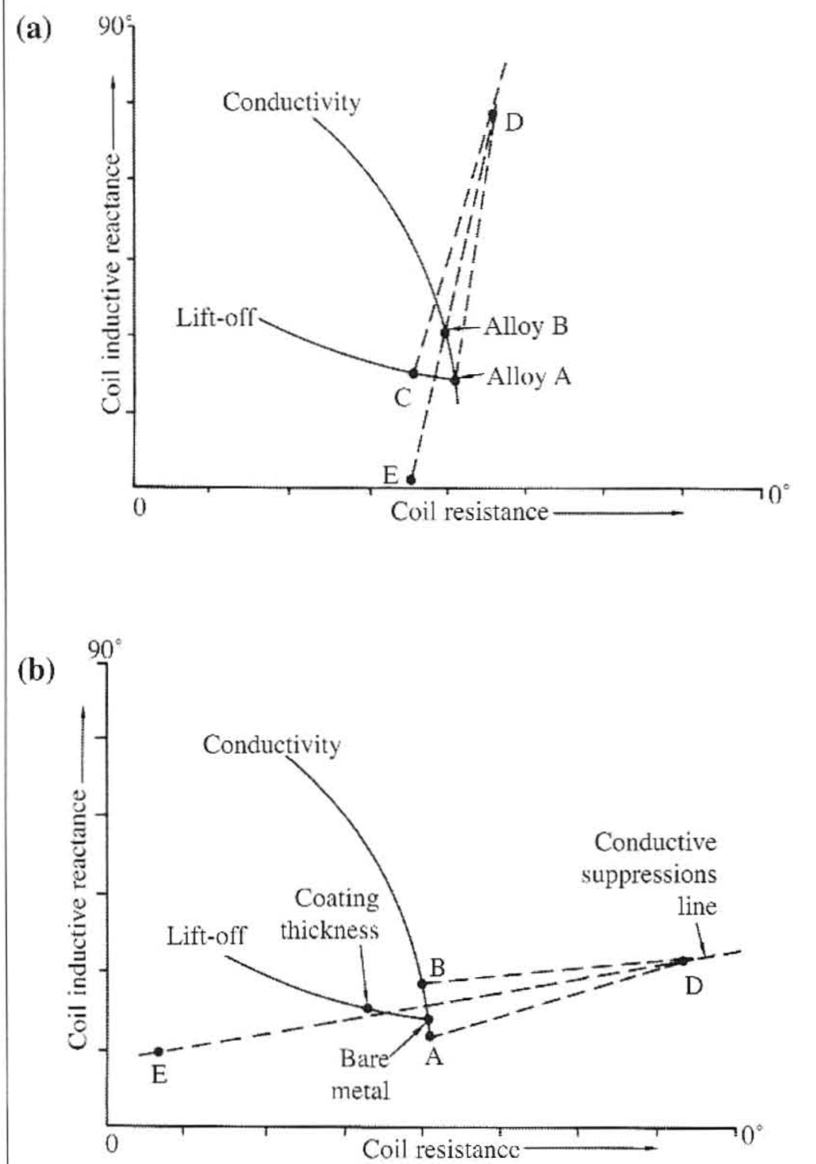
on the other. In practice, the best procedure is to evaluate test points on both sides, then choose whichever gives the best results.

Suppression of the Conductivity Variable

In measuring the thickness of nonconductive coatings on conductive materials, it is necessary that the lift-off variable be measured and that the conductivity variable be suppressed. To accomplish this, a test point is selected (see Figure 9.9b) that lies on a line that is perpendicular to the conductivity curve at the point of interest.

Figure 9.9: Test point selection.



Conductivity and Permeability

For magnetic materials, the lift-off and magnetic permeability loci curves are virtually superimposed (Figure 9.10a) but their respective values increase in opposite directions. Figure 9.11 shows that the reactance component of the test coil impedance is decreased by the presence of nonmagnetic materials. This reactance reduction occurs because induced currents flow in the conductive and nonmagnetic object and set up a secondary field that partially cancels the primary field of the coil. The opposite is true when a magnetic material such as iron or ferrite is placed within the field of the coil. This happens because the presence of the magnetic field intensity of the primary coil field causes atomic magnetic elements of the magnetic material to become aligned with the field, increasing the flux density. The magnetic permeability μ is the ratio of flux density B to magnetic field intensity H:

Eq. 9.1 $$\mu = \frac{B}{H}$$

where B is magnetic flux density (tesla) and H is magnetizing force or magnetic field intensity ($A{\cdot}m^{-1}$).

The nickel zinc ferrite cores (Figure 9.10b) were chosen as examples because they have a low conductivity and two different values for permeability. The effect of the increased flux density gives a greater induced voltage in the test coil that in turn raises the impedance. The increase in impedance is in the reactance direction except for the effect of a small amount of energy loss resulting from hysteresis. The nickel zinc ferrite cores may have an initial permeability of 850, high on the permeability line of Figure 9.10a. Usually practical engineering materials also have an associated electrical conductivity that affects the impedance, as shown for 422 steel and 4340 steel in Figure 9.10b. The relative relationship of the permeability loci lines and the conductivity curves for three materials are shown in Figure 9.10c.

The vector or phasor values of inductive reactance and resistance for different material conditions yield unique loci or phasor plots on the impedance-plane at particular operating frequencies. The phase angle of the impedance vectors will change at different frequencies because the inductive reactance value is a function of inductance and frequency. Hence vector points may move relative to one another along the conditional loci curves when the operating frequency is changed. This shift in phase is shown in Figure 9.12 for the conductivity values of nonmagnetic materials. Similar phase angle changes for the permeability of 4340 steel are shown in Figure 9.13 as the frequency changes from 75 to 300 kHz. These changes in phase shift at different frequencies do not interfere with impedance-plane analysis, provided that the operator is aware of this factor. In some cases, test results may be improved by changing the frequency to cause phase shifts.

Figure 9.10: Permeability, lift-off and conductivity loci on impedance-plane: (a) permeability and lift-off locus; (b) permeability loci for different materials; and (c) loci for permeability μ and conductivity σ.

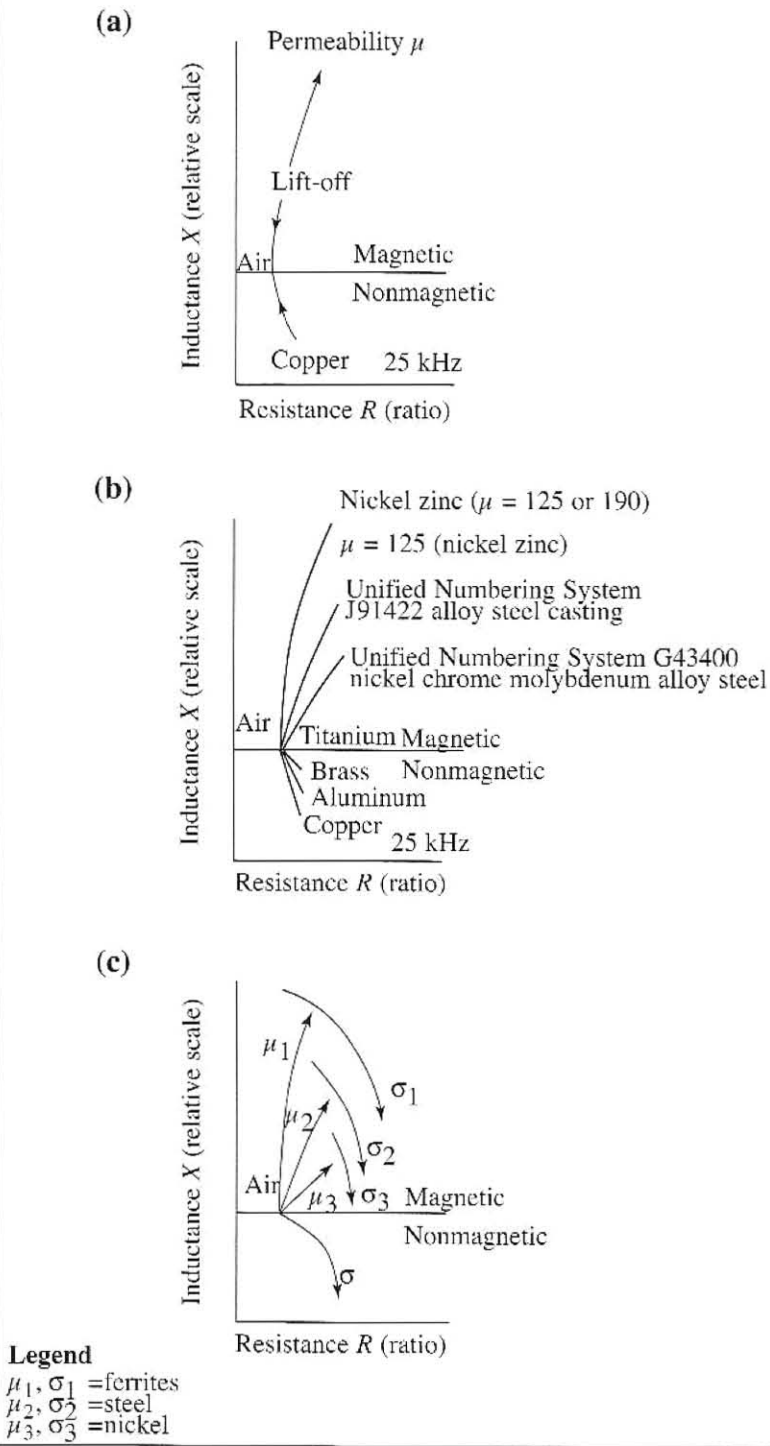
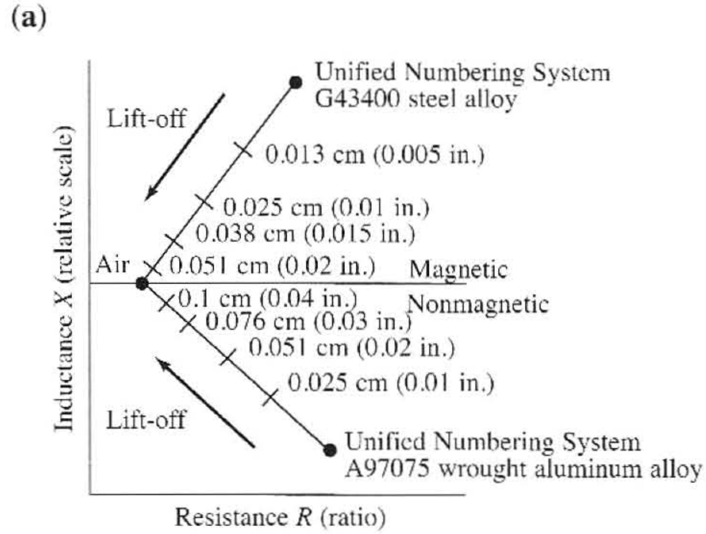


Figure 9.11: Lift-off and edge effect loci on impedance-plane: (a) lift-off loci; and (b) edge effect loci.



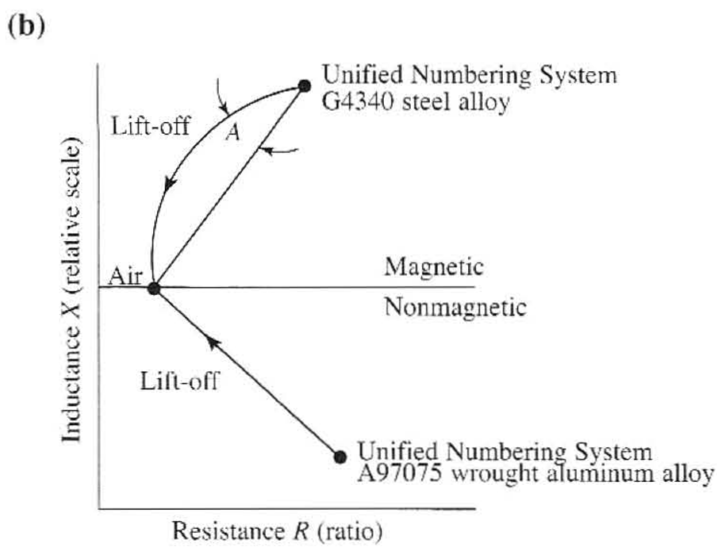


Figure 9.12: Movement of material points by frequency changes: (a) low frequency, 20 kHz; (b) medium frequency, 100 kHz; and (c) high frequency, 1 MHz.

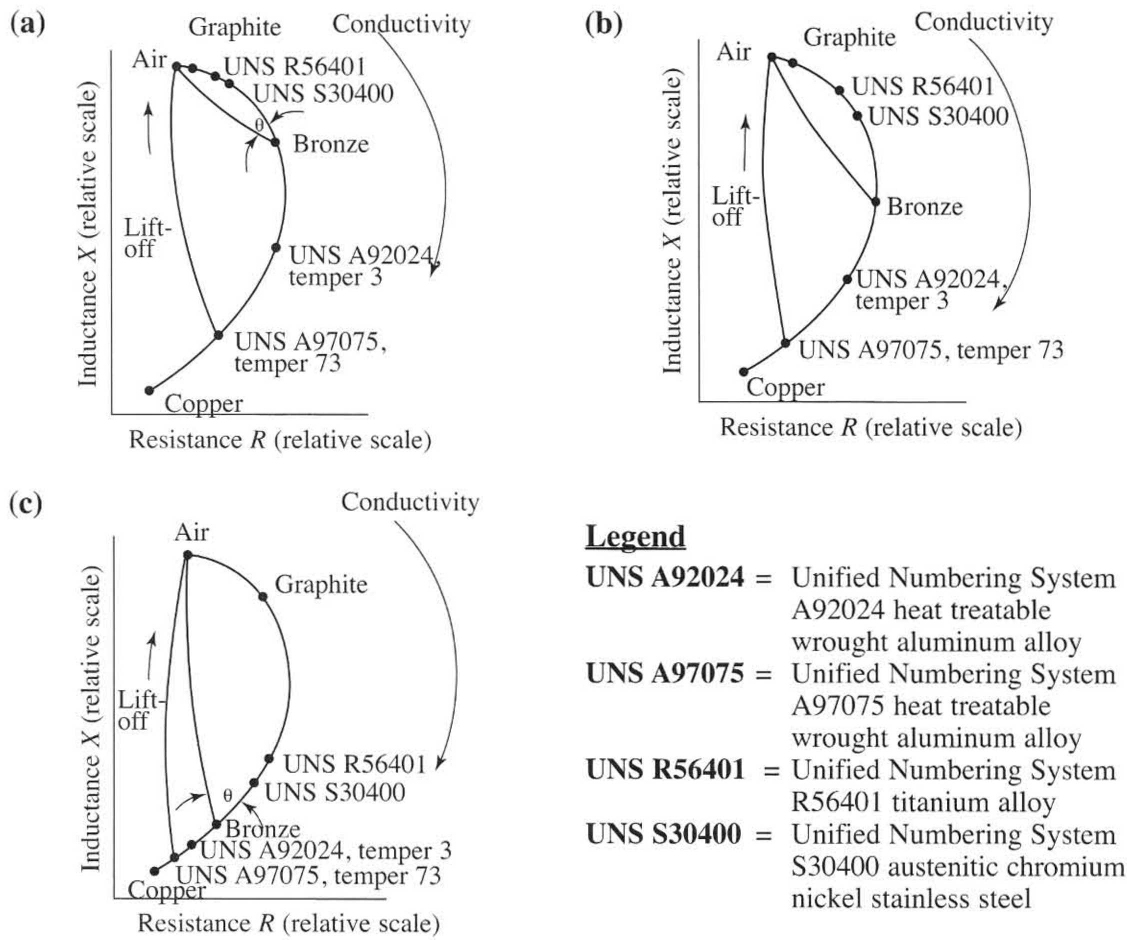
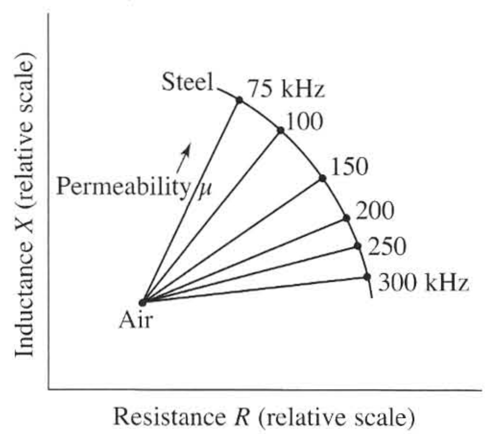


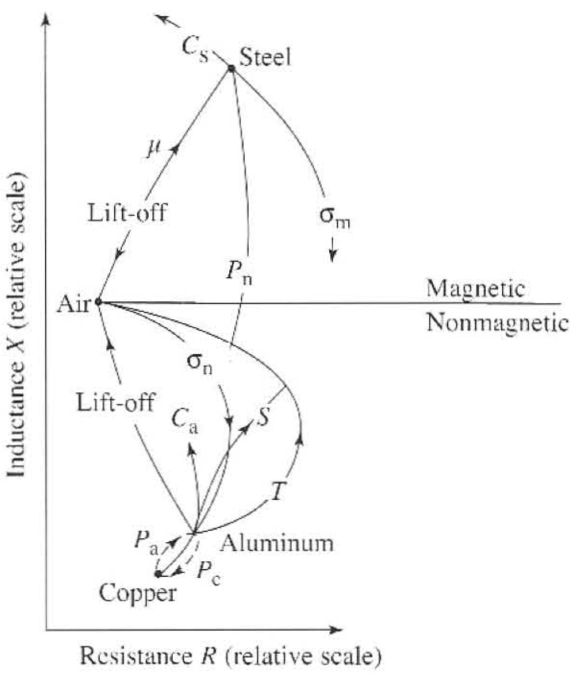
Figure 9.13: Phase angle changes on impedance-plane caused by frequency changes.



With phase analysis eddy current instruments, an operator can produce impedance-plane loci plots or curves automatically on a flying dot oscilloscope or integral cathode ray tube. Such impedance-plane plots can be presented for the following material conditions, as shown in Figure 9.14.

1. Lift-off and edge effects.
2. Cracks.
3. Material separation and spacing.
4. Permeability.
5. Specimen thinning.
6. Conductivity.
7. Plating thickness.

Figure 9.14: Impedance changes in relation to one another on impedance-plane.



Legend

C_a = crack in aluminum
C_s = crack in steel
P_a = plating (aluminum on copper)
P_c = plating (copper on aluminum)
P_n = plating (nonmagnetic)
S = spacing between aluminum layers
T = thinning in aluminum
μ = permeability
σ_m = conductivity for magnetic materials
σ_n = conductivity for nonmagnetic materials

Evaluation of these plots shows that ferromagnetic material conditions produce higher values of inductive reactance than values obtained from nonmagnetic material conditions. Hence the magnetic domain is at the upper quadrant of the impedance-plane, whereas nonmagnetic materials are in the lower quadrant. The separation of the two domains occurs at the inductive reactance values obtained with the coil removed from the conductor (sample); this is proportional to the value of the coil's self-inductance L.

Linear material values do not produce linear responses on the impedance-plane loci. With the eddy current probe balanced on the metal specimen, the loci values for linear material conditions are displayed as follows.

1. Magnetic and nonmagnetic lift-off conditions are displayed logarithmically (in X).
2. Magnetic and nonmagnetic edge effects are displayed logarithmically.
3. Magnetic and nonmagnetic conductivities vary with test frequency.
4. Magnetic permeability varies with test frequency.
5. Metal thinning varies exponentially.
6. Nonmagnetic plating thickness is displayed logarithmically.
7. Material spacing or separation varies exponentially.

Electromagnetic induction effects are not easy to understand. Neither the magnetic fields nor the eddy currents can be seen.

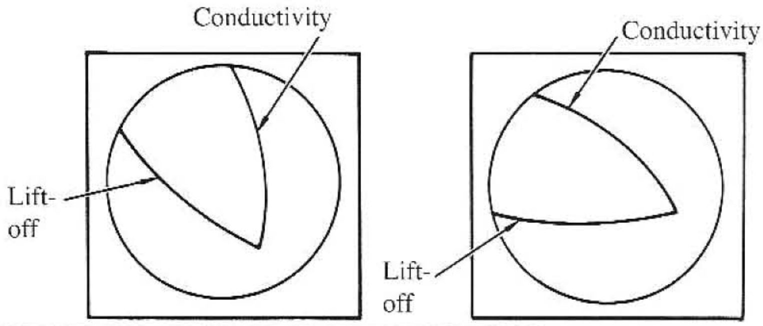
In a problem solving situation, impedance-plane analysis is a useful tool because it improves the ability to detect various conditions and provides a better understanding and interpretation of the eddy current test results.

Cathode Ray Tube Methods

Cathode Ray Tube Vector Point Method

When a cathode ray tube (CRT) is provided as part of the test equipment, the equipment may be set up to show on the tube the locus of all the points in which the technician is interested. Thus, the operator may construct, point by point, the impedance-plane diagram directly on the tube rather than on a separate sheet of graph paper. During actual testing of specimens, the impedance of the coil will cause a dot to appear at some point on the screen. Its position with respect to the impedance-plane diagram tells the technician what has occurred within the test object. An advantage of using a cathode ray tube is its extreme flexibility. For example, the equipment may be set up so that the display is rotated to a position where a change in lift-off would move the dot left or right, while a change in conductivity would move the dot up or down. The presence of a discontinuity would cause the dot to move up and to the left, as shown in Figure 9.15.

Figure 9.15: Rotation of cathode ray tube display.



Cathode Ray Tube Ellipse Display Method

A CRT may also be set up to compare a test object with a reference standard. The ellipse method uses an inspection coil in conjunction with a reference coil. When a standard is placed under the reference coil and the test object is placed under the inspection coil, the CRT shows the phase relationships between the signals obtained. This comparison between the signals provides indications of the dimension variable and the conductivity variable.

The dimension variable and the conductivity variable are shown on the CRT by the width of the ellipse and the angle tilt of the axis. Figure 9.16 shows CRT displays for dimension and conductivity.

Modulation Analysis

A modulation analysis system, shown schematically on Figure 9.17, adds a modulating device between the test set and an indicating device — a strip chart recorder. The modulating device is simply an electronic filter that will pass only certain frequencies. In modulation analysis a differential coil is used so that two adjacent areas of the article are compared.

Figure 9.16: Cathode ray tube displays for dimension and conductivity.

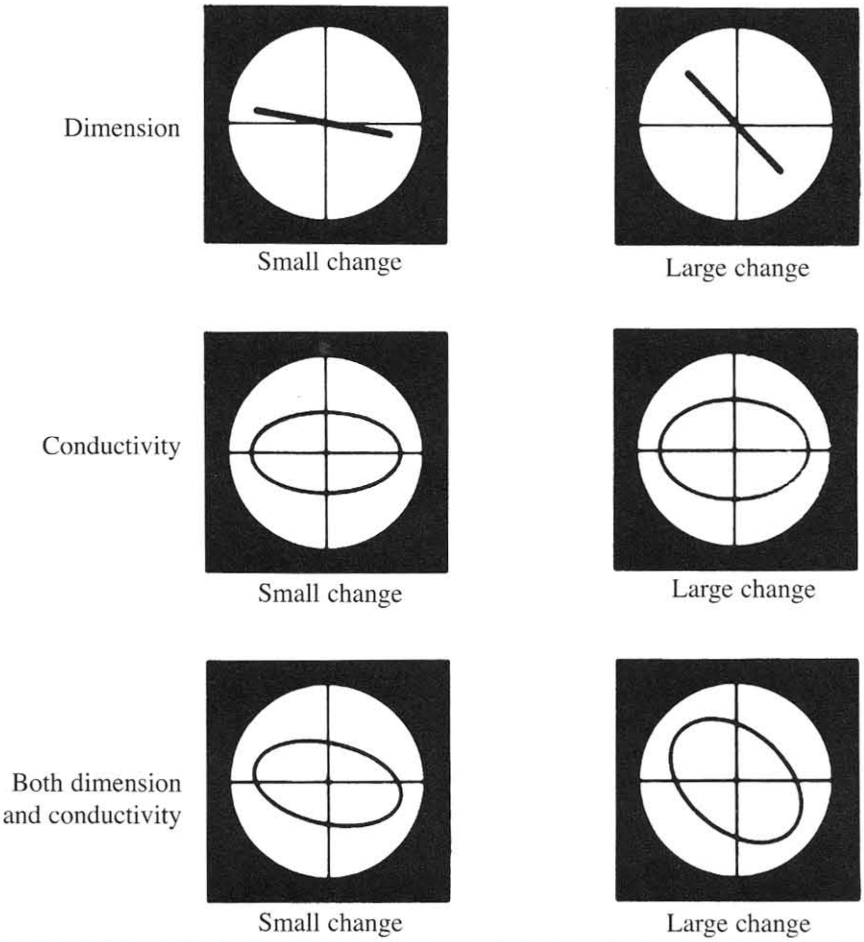
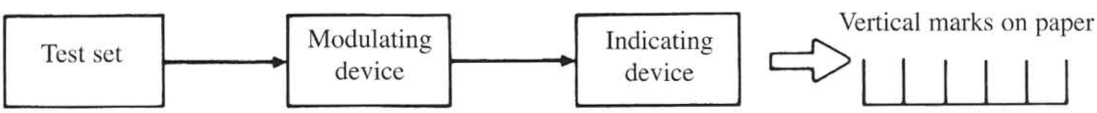
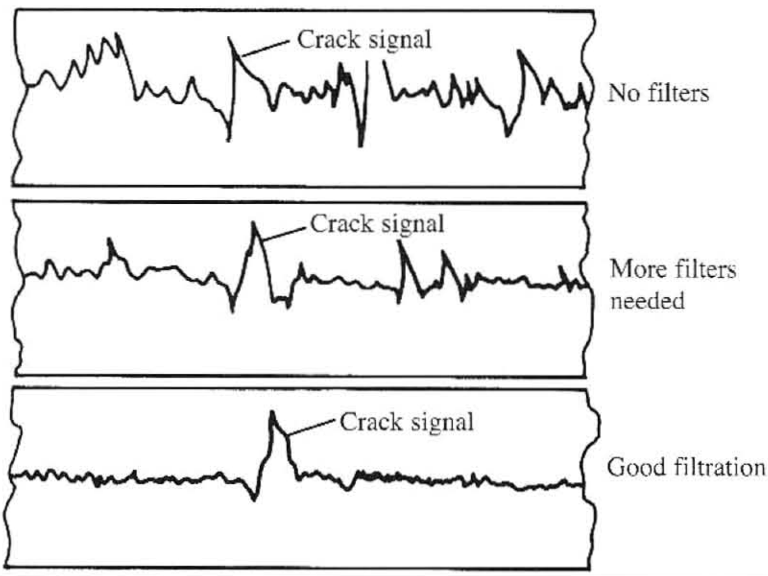


Figure 9.17: Modulation analysis system.



As the test specimen passes under or through the coils at a constant rate, various variables being sensed cause the equipment to register a signal. A discontinuity such as a crack will be indicated by a sharp rise in signal, followed immediately by a sharp drop. A dimension change, on the other hand, is most likely to occur gradually. Thus by using either a low frequency or high frequency filter, the effect of one variable or the other is eliminated from the strip chart readout. Figure 9.18 illustrates this.

Figure 9.18: Elimination of noise.



Chapter 10

Selection of Test Frequency

Test Frequency

The frequency of an alternating current is defined as the number of cycles (one complete cycle of current) that occur in one second. Its unit is the hertz – one hertz (1 Hz) being one cycle per second. Thus, house current at 60 cycles per second has a frequency of 60 Hz. The most important parameter of the test system that affects the depth of penetration is the test frequency.

The type of alloy involved and the variables to be measured or suppressed determine the best frequency. The depth of eddy current penetration within test materials is strongly affected by test frequency, permeability and conductivity. For a given alloy, higher frequencies normally limit the eddy current test to inspection of the excited metal surface nearest the primary coil winding. Lower frequencies permit deeper eddy current penetration. A given test frequency will allow eddy currents to penetrate deeper in lower conductivity alloys than in higher conductivity alloys.

High test frequencies are normally used for detecting small surface cracks or surface contamination and for gaging thin coatings. Medium frequencies are useful for conductivity measurements such as alloy sorting. Low test frequencies are usually required for testing thicker materials (for opposite side corrosion, for example), for thickness gaging and for penetrating into magnetic materials.

Penetration depth, however, is only part of the process for selection of optimum eddy current test frequencies. The geometric relationship between the impedance curves for the variable magnitudes (different conductivity points or lift-off points) along their respective impedance curves is important.

Depth of Penetration

Eddy currents are not uniformly distributed throughout a test object. They are mostly dense at the surface closest to the coil, and become progressively less dense with increasing distance below the surface of the material. At some distance below the surface of a thick material there will be essentially no currents flowing. The depth of penetration is affected by the frequency, conductivity and permeability of the material.