The frequency of the alternating current also influences impedance. Higher frequencies produce more flux changes per unit of time which result in greater inductive reactance. Extremely low frequencies begin to take on the characteristics of direct current which has no inductive reactance associated with it.

Material characteristics, such as conductivity, permeability, thickness, and the presence of defects, influence the impedance value of the coil. Early eddy current instruments used an analog meter as an output device. The inspector made evaluations based on how much the impedance increased or decreased. This type of instrument is still in use today but makes only part of the information available to the operator at any given time.

**Frequency**

Frequencies typically used for eddy current testing range from 100 Hz to 4 MHz. Lower and higher frequencies are used with many special-application eddy current instruments. The frequency is selected by the operator and is determined by several factors.

The depth of penetration of the eddy currents is dependent upon frequency. Because of skin effect associated with alternating current, high frequencies tend to keep the eddy currents circulating near the surface. Lowering the frequency allows the eddy currents to penetrate deeper into the material.

Eddy currents lose their strength with depth regardless of frequency. Eddy currents are most effective from the surface to a depth at which their density is 37% of that of the eddy currents at the surface. This is referred to as one standard depth of penetration. Since the depth of penetration is determined by frequency as well as other factors, the standard depth of penetration will vary as well. This can be seen in figure 4-8.

The depth of penetration is also determined by conductivity, and in the case of ferromagnetic materials, permeability. Depth of penetration in materials with high conductivity and/or permeability is less than those with low conductivity and/or permeability for a given frequency.

Depth of penetration must be considered when setting up eddy current tests. When material thickness is of interest, the frequency should be one that produces three times the standard depth of penetration or three standard depths of penetration (one effective depth of penetration) at the thickest point of the material being tested. This is because eddy currents beyond one standard depth of penetration continue to influence the probe coil. Material thickness that is at least three standard depths of penetration appears infinitely thick to the eddy currents. A frequency that yields at least three standard depths of penetration in the thinnest material should be selected when sorting so that indications from varying thicknesses will not confuse the conductivity indications.

The size and location of cracks will dictate test frequencies to be used as well. Sensitivity to surface cracks is improved by choosing higher frequencies. Locating subsurface defects requires low frequencies for adequate penetration. However, sensitivity is reduced and only large subsurface defects can be detected.

**EDDY CURRENT INSTRUMENTS**

A typical eddy current tester consists of an oscillator, amplifier, test coil, detector circuit, and an output device. The oscillator generates the alternating current, which is sent to the test coil. The operator controls the frequency through the oscillator.

Amplifiers are used to increase weak signals from the test coil. The detector circuit processes the signal into useful information, which is sent to the output device. Analog
meters, digital meters, CRTs, LCDs, strip chart recorders, and simple lights or audible alarms are all output devices used for eddy current testing.

The most popular instruments used today in aircraft maintenance incorporate an impedance plane display, using either a liquid crystal display (LCD) or a cathode ray tube (CRT) such as the ones shown in figures 4-9, 4-10, and 4-25. This type of instrument is very versatile in that all the information detected at the inspection coil is

**Figure 4-8.** Effects of frequency, conductivity, and permeability on the depth of eddy current penetration.

![Figure 4-8](image)

**Figure 4-9.** A typical impedance plane eddy current instrument using a CRT. (Courtesy of Staveley Instruments, Inc.)

**Figure 4-10.** Eddy current instruments which are lighter and much more portable than their predecessors.
displayed and the variables can be easily separated. They can be used for crack detection, material sorting, thickness measurement of thin metals, and measurement of non-conductive and conductive coatings or platings on conductive base materials.

While there are a wide variety of features available on this type of machine, some are common to most. Frequency can be selected via a keypad or can be dialed in. Some instruments feature a touch screen for selection of all the test variables. Horizontal, vertical, and rotation controls allow positioning of the indication on the screen. Horizontal and vertical gain controls make it possible to expand the indication to accentuate fine details or to separate points which are otherwise too close together for accurate evaluation. An automatic null-balance button makes it possible to instantly balance the machine to a probe/cable combination.

High and low pass filters are incorporated to minimize noise or interference. The signal generated from material characteristics that are of interest should always be three times greater than unwanted noise. This is known as the signal-to-noise ratio which should be no less than 3:1. Sources of noise might be electronic circuitry within the instrument, external electrical interference from lighting or high draw electrical equipment, variations in the test object, or scan related. Low pass filters, which block high frequencies, are used to reduce electrical interference, whereas high pass filters filter out low frequency noise associated with scanning.

Improving signal to noise ratios can also be accomplished by adjusting the probe drive. Best results are achieved by selecting the highest probe drive possible without causing signal saturation. If the signal suddenly deviates from a smooth curve or line on the display when the probe is moved onto the surface of the test piece, saturation has occurred. Or, if the signal does not appreciably change in amplitude when the next lower probe drive level is selected, the signal was saturated at the higher drive level.

Modern electronic technology has made it possible to incorporate many helpful features. Gates and alarms, auto-erase, sweep displays, memory and storage for screen images, and test parameters are just a few. Some machines are readily interfaced with computers and printers which expand their capabilities even more.

The need for greater portability has prompted manufacturers to reduce the size and weight of their instruments. These instruments have nearly all the same features found in their larger counterparts and weigh as little as six pounds. See figure 4-9.

The analog meter has been around for a long time and should not be overlooked. These machines are still used today for crack detection, material sorting, and can even be used for measuring non-conductive coating thicknesses. They are available with many convenient features at a price considerably less than that of the impedance plane display instruments. This type of machine is relatively simple to operate and can be very useful and reliable. Figure 4-11 is an example of an analog meter eddy current instrument.

**TEST COILS**

Eddy current test coils come in a wide variety of shapes, sizes, and types. They are available in standard sizes and styles or can be custom made for special applications.
Regardless of the configuration, they all perform the same function. AC through a coil produces an alternating magnetic field which moves through the material being tested. The alternating magnetic field generates eddy currents which interact with the properties and characteristics of the material. The magnetic fields associated with the eddy currents interact with the coil's magnetic field, modifying the original impedance of the coil. The impedance is analyzed and displayed by the eddy current instrument.

There are three basic types of eddy current coils: surface coils, encircling or external coils, and internal coils. Encircling coils are used for inspecting bar stock, tubing, or wire. They are usually associated with some phase of a manufacturing process. Internal coils are used to inspect tubing in situations where the condition of the inside walls is of most interest, or where it is only possible to inspect from the inside such as in boilers or air conditioner heat exchangers.

Surface coils, also referred to as probes, are extensively used in aviation nondestructive testing. For this reason, several variations of surface coils will be presented.

Surface coils come in a wide variety of configurations. Figure 4-12 illustrates some of the basic surface probes. The coil itself is wound with very fine wire and is encased in a non-conductive housing. The shape and size of the coil and its housing is determined by its intended purpose. The coil is connected to the eddy current instrument by a shielded cable. Probe coils may have detachable cables, allowing several probes to be used with one cable, while others are available as probe/cable assemblies.

Figure 4-12. Surface probes. (Courtesy of Zetec, Inc.)
Small Diameter Coils

Generally, small diameter probe coils, such as the pencil probe, are used for locating fine surface cracks or pits. They are designed to be used with relatively high frequencies and thus concentrate the eddy currents in a small area. They are usually hand-held and moved across the surface in a scan pattern. Care must be taken to keep the center axis of the coil perpendicular to the surface and to prevent the coil from lifting off of the surface. Some coils are spring loaded in the probe housing to prevent separation of the coil from the surface of the test piece (figure 4-13).

The coil may be wound on a ferrite core, which is a ferromagnetic material (figure 4-14(A)). The core concentrates and focuses the flux lines. This reduces the effects of probe wobble and lift-off and provides greater sensitivity. Lift-off will be discussed later in this chapter.

Shielding the coil will also increase sensitivity. Shielding (figure 4-14(B)) restricts the spread of the magnetic field. Sensitivity to cracks is improved and it minimizes edge effect. Edge effect is caused by distortion of the eddy currents as the coil approaches the edge of the material. The indications caused by edge effect may confuse or mask any defect indications or other material characteristics of interest which lie close to an edge. Shielding also isolates the coil’s field from bolt heads or other conductive protrusions.

Figure 4-14.
(A) The magnetic field is concentrated through the ferrite core of the coil.
(B) Shielding, a ferromagnetic material, restricts the spread of the magnetic flux lines.
The coils previously discussed are absolute coils. These are single coils and their impedance is simply affected by the conductive characteristics of the material being examined.

Differential coils consist of two small coils wound in opposite directions and connected in series. The coils are positioned side by side in a common housing. When both coils are in air or affected equally by a conductive material, they will cancel each other and send a null signal to the instrument. For this reason, they are lift-off compensated and have little or no lift-off indication associated with them.

Differential coils improve sensitivity since only small differences between the coils are required to produce a usable signal. Also, crack indications are twice as large as those generated by an absolute coil. Figure 4-15 illustrates the indications of the differential probe as it passes over a crack.

As can be seen, the direction of scan is important. One coil must lead the other. If both coils were to pass over the crack at the same time, they would be affected equally and produce no signal. Differential coils incorporate a mark or notch to indicate the proper scan direction.

Differential coils make it possible to locate small defects in materials that have variations in conductivity and permeability. An absolute coil would respond to each

Figure 4-15. (A) through (E) shows a typical impedance plane display for a crack using a differential probe. The direction of the scan is critical. One coil must follow the other.