Pulse Induction Metal Detectors - The Principle

About Pulse Induction Metal Detectors

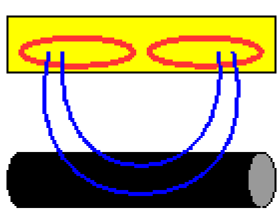
Introduction.

All types of metal locator are "electromagnetic" in nature, and share a certain amount in common:
the search head contains one or more coils carrying a time-varying electric current, and this generates a time-varying magnetic field which propagates towards the metal target (and in other directions as well of course).
This primary field reacts with the electrical and/or magnetic properties of the target which responds to it by either modifying the primary field or, as a more general and more accurate description, generating a secondary magnetic field; one way or another, the effect links back into the coils in the search head (sometimes the same coil as the transmitting one, sometimes a different one), and induces an electrical voltage in the receiver coil(s).

Beyond this basic similarity, there are a wide range of different variations used: in the number of coils (one, two or three); the "shape" (spatial extent) of the primary magnetic field; the frequency of the transmitter; the waveform transmitted (sinusoidal or pulsed); the dominant target property responded to (magnetic permeability or electrical conductivity); whether the head coils(s) have a magnetic core or are air-cored; and how the electronics separate the (very weak) received voltage out from the (potentially much larger) voltages present in the search coils even in the absence of any metal target. Although all these factors can affect the sensitivity to any one particular target, the last factor is probably the most important, as it determines the stability or "zero-drift" of the instrument:-- if the zero-point is unstable, high sensitivity will never be achieved, however much the other factors are optimised.

Pulse Induction.

All Proceq metal locators use the Pulse Induction Eddy Current technique.



A pulse of current is sent (repeatedly) through a coil in the search head. This current tends to start up fairly gently (and is allowed to do so); see figure 1a. However, at the end

of the pulse, it is arranged that the current turns off very rapidly (within a few microseconds); this (briefly) induces a very large "voltage spike" or "back-e.m.f" across the coil (rather like the induction coil used to generate the spark for a car engine ignition, though in this case the voltage is only(!) about 100 volts); see figure 1b.
After the mayhem of this transient is over, there is no current flow through the coil and no voltage across it. After about a millisecond (or less or more, depending on the particular model) the whole cycle is repeated.

The primary (or transmitted) magnetic field will vary with time exactly in step with the figure 1a current waveform, and propagates (rapidly -- at the speed of light) down to and through the target. When the pulse is switched off, and if the target is a conductor, eddy currents are induced to flow in the target.
These eddy currents always flow in such a direction as to try to re-create the magnetic field that has just disappeared, and, initially at least, they actually succeed in this; but once the primary field has all gone, there is no source of energy to maintain these currents, so they decay gently away -- nevertheless persisting for about a hundred microseconds; see figure 1c.

Figure 1: Coil Waveforms

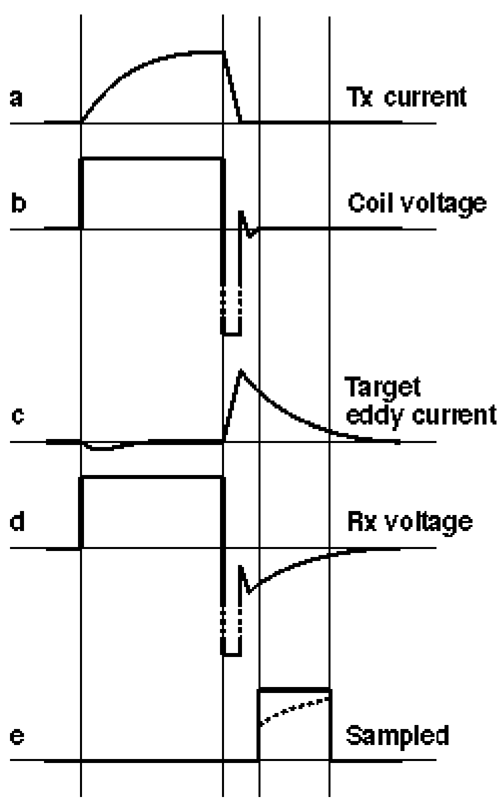


Figure 1: Coil Waveforms

The eddy currents generate a secondary magnetic field which propagates in all directions, including back towards the search head, where it induces a (small) voltage in the coil; this voltage also decays away at the same rate (see figure 1d), and has the same sign

(polarity) as the back-emf spike.
The received voltage from a target at the limit of the detection range may only be a few microvolts: one ten-millionth of the back-emf spike! It would be quite out of the question for the electronics to notice such a tiny change actually during the back-emf spike, and that is not the way it's done.
The signal is "sampled" by an electronic switch which ignores the signal during the transmit pulse and immediately after (during the back-emf), and only "looks at" the signal after a short delay which ensures that the switch-off transient is over (see figure 1e). In this way, the transmitted and received signals are separated from each other.

If the target had been purely magnetic, but non-conductive, it would have become magnetised by the transmit pulse, and then demagnetise just as promptly at switch-off; by the time of the delayed sample pulse, nothing would be happening down at the target, and therefore nothing would be happening up at the search coil.

If the target is both conductive and magnetic (e.g. a ferrous metal), the eddy currents would be produced exactly as in the purely conductive case; the effect of the target's magnetic permeability is to enhance the magnitude of the effect (and also to modify the "time-constant" of the decay of the eddy currents).

If there is no target at all . . . . nothing happens!
Actually, there will always be a certain inescapable amount of electrical "noise" in the receiver coil and circuitry, and three techniques are used to filter this out to produce a final signal (in the absence of a target) which is very close to zero and absolutely rock-steady.

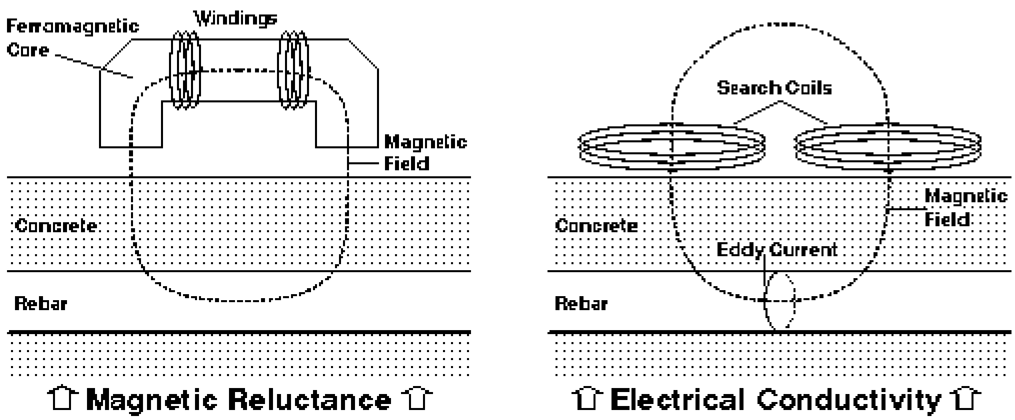
The decay time-constant (persistence) of the eddy-currents, and hence received signal, depends (predominantly) on the target's electrical conductivity and size. Targets such as low-conductivity alloys or thin foils have a very short decay time; and the choice of a short or long delay between switch-off and sample can be arranged to either detect or ignore such targets. The ionic conductivity of sea- or brackish water is so low, and its decay time so short, that such signals have always decayed away before the sample is taken; so the P.I. technique is not affected by moisture.

Reinforcement Location.

For many years the commonly used method was that of "Magnetic Reluctance".
A U-shaped core (or yoke), of iron laminations or ferrite, carries two windings (see figure 2a). As in induction balance machines, the coupling (mutual inductance) of the two windings is measured, using a "bridge" circuit to monitor changes. The physical quantity being inferred is the "reluctance" of the magnetic path, which is determined predominantly by the magnetic properties of the core, and only affected to a lesser extent by the presence of nearby magnetic steel. Since the magnetic properties of the core are inevitably temperature-sensitive (and even affected by other magnetic fields, including the Earth's), zero-drift is as much of a problem as in any other "balanced" technique.
The Pulse-Induction technique (see figure 2b) does not use any magnetic core inside the

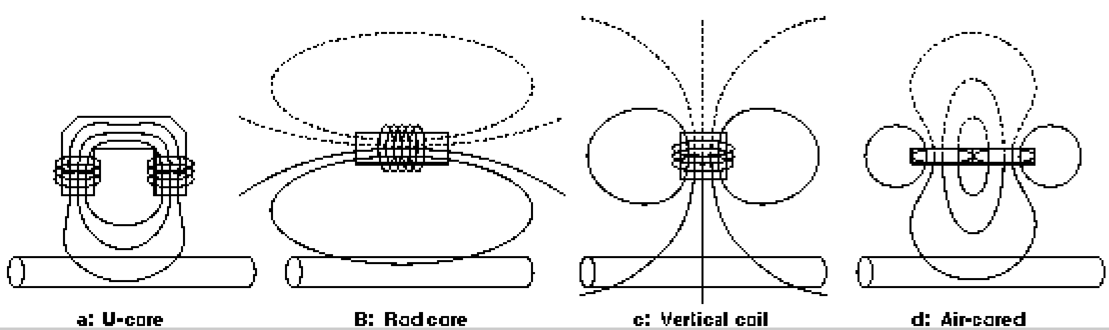
search head, and so is completely immune from these effects.

Figure 2: Magnetic Reluctance and Electrical Conductivity



Some more recent rebar locators and cover meters have used methods which are electromagnetic in nature (rather than purely magnetic), but the coil configuration dictated by the detection technique is invariably far short of optimum for practical bar location:- either the field is too widespread and diffuse, which makes resolution of closely-spaced bars impossible (see figure 3b); or else (if more compact) the field is non-directional, and cannot allow distinction between horizontal and vertical bars (figure 3c).
Since a Pulse-Induction coil can (in principle) be any shape required, the "shape" and extent of the field can be optimised for both bar-resolution and bar-orientation, with total zero-point stability (figure 3d).

Figure 3: Coil Configurations



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