UNDERSTANDING THE PI METAL DETECTOR

BY REG SNIFF

One of the more popular metal detectors used for nugget hunting today is a type of detector commonly called the Pulse Induction or PI for short. A lot has been written on the general principles of operation but many questions are still unanswered or not answered completely about this strange machine. Also, there is a lot of misinterpretations of information that has been written about PI's and how they work.

As an example, in some books there is a statement that a PI does not "see mineralization" so it is therefore a great detector to use in mineralized areas. Is this really a true statement? The answer is both yes and no.

PI's basically do not respond to the typical iron mineralization such as magnetite or black sand. However, other minerals of the same family can and many times do cause a response. Iron oxides such as maghemite, clays, and other things such as salts commonly found in the ground can cause a PI to produce a rather strong signal. So, generally a very sensitive PI, normally used for gold hunting will respond to ground signals, especially if it does not have some form of ground balancing circuitry built in.

One question that is often asked is what is the operating frequency of a PI. This question is often asked by someone who is trying to relate their knowledge of VLF's to the PI. Unfortunately, because of the nature or differences between types of detectors, comparing a PI to a VLF is sort of like comparing an apple to a potato, so trying to relate the operating frequency of a PI to a VLF or sensitivity to small gold is of little value. The differences between the two types of detectors or the affects of their operating frequencies are quite dramatic so it is best to not try to use the same standards when trying to determine certain things about a PI.

As for a PI, the pulse rate or pulses per second (pps) refers to the number of high current pulses that occur over the time specified. Rates vary from a few hundred to several thousand per second: Generally, more pulses allow for a little better averaging and thus a little better signal to noise ratio. However, a detector will have a tendency to consume more current with a higher pulse rate. A faster pulse rate doesn't mean a detector will detect small gold better. In fact, it is quite easy to build a PI that has a very low pulse repetition rate (PPS) that is very sensitive to very small gold while designing a PI with a high PPS that is not sensitive to small nuggets.

Now, both PI's and VLF's will detect metals, respond to different ground different.

VLF's generally produce a relatively low power continuous sinewave into the transmit coil and, analyze a signal received with a separate receive coil winding. A signal from an object will increase the amplitude of the receive signal level but will also shift the receive signal with respect to the transmit signal. Thus, an object can be analyzed by not only the intensity or amplitude increase of the signal but by just how much the signal has shifted.

VLF's generally operate at a single frequency but can be produced to operate at different frequencies. However, each frequency has to be analyzed as if it is the primary frequency and as such, both the signal strength and the shift are used to determine the presence of an object as well as type of metal.

PI's are a different beast all together. Instead of transmitting a low power continuous signal, the PI generates a brief high current pulse to energize the coil and this pulse is repeated at some nominal repetition rate, which can vary from a few hundred pulses per second to thousands per second.

The technique to determine whether an object is present is to analyze the signal coming from the receive coil shortly after the high current pulse is turned off. This is done by sampling the signal coming from the coil some time after each high current pulse. This time after the pulse is often referred to as the delay time Remember, on a PI, the transmit coil may become the receive coil once the transmit signal is turned off so there is no need for a separate receive coil winding. This type of coil is often referred to as a Mono coil.

PI History

There has been considerable work on PI type detectors since the early 1960's. One of the main reasons for their design was so they could be used for archaeological purposes. Most of the work in the evolution of the PI occurred in Europe during those early years, and much of this work was done in England by a young engineer by the name of Eric Foster.

As a result of his involvement with PI's during their early years, Eric Foster began his own business building PI's for industry as well as the consumer market. Many of his initial designs are the cornerstones of some of the PI's used today. Sometime in the early 1980'5, Eric Foster built a PI with ground balancing capability and a rudimentary form of discrimination. He also built a much better discriminating PI around the same time frame.

Minelab was the first to introduce a PI specifically designed for gold hunting in the US some time the 1990'5. The introduction of the SO 2000 really started the serious use of PI's to search for gold even though people began using Eric Foster's detectors for nugget hunting sooner in Australia. What made this ML PI detector excel was the introduction of the use of a DD coil on a PI. The DD coil had the ability to eliminate much of the ground problems making it a quieter choice. One other major advantage of the ML was it operated and

Eric Foster's ground canceling detector had a putt-putt type audio, required the operator to retune the detector frequently, and had several different modes, some of which made the ground balance mode seem much less sensitive. Also, since only a mono type coil was available, some of the more severe areas still caused problems even when the ground balance was used. As a result, Eric Foster's ground canceling PI, the Goldscan, never really caught on.

Strange as it may seem, one of the first US patented designs using a high current pulse to detect metals that also had ferrous/non-ferrus discriminating capabilities was designed by George Payne in about 1978 or so. This design not only would distinguish iron objects but also had a basic form of ground balance. This strange design used a bi-polar form of pulsing, which was also unique. Unfortunately, because of the high current necessary for operation and thus, the need for a very large battery, the design was never produced and sold. Instead, American manufacturers focused on developing VLF's for both coin and gold hunting.

How do PI's really work and what makes them sensitive to small gold?

As stated earlier, PI's operate on the principle of generating a large current pulse in the coil and then analyzing the signal in the coil a short time after the pulse is turned off. This cycle is repeated on a continual basis.

As simple as this sounds, the design is quite critical. The key to increasing the sensitivity of a PI is to turn off the current pulse as soon as possible, and then stopping the resulting high voltage spike as soon as possible.

By nature, a PI coil is an inductor and as such, any immediate disruption in current will cause the inductor to produce a very large voltage spike in its attempt to keep the current flowing. This high voltage spike is a side affect of the current disruption that has to be dealt with as quickly as possible so any signal from a metallic object can be distinguished.

When the current is flowing in the coil, a magnetic field is generated that expands from the coil. When this field encounters a metallic object such as a gold nugget, current begins to flow in the nugget as the result of this magnetic field. When the current suddenly stops in the coil, the coil field collapses which in turn causes the current in the object to collapse. This secondary collapse of current in the nugget causes it to produce its own field that now generates back to the coil. This target signal ultimately adds to the collapsing coil signal, thus making the coil signal change very slightly.

The signal strength, and just as important the duration or time of the signal produced by a detected object is a function of the size, shape, and actual composition, among other things. Gold and other low conductive materials may produce a strong signal but the duration of the signal is much shorter than a signal from something like a piece of iron, copper or silver. Very small nuggets, in the few grain range, not only generate a very small signal, but also a very well as a much longer signal than a piece of gold of similar size. Thus, it is much easier to detect a very small piece of iron than it is to detect a very small piece of gold.

Finding the small stuff in Greater Detail

The key to the success or sensitivity of a PI to small conductive objects such a small gold nuggets is the ability of the PI circuitry to turn the coil pulse current off very rapidly, and then be able to analyze a signal very shortly after the pulse of current has ended. This sudden stop of current in the coil will cause a very large voltage spike that rises almost instantaneously to some voltage generally between 50 to 400 Volts (V). Generally, the voltage level is a function of the FET (field effect transistor) used to deliver the high current. Once this voltage peaks, it will then quickly decay to very near 0 Volts (0V) in just a few microseconds (usecs). The rate of the decay is extremely important, just as is the characteristics or shape of the decay of this large voltage spike.

One important factor to remember is a large current normally requires more time for the spike to decay. This becomes important when determining the best design for small gold. Another critical factor is the inductance of the PI coil itself. The larger the inductance, the longer the decay time to OV.

It is also critical that this high voltage spike doesn't result in oscillations, which can easily happen. Generally, the coil, for a PI, is made by first determining the desired inductance. Then the coil size or diameter selected. Once the two characteristics are determined, calculations are made to determine the required number of turns of wire to produce the calculated value of inductance.

Once built, the coil of wire is basically an inductor that has some internal resistance. However, because the coil consists of multiple windings, generally a number between 10 and 35, the windings produce a certain amount of capacitance between windings. This capacitance when combined with the inductance of the coil will create a "tuned circuit that will oscillate if additional circuitry isn't added to dampen or stop the oscillation. The basic damping device normally used is a resistor, generally called the damping resistor.

So, by carefully selecting the right resistor, a coil will produce a rapidly decaying voltage spike that doesn't ring or oscillate. If the resistor has too high a value, there will be some very minor oscillation, and if the resistor is too low in value, the spike voltage will take too much time dropping to the OV range.

One other critical part of a search coil that is seldom talked about is the shielding of the coil. Generally, coils have some form of a shield called a Faraday shield. The purpose of this shield is to minimize the capacitive effect between the coil and the ground, reduce static, and to absorb or reduce external noise. Like other factors, the shielding and the technique used, is quite critical. Too much or the wrong type of shielding can reduce sensitivity, especially to small objects such as gold nuggets. Too little shielding will allow other factors

It should be noted that some manufacturers do not use any shielding at all. However, these detectors normally are designed for the detection of very large iron objects so any minor variations in noise or ground capacitance that normally affect very small non-ferrous objects such as small gold nuggets is not a problem. Such detectors normally operate with a very long delay before sampling. This long delay will cause most of the ground signal to be eliminated since it will decay much faster than a signal from a large iron object.

The technical information mentioned above is of little value to the average user of a PI. However, it can be important to anybody who wants to try to build a coil for their detector. The first rule of thumb when trying to build a different coil is to try to duplicate the electrical characteristics of the factory coil. By this I mean, one should try to keep the resistance the same as well as the inductance the same.

How is detection really done?

Both PI's and VLF's take a sample of the receive signal for analysis. In the case of the VLF, the receive signal sample is analyzed with respect to the transmit signal. By doing this, any signal "shift", commonly called phase shift, can be "seen". In other words, the sample is taken by syncing the sample to the transmit signal so the sample is always synchronized to the transmitter. The circuitry used to sample the received signal is normally called the synchronized demodulator.

On a PI, the signal from the coil is initially amplified and some time after the large current pulse is stopped, a sample of the amplified coil signal is taken. Since there is no transmitting going on at the time of the sample on a PI, timing is generally done by waiting a finite time after the termination of the large current pulse and then taking a sample. In this way, there is a form of synchronization also. The time between when the pulse quits and the sample is taken is often referred to the delay time. The delay time on most Gold Hunting PI detectors is 15 usec or less. A delay of 10 usec will show a distinct improvement, especially to very small gold in the few grain range over a detector having a delay of 15 usec.

This delay time is quite critical and is sometimes changed to create a crude form of discrimination, or rather reverse discrimination in the case of gold. As I mentioned before, the signal from gold can decay very quickly. In fact, the signal from most gold nuggets smaller than a 1/4 oz can decay in less than 50 usecs. If the delay is adjusted to 50 usec, then most small nuggets will be ignored, or phrased another way, will not produce any audio response. However, signals from objects made of iron, copper, silver or other highly conductive metal will normally still produce a strong signal. So, if a detector samples the signal at a time later than 50 usec or so, and this sample does not "see" a target, there is a good possibility the object is gold or some other type of low conductive material.

will cause very small gold nuggets to be missed. The reason is because the reflected signal caused by the nugget is very brief and it combines with the normal signal from the coil.

If the nugget signal dissipates before the main signal decays to OV, then, when the sample is taken to determine whether an object is present, the signal from the small nugget will have already subsided and the nugget will be ignored.

Once a sample is taken, this sample voltage is held in suspension, for a better choice of words, until the next sample occurs, which adds to or subtracts from the previous sample. Because of the suspension, normally called sample and hold, and the filtering process built in to reduce noise, multiple samples are required before a true average signal is developed.

Once this average has leveled out, which normally takes a very brief time (in the thousandths or hundredth's of a second), any object that produces a change sufficient to be seen, will cause an additional signal that alters the receive sample average, which then causes the output to change or increase. This subsequent change is further amplified and ultimately is heard as an audio response, normally in a set of headphones.

The Up Side of PI's

Probably the biggest claim to fame of a PI is the additional depth that can be obtained. The key to this is the increased amount of power into the coil that can cause a stronger return signal from a buried object. However, even though there is a significant increase in current, the depth difference between a PI and a VLF isn't as dramatic as one might expect.

Many people question whether this depth advantage between a VLF and a PI is really that great in areas having almost no mineralization but overall, the PI appears to be superior simply because such places are few and far between. Where the PI really excels is in places having a much higher ground mineralization as will as locations where magnetite type hotrocks are common.

Next comes the big debate of just how a PI only using AA batteries can even come close to obtaining the depths of a different PI using a very large heavy duty battery .Obviously, the PI using the AA batteries cannot be pulsing with the same amount of current as a PI using a much bigger battery.

The fact is, the PI that uses AA batteries can approach the depth of other more powerful PI's, especially on gold less than an ounce in weight. There are multiple reasons this can be true. One reason is the fact that there because of a law of diminishing returns, which simply means it takes a whole lot of current to produce a very small depth increase because of shear power alone. As an example, it may take something like 4 amps of current to increase the depth 1 inch over a PI only pulsing with 1 amp, and this is only true if all other factors are equal.

that will be seen. In other words, it is quite possible to take a sample sooner and produce a stronger signal on a PI operating with less current than might be seen on a more powerful PI using much more current and having a longer delay. One simple way to allow earlier sampling is to reduce the coil current.

In other words, there are a whole lot of other factors that need to be taken into account to determine what is the best combination. Ah, but someone who just read the previous information might simply say, pulse with a strong signal and then simply sample sooner to make the best detector. Well, unfortunately, the stronger the pulse, the more difficult it is to sample sooner because of the reasons mentioned before. A longer pulse or lower coil resistance will result in more coil current, which will affect how long it takes for the spike to decay. A larger inductance will also result in a longer decay time. In fact, it becomes almost impossible to obtain the very short delay times when using a very strong pulse of long duration.

One way to help shorten the delay time of the decaying pulse is to reduce the number of turns of wire in the search coil. However, the field strength of the coil produced when current flows in the coil is a function of both the current and the number of turns, so reducing the number of turns also reduces the field strength produced. So any reduction in number of turns directly relates to potential depth loss.

If all this seems confusing, it is. Not only does the actual current have an effect, but the actual pulse length or time the current flows has an effect as mentioned before. Therefore, it is possible to pulse fewer times and use a shorter pulse and obtain very satisfactory results.

Pulse lengths of 50 usec or less will still produce a very decent signal from most of the gold nuggets that are found with a detector. Increasing the pulse length to 200 usec will really only have an impact on the signal coming from very large gold objects. The reason why the large increase in pulse time doesn't help on most smaller gold is simply because most of the smaller gold is fully saturated by the shorter pulse. Any additional pulse really does nothing to the potential signal that will come back form that gold object.

As a general rule though, a more powerful PI having a very long pulse will generally go deeper on very large gold, meaning nuggets weighing several ounces or more will be more readily detected to greater depths.

A detector using a high current short pulse will have a tendency to be more sensitive than a detector using less current. However, this difference normally is not dramatic, if at all. The key lies in early sampling and noise reduction.

One other major advantage of a Pl over a VLF is the fact that many of the hotrocks or black sand that make a VLF Scream will cause little or no signal on a PI. Normally, these intense hotrocks create a response on a VLF because of the magnetite within the rock.

before a sample is taken. However, an unbalanced earth field effect elimination can cause a hotrock to create some response, as can a very quick sample. In the case of some of the PI kits people build, where there is no earth field effect elimination, a long transmit pulse will cause a magnetite hotrock to produce a very strong signal, much like the signal from a metal object.

When a PI is pushed to the limits, even a PI will begin to produce a much louder signal on more and more magnetite type rocks just due to all the factors involved.

Where a PI really excels is in situations where a nugget is buried under or along side a magnetite hotrock. This combination spells disaster for most VLF's simply because the rock will generate a much stronger negative signal than the slight positive response from a piece of gold. So, it is very possible a VLF will miss a piece of gold in such a combination.

A PI, on the other hand, will look though the magnetite as if it isn't there, so a magnetite hotrock and gold combination will produce a desired signal. In some cases, the rock may just add a little positive signal thus causing the evasive gold target to be detected.

I do want to mention again that if the delay is extremely short, the earth field effect cancellation circuitry isn't perfect, or the rock or black sand contains other types of certain materials, a typical magnetite rock or black sand can generate a small but noticeable signal. One should also remember that it is quite likely that there are other members of the iron oxide family or even other metals in very small quantities that will cause a response and these other oxides may be present in the black sand or in a rock that appears to have large quantities of magnetite. So, any response a person gets from a rock my be caused by a combination of things.

Other hotrocks such as basalt or other similar hotrocks may cause a weak but noticeable signal much like a deep target. Fortunately, the signal from such rocks quickly subsides as the coil is raised a little. Thus, deeper hotrocks will seldom produce a signal.

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