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METAL DETECTING SCIENCE

This article explains the general differences between the most common and popular type of metal detectors used in present days, it is based on scientific facts, but intentionally not written in academic manner, to enable as many metal detector users as possible to understand some of the basic principles on which the functionality of all metal detectors are based.

So how can any average detector user make a realistic assessment about the real capabilities of their metal detector vs all others?

What are the most important factors defining which metal detector is best? Firstly, best is a very relative term when talking about metal detectors. It is almost impossible to define which detector is really the best, unless some criteria is set first and then the particular unit is judged according to that criteria.

Please note that the term **best** in this article is related to the following criteria:
• Depth penetration capabilities.
• Accuracy in discrimination analysis.
• Any other aspect regarding practical qualities of any metal detector will be set aside, considering that it is not covered by any claim made by Nexus Metal Detectors.

All information in this article is meant only for basic educational purposes and not to define which metal detectors trade mark or unit offered on the market is best. That conclusion will be left for all readers of this article to decide for themselves after carefully considering all information.

How does a metal detector work?

The most common of detectors used in present days are Induction Balance (IB) type. In the basic version their search head consists of two loops (coils).
One is for transmitting signals (TX) and the other is for receiving signals (RX).

Another very popular metal detector type is the Pulse Induction (PI). This type of detector utilises in most designs search coil consisting of only one loop used for both transmitting and receiving signals. There are some PI designs utilising search coils with more than one loop.

This article does not comment on other basic topologies upon which metal detectors are built for a reason that the IB and PI detectors are the most efficient and powerful commonly used metal detectors to date.

There is one most common belief that the receiving coils in the search head of all metal detectors are actually receiving signals reflected by the metal targets buried under the ground. The pure scientific fact however is this:

IB Detectors (Induction Balance)

In IB detectors the two loops forming the search head are supposedly in perfect induction balance, meaning that the residual signal (offset voltage) in the receiving coil is as close as possible to 0.

When a piece of metal comes across the electro-magnetic field transmitted by the TX loop some amount of Eddy currents will occur in the moment of crossing the transmitted field. The Eddy currents in the metal piece will cause an electro-magnetic field to form around the metal piece.

That electro- magnetic field then will cause the TX and the RX loops to get out of balance within a certain amount. Out of balance will mean that some amount of offset voltage signal will occur in the RX loop. This offset voltage signal is not a signal reflected or returned by the metal piece, but a signal transmitted by the TX loop. The presence of a metal piece in front of the search head will result in the new offset voltage signal in the RX exhibiting a bit different characteristics than the original offset voltage signal remaining after the factory balance procedures on the search head. The difference of the new offset signal to the original can be measured in both phase and amplitude.

Exactly on the changes of the phase and the amplitude of the residual offset voltage signal all IB metal detectors are reacting, not on reflected or returned signals.

Another way of explaining this process is to say that the presence of any, external to the search head, metal targets will alter to some degree the electro-magnetic properties of the TX and the RX loops, which will result in a different balance situation between the TX and the RX loops.
The electronic circuits of all IB metal detectors are actually measuring this very change in the balance between the two loops in the search head.
From this point of view it will be safe to state that the sensitivity of any IB metal detector will depend mostly on the electro-magnetic properties of the search head loops. The most important of those properties is the Q, quality factor.
This article will not get any further into the academic aspect of the Q, but wish to tell that the Q is the main of all factors which could influence the performance of any search head or single loop. The Q is of equal importance when PI metal detectors are concerned.

PI Detectors (Pulse Induction)

However the PI works on a different principle than the IB detectors. A PI detector utilising search head consisting of one loop, works (in a few words) in the following way;
The loop in the search head is used to transmit high voltage (few hundred volts) pulses. After each transmitted pulse the electronic circuit measures the residual signal left in the loop after the pulse. That residual signal will decay in a certain manner.

The most important characteristic of the residual signal is the time constant of the decay.

If a metal target is placed in front of the loop the time constant of the decay will change as a result of the same Eddy currents described in the case with IB detectors. In this case the Eddy currents will have pulse characteristics as the transmitted signals. However the basic principle stands, meaning that the metal target placed in some proximity to the loop will alter to some degree the electro-magnetic properties of the loop, which will cause different decay in the residual signal in the loop.

Again, the most important of all characteristics of the mentioned loop is the Q. The Q factor will define the capability of any loop (coil) to transmit or receive any signals.

The Q of any loop can be maximised in only one way; by using a capacitor with a calculated value, which will form with the loop a resonance circuit at the desired operating frequency.
A loop tuned in resonance will always have the highest Q and best performance characteristics, compared with any other loop, which is not tuned.
A loop can also be partially tuned, meaning that the capacitor value in the resonance circuit will be different than the calculated for total resonance. In such a case the Q will still be better than a loop not tuned at all, but not as good as a loop tuned in total resonance.

There is one other important aspect related to the type of search heads consisting of at least two loops or more, which has to be mentioned before proceeding further: This is the actual balance between the TX and RX loops.
If two loops, one TX and one RX, with constant Q for each one of them, are balanced to a minimum offset voltage in the RX at a certain frequency, they will become a part of a constant electro-mechanical system.
If the RX loop is tuned completely to the frequency transmitted by the TX then the two loops will get in full electro-magnetic resonance. In this situation the Q of the whole system will be at

maximum, which means that the search coil will be with best detection capabilities.
If the same system is tuned later to work at different frequencies that will lead to loss of Q regardless if it is still tuned to a total resonance or not. The reason for this phenomenon is quite simple. Ones a system of two loops is balanced and dipped in resin, the loops can not be moved to a different mechanical position. In order to achieve maximum Q at various frequency settings every two loop system will need some allowance for mechanical repositioning of the loops. This requirement comes as a result of the fact that for every different frequency, at which the loops in any system are tuned to work they will exhibit different Q. From the well established electro-technical laws it is known that the Q of a loop (coil) is a factor of external and internal diameter of the loop, cross section of the windings, number of turns and operating frequency. Since the diameter, the cross section and the number of turns in a loop are mechanical constant, then the only factor which can seriously influence the Q is the operating frequency. Another factor which can lead to change of the Q is temperature, but providing that metal detectors are not often used in conditions with excessive thermal changes, we can accept that the temperature is a relatively small problem for any loop.

How is all of the mentioned above related to comparison between different types of metal.The graphic image in this article will give explanation about Multi Frequency Technology (MFT) type of detectors.
Firstly, it is important to mention that amongst all detectors based on IB principle, the MFT has the lowest efficiency, concerning depth penetration capabilities and discrimination accuracy.
The reasons:

Setting a search head to work on various frequencies will define low Q at all of the frequency settings. That will result in average to poor depth penetration and unreliable discrimination.
TX loop is possible, but that kind of transmission will make the work of any IB detector impossible. Also simultaneous frequency transmission will most certainly result in a very low Q for the whole system. MFT can not offer any real practical advantage to the IB type of metal detectors as far as depth penetration and discrimination accuracy is concerned.

Another popular type of IB metal detectors are those with dual frequency settings. All of the mentioned above conditions apply to this type of detectors as well as to the MFT.

The difference in this case is that having the search head system to work only on two frequency settings (one at a time) will provide an opportunity to have maximum Q on at least one of the two frequency settings. That will give a good chance for better depth penetration and discrimination accuracy.

The most common type of IB detectors are the single frequency metal detectors. Metal detectors set to work at only one frequency, have the best chances to achieve good depth penetration and discrimination accuracy.

The next popular type of metal detectors, capable of competing for better depth, are the PI metal detectors.
Relative to the transmitted in the ground energy, the PI detectors are with lower efficiency than the IB. However the fact that average PI metal detector can
detect targets deeper underground than the average IB detector, due to the very high level of the transmitted signals (few hundred

volts pulses). With that allowance in their basic principal the PI metal detectors can win almost any competition for depth. However, the greatest disadvantage for the PI detectors is the lack of reliable discrimination. Regardless of all claims on the PI market, the PI principal can not allow good discrimination to be achieved.

The best metal detectors regarding depth penetration and discrimination accuracy are the IB detectors tuned in total or as close as possible to total electro-magnetic resonance.
The reasons:
It is not possible for any kind of loop to achieve higher Q than the Q as a result of electro-magnetic resonance. In comparison to a standard, not tuned in resonance search head system, one tuned in total resonance can exhibit up to 100 times higher sensitivity to any desired target. That fact alone led to use of lower electronic amplification, lower electronic instability and much better resistance to thermal changes for the electronic circuit.
A RX loop tuned in total resonance will act also as 10 th order band pass filter against any external interference, which will almost eliminate the need of any interference prevention filters.
In comparison to off resonance RX loop, one tuned in total resonance is much more sensitive to phase and amplitude changes, which can guarantee best depth penetration and discrimination accuracy as can be achieved with any metal detector.