White Paper

SAFELINE
Metal Detection & X-ray Inspection

# Understanding Challenging Applications

## for Improved Metal Detection

Contents



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# Understanding Challenging Applications for Improved Metal Detection

In the food and pharmaceutical industries many of the products being inspected for contamination exhibit a phenomenon known as 'Product Effect'. This is where the type of product being inspected, can itself hinder the inspection technologies capability to identify that particular contaminant.

Other inspection technologies may refer to this phenomenon differently but for metal detection technology the extent of this effect normally categorizes products as being either "wet" or "dry". The purpose of this white paper is to explain what is meant by these terms and also to develop an understanding as to why this is important when choosing the right metal detector to use.

## 1. How a Metal Detector Works

To understand Product Effect, it is important to understand, firstly, how a metal detector works. It will then be clear why products have product effect and why product effect matters.

### 1.1 Balanced Coil System

At its most basic level, a metal detector consists of three sets of coils that are said to be 'balanced'. These coils are typically made up of copper wire wound around a coil former.

The coil former is usually rectangular or round – and these are the most common aperture shapes for metal detectors used in the food and pharmaceutical industries. (See Fig 1a.) The center coil is called the 'transmit' coil (Tx) and the outer coils are called 'receive' coils (Rx1 & Rx2). The receive coils are wound in opposite directions to each other, with one end of each coil connected (Fig. 1b). The product being inspected by the metal detector is passed through the coil former, which is also known as the 'metal detector aperture'.

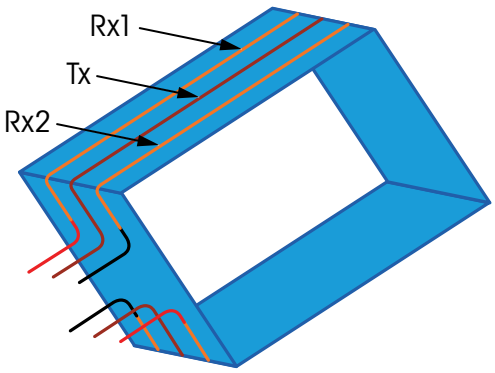


Fig. 1a

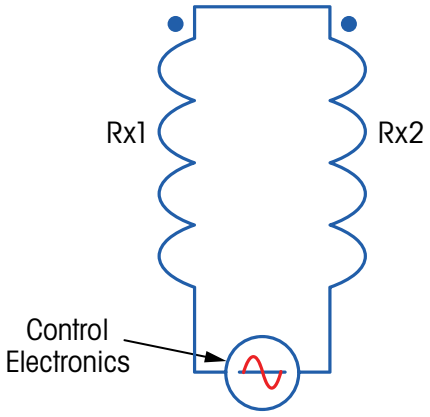


Fig. 1b

The metal detector works by transmitting a high-frequency signal into the Tx coil, which generates a magnetic field in the aperture. This magnetic field induces a small voltage into each of the Rx coils. These induced voltages will have reversed polarities, due to the fact that the coils are wound in opposite directions. The metal detector's control electronics measure the difference between the voltages - and for a well-balanced detector, this value should be zero volts.

In reality, a metal detector is very seldom perfectly balanced and the control electronics are designed to compensate for small imbalances present when the metal detector is built or changes caused by thermal, mechani-

cal or electromagnetic effects on the coil system. The build quality and 'auto balance' functionality are, therefore important considerations when buying a metal detector. A poorly designed or manufactured detector is likely to drift out of balance, which could result in unnecessary downtime, poor performance and/or false triggering.

## 1.2 How Metal Affects the Balance Condition of the Metal Detector.

If a metal object is brought closer to the receive coil Rx2 (See Fig. 2), the magnetic field is disturbed by the metal, and this disturbance will affect Rx2 more than it will affect Rx1. The voltage induced into Rx2 (VRx2) will thus change, relative to the voltage in Rx1 (VRx1). As the metal continues through the aperture, it will start to affect Rx1 more than Rx2. The metal detector will detect these changes in the balance condition and interpret it as a metal contaminant.

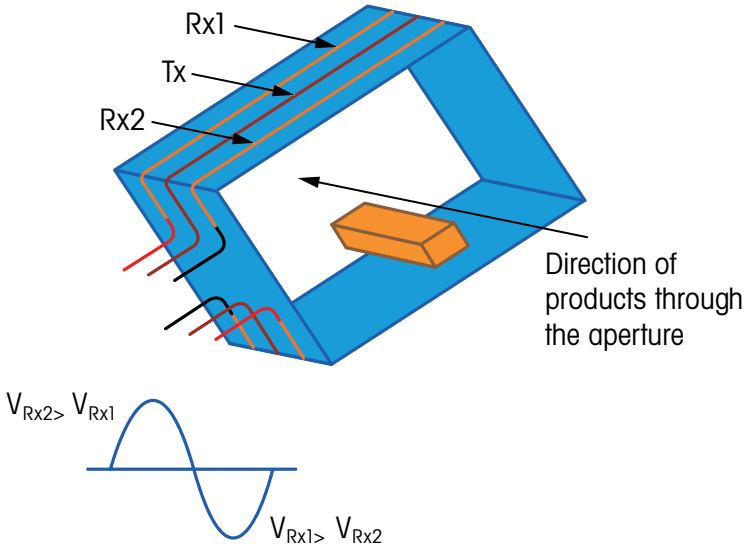


Fig. 2

## 1.3 Magnetic Fields, Conductivity, Permeability and Eddy Currents

The reason metal changes or influences the magnetic field can be explained as follows:

If metal is exposed to an alternating magnetic field, a small amount of current (called 'eddy' current) is induced into the metal (See Fig. 3). These eddy currents will create a magnetic field that will alter the total magnetic field.

The magnetic field surrounding the receive coils will now have a different field strength, changing the amplitude and phase angle of the voltage induced into the receive coils. The difference in the voltages in the receive coils will no longer be zero volts. When this voltage difference exceeds a predefined 'noise' level it triggers a detection event.

The characteristic of the metal that allows eddy currents to exist is called 'conductivity' (in other words, the metal's ability to conduct electricity). The high conductivity of the metal allows eddy currents to be generated in the metal, and these eddy currents create their own magnetic field.

The 'permeability' of a material is its ability to be magnetized. A metal with high permeability allows the magnetic field from the transmit coil, and from the eddy currents, to pass through it more easily than through free air. This behavior alters the magnetic field in the aperture.

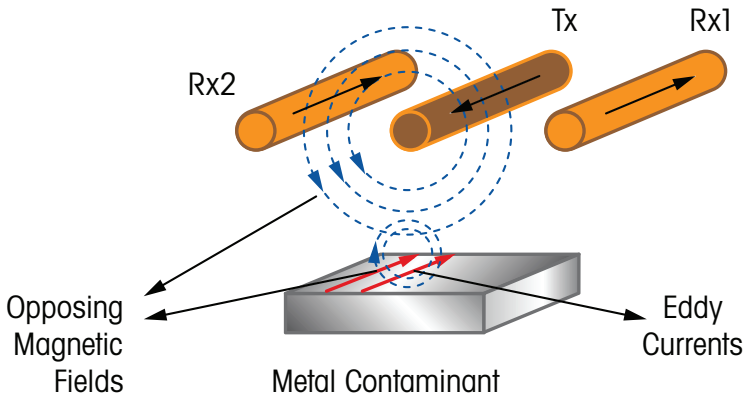


Fig. 3

Different materials have greatly different conductivity and permeability values. For example, ferrous metal (iron) has higher conductivity and much higher relative permeability values, than 316 grade SS (Stainless Steel). This means that ferrous metals would alter the magnetic field in a detector much more than 316 grade SS, making it much easier to detect.

## 2. Product Effect Explained

Metals are not the only materials that have the ability to conduct electricity and generate magnetic fields. Many of the food and pharmaceutical products that we consume have, to a lesser extent, the same ability.

Salt water (Saline), for example, is a relatively good conductor of electricity, but has very low permeability compared to iron. If a saline-rich product is subjected to a magnetic field, eddy currents will form in the product and, as is the case of metals, it will produce a magnetic field.

The low permeability of the saline solution will tend to weaken the magnetic field, but will not cancel it out. This magnetic field is relatively small compared to an equivalent-volume of iron, and will thus have very little effect on the magnetic field in the aperture.

Metal detectors are, however, precision instruments intended to detect very small metal contaminants in much larger products. If a saline-rich product were big enough, it would create a magnetic field large enough to disturb the magnetic field in the same way as a small metal contaminant.

In real-life applications, the volume of the metal contaminants are many hundreds or even thousands of times smaller than the products that are being inspected – and it is this volume difference that causes the product to affect the magnetic field in the aperture, in the same manner as a metal contaminant. When a product is able to affect a metal detector to the same extent as a metal contaminant it is said to have 'Product Effect'.

There are many products that are naturally high product effect applications with high moisture content - and are generally referred to as 'wet' products. Items such as fresh meat, chicken and fish have high moisture content and are relatively good conductors. These products are thus more likely to produce a signal in the metal detector in the same way as small metal contaminants would. This product effect makes it more difficult for the detector to distinguish between the product and the metal contaminant.

The size of the contaminant, which can be detected in product effect applications, is, therefore, larger than in 'dry' applications. The detector sensitivity also varies with the type of metal contaminant.

## 2.1 Factors that Influence Product Effect

There are many factors that affect the characteristics of a product, and these variations are difficult to control on a production line. To compensate for such variations, metal detector sensitivity is often reduced, so that the majority of products can pass through the detector without false triggering – however, this means that overall detector sensitivity is reduced.

### 2.1.1 Moisture Content

The moisture and salts content can change significantly from pack to pack; in beef, for example, the moisture and salt content is dependent on the cut of beef that is being inspected and will vary from one animal to the next.

If the product is marinated, the amount of marinade and the consistency is not always constant, and these factors can very quickly change the conductivity and permeability of the product.

### 2.1.2 Temperature

The temperature of the product being inspected has a major impact on its ability to affect the magnetic field in the detector. Changing the product temperature alters the product's conductivity, thus altering the formation of eddy currents and the resultant magnetic field.

When frozen products are exposed to higher temperatures, condensation forms on the outside of the product, changing its influence on the magnetic field. If the product is allowed to warm up even further it will start to thaw. This in turn allows the moisture in the product to conduct eddy currents better than when frozen. Both surface condensation and thawing can have a major impact on the ability of a metal detector to maintain its sensitivity.

The greater impact from changing temperature is, however, not the strength of the magnetic field generated, but the resultant change in the characteristics (phase angle) of the voltage induced into the receive coils. Relatively small temperature changes (i.e. 5°C) will significantly change the products signal in the metal detector.

### 2.1.3 Size and Shape of the Products

Typical packaged products have a uniform shape that gives a consistent product signal, which is easily interpreted by the detector. Other products, such as whole chickens, vary significantly in size, shape and weight. In general, a bigger chicken will give a bigger product signal than a smaller chicken.

### 2.1.4 The Position and Orientation of the Product Through the Detector

If the size and shape of a chicken influences the magnetic field, it is easy to understand why its orientation through the detector can have a similar effect. If a chicken is passed through the detector with its short edge leading (i.e. head-first), it appears much smaller to the metal detector than when it is passed through the detector sideways. Controlling the orientation of products such as fresh chickens on a production line can be very difficult. It is not uncommon for multiple chickens to pass through the aperture at the same time. This increases the variation in the product signal dramatically.

The product position on the conveyor is also a variable in the detectability of metal contaminants. The magnetic field in the metal detector aperture is the weakest in the center of the aperture. A product that passes through the center of the aperture is thus exposed to a weaker magnetic field than a product passed through the detector close to the sides of the aperture, (where the magnetic field is at its strongest). The impact of the product on the magnetic field is thus dependent on its position in the aperture.

### 2.1.5 Consistency and Density of the Product

Different materials exhibit different levels of permeability and conductivity and their impact on the magnetic field in the aperture will also vary significantly. The ratio of the ingredients (or the bone content in meats), will thus all have an impact on its ability to be inspected.

This inconsistency in the product being inspected is one of the biggest challenges when inspecting products such as, ready meals. A tray with mashed potatoes, sausages and gravy has a product signal, which varies significantly, with variations in both the quantity and ratio of the ingredients.

### 2.1.6 Packaging Material

There are a variety of packaging materials used in the food and pharmaceutical industries today. Many of these have very little effect on the metal detector's sensitivity. Packaging materials such as metallized film, however, can have a big impact on achieved sensitivity.

Metallized film is a material made by coating materials such as polypropylene or polyethylene terephthalate with a thin layer of metal, typically aluminium.

The thin layer of aluminium (~0.5um) on the film's surface, will have a similar magnetic permeability to free air, but has relatively good conductivity levels (dependent on the thickness and uniformity of the aluminium layer). The relatively high conductivity of the metallized film will allow the formation of eddy currents in the thin layer of aluminium, generating a magnetic field that will affect the magnetic field in the metal detector aperture.

Metallized film packaging can make it more difficult to detect metal contaminants inside the product. In such cases it is generally recommended that products be inspected before they are packaged into metallized film. The widely adopted practice of using throat metal detectors in the snack food industry is a good example of this. If this is not possible, there are multi-simultaneous-frequency metal detectors on the market that are very good at inspecting metallized film packaged products that also deliver excellent levels of sensitivity.

## 3. What is a 'Dry' Product?

In the balance coil detector described above, there are various products that can be passed through the detector without any significant change in the magnetic field. For example, if a bag of dry flour (with very low conductivity and permeability) was passed through the detector, it would not have a significant impact on the metal detector's balance state. These products are referred as 'dry' products.

The term 'dry' can sometimes be a little confusing, since some dry products do have significant product effect, while some wet products appear as dry products when being inspected.

Products such as fresh meat have high levels of product effect, though frozen meat appears more like a dry product. The main reason for this is that the conductivity of frozen water drops to almost zero, preventing the formation of eddy currents and their resultant magnetic fields.

## 4. Dealing with Product Effect

Despite the challenges presented by the Product Effect, a modern well designed metal detector using the optimum technology should still be able to perform inspection functions to a very high standard assuming it is specified to suit the application.

## 4.1 Low Versus High Frequencies

Metal detectors can be designed to operate at a variety of frequencies, from as low as 25 kHz up to 900 kHz. If a metal detector operates at 900 kHz, the magnetic field in the metal detector aperture changes polarity 900,000 times per second.

Eddy currents are formed in an alternating magnetic field and the amount of current generated is depended on the magnetic field strength and frequency. The eddy currents generated in a product will be much higher at 900 kHz than at 25 kHz.

At low frequencies, such as 25 kHz, the magnetic field generated in the aperture is relatively strong, but the corresponding eddy currents and magnetic field generated in the product are relatively low. The magnetic field in the product has very little effect on the very strong magnetic field in the aperture and the product signal is thus relatively low.

The signal from the metal contaminant is, however, also relatively low - and at these low frequencies, the electric and electromagnetic noise becomes a dominant factor in the sensitivity that the metal detector can achieve.

At very high frequencies, the maximum power that can be switched into the transmit coil is limited, so the magnetic field in the aperture is much lower than at the lower frequencies. The amplitude of the eddy currents in the product and the contaminant are, however, higher at high frequencies allowing a bigger magnetic field to form around the product. The resultant product signal is relatively high, compared to the magnetic field in the aperture - and this makes it hard to detect the metal contaminant. At very high frequencies (900 kHz), the metal detector is easily saturated by high product effect applications, and the sensitivity is compromised.

In traditional metal detector technology, there is always a trade-off between the product effect, the maximum operating frequency and metal detector sensitivity. The simple rule is that the higher the product effect (i.e. the wetter the product), the lower the optimal frequency and the lower the sensitivity of the detector.

In comparison, the lower the product effect the higher the operating frequency and detection sensitivity is. Dry products with low product effect have very little impact on the metal detector at high frequencies, so the detector can easily detect very small metal contaminants at these frequencies.

## 4.2 Phase Discrimination

Operating frequency alone is not sufficient to deal with the effect from a product, so additional techniques are required to allow detection of very small metal contaminants.

The most common technique used in modern metal detectors is called "phase discrimination". This technique separates or discriminates between signals, meaning it can dramatically reduce the product signal while amplifying the metal signal. It does this by learning the characteristics or phase of the product signal and placing a "discrimination envelope" around the product signal to effectively ignore the product signal inside the envelope while detecting signals outside the envelope. Other common names for this are phase filter and phase control.

In early analogue metal detectors, phase discrimination was implemented using a relatively simple technique giving a basic level of sensitivity performance. As industrial metal detectors evolved and became more digital based, phase discrimination became more sophisticated and sensitivity performance improved. The most sophisticated metal detectors on the market today have a dedicated Digital Signal Processor (DSP) to handle phase discrimination and other advanced signal processing techniques. This allows the detection of even smaller metal contaminates.

## 4.3 Multi-Simultaneous-Frequency Metal Detectors

The most sensitive metal detectors on the market today operate at more than one frequency simultaneously, known as Multi-Simultaneous-Frequency (MSF) and address the problem of product effect in a new and innovative manner.

The new MSF metal detectors use various combinations of high and low frequencies simultaneously. The most sophisticated detectors use built-in Product Signal Suppression technology with two stages of discrimination, frequency and phase. This cancels the information from these combinations of high and low frequencies to effectively remove the product signal, allowing for much smaller metal contaminants to be detected.

This technology is also able to deal with product variations very effectively. Once a product has been set up on a detector, the product signal suppression technology is applied to each product that passes through the detector. The electronics adjust for variations in product effect for each product inspected, dramatically increasing its ability to detect small metal contaminants consistently. It is so effective at adjusting for these variations that it can even compensate for several of the same products passing through the metal detector at the same time.

The improvement in detector performance - from the traditional single-frequency metal detectors to the multi-simultaneous-frequency detectors - is as much as 50% in product effect or metalized film applications.

In the more challenging applications, operating to a factory detection standard can prove difficult for any one or all of the product effect factors listed in this paper.

Attempts to meet a factory standard normally involve increasing sensitivity levels to a point where the metal detector setup becomes unstable and the system rejects good product, known as a "false reject" or a "false positive". Operating with a high false reject rate (FRR) can be very costly for a business, to the extent where a trade-off or concession to the factory detection standard has to be given.

The advent of MSF and Product Signal Suppression technology now gives greater confidence to meet or exceed a factory detection standard without the worry of generating costly false rejects.

# 5. Summary

Every product inspected by a metal detector has an influence on the ability of the metal detector to find a metal contaminant in the product. This influence is called its 'product effect'. Products that have high product effect are usually referred to as 'wet' products or 'high product effect applications'.

The factors that influence the inspection of wet products or products with high product effect are:

- The moisture content in the product
- The temperature of the product
- Size and shape of the product
- Position and orientation of the product through the detector
- Consistency or density of the product
- Packaging material
- Frequency at which the product is inspected

Products with very low product effect are often referred to as 'dry' products. These products can be inspected at very high frequencies and sensitivity levels.

Products with high product effect are much more challenging and the choice of metal detector and the metal detector supplier is much more complex. For such applications we recommend that you consult with an expert supplier with the technology and service support to take this worry away.

A good metal detector supplier should offer a wide range of metal detectors for every application, so when choosing a metal detector, be sure to assess the supplier equally carefully.

Below is some useful guidance on what a good metal detector supplier should offer:

- A complete range of products with the best sensitivity
- Good-quality, highly stable metal detectors with good protection from electromagnetic and other interference
- A reliable service support network with worldwide coverage, so that the support is available wherever a metal detector is installed.
- An understanding of what is needed to develop a contaminant detection program that meets the strictest food safety standards.
- A metal detector that is easy to set-up and use.
- Metal detector solutions that can grow with your business and are as future-proof as possible

So as to make it easier for users to pick the right metal detectors for their product, suppliers should offer various ranges of products to suit each requirement. Single frequency tuned metal detectors for the inspection of dry products and multi-simultaneous-frequency detectors for all product effect and metallized film applications.

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