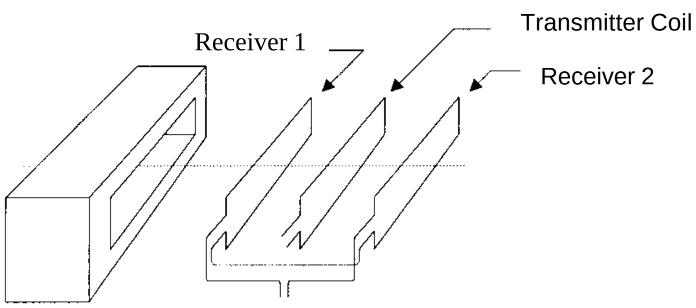
1. Metal Detection – The Basic Principles

1.1 Theory Of Operation

Balanced Coil
Most modern metal detectors operate on the balanced coil, full loop system.

Three coils are wrapped around the aperture through which the product passes. In the center of the enclosure is the transmitter coil that broadcasts a radio frequency signal and generates an Electro-magnetic field.

Equally spaced on either side of the transmitter coil are two receiver coils (see figures 1 and 2).



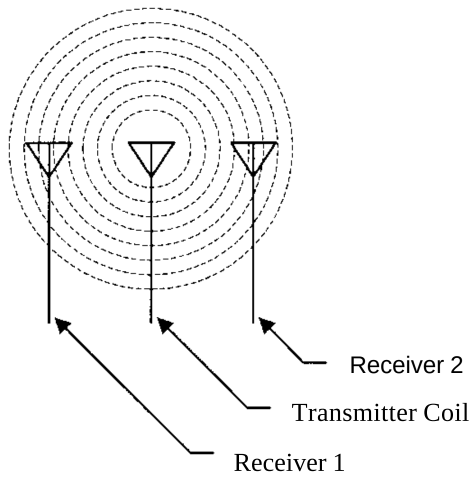


Figure 1 **Figure2**

The field is generally trapped inside the shielded enclosure of the detector but some field escapes from the aperture on both sides of the detector. Anything that enters into this field that is either **Magnetic,** or Electrically **Conductive** will cause a disturbance in the field strength around it. All metals have either one or both of these characteristics and will be detectable if the size of the signal is large enough.

The signals from the receiving coils are connected in opposition to each other and therefore when no disturbance is occurring there will be a net signal across the coils of zero – they are balanced. This forms the electrical equivalent of a balance weigh scale (figure 3).

As metal passes through the detector the balance will be offset as the contaminant enters the aperture and again as it leaves the exit side. This disturbance is amplified and analyzed by the control electronics and detection will occur if the sensitivity threshold has been exceeded.

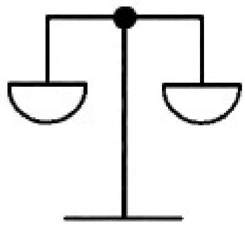
Ferrous In Foil

The exception to this design occurs when a product is packaged in foil (pure aluminum). Foil lids and trays are common examples where an alternative system is required. Here the detector operates using a series of magnets and is referred to as a Ferrous in Foil detector. The drawback of this type of inspection is that Non Ferrous and Stainless contaminants can not be detected.

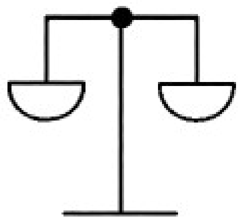
1.2 Product Effect and Phasing

The control electronics actually split the received signal into two separate channels: magnetic and conductive. This means there are effectively two balance scales in the detector (see figure 3). These scales continuously measure the magnetic and conductive signal component of every disturbance.

Products that are being inspected can also have one or both of these characteristics.



Conductive Scale



Magnetic Scale

Figure 3

<u>Product Effect</u>

Metal detectors detect metal based on measuring electrical conductivity and magnetic permeability. Many products to be inspected inherently have one or both of these characteristics within their makeup. For example, any product which is iron enriched such as cereals, create a large magnetic signal which the detector must overcome in order to detect small pieces of metal. These are referred to as “dry” products. Conversely, products with high moisture and salt content such as bread, meat, cheese, etc. are electrically conductive and produce a conductive error signal. These are referred to as “wet” products. The table below shows typical product error signals and categorizes them as wet or dry.

The detector must remove or reduce this “product effect” in order to identify a metal contaminant. Most modern detectors will have some form of automatic calibration to do this it is often referred to a phasing

Typical *‘Wet’* Products	**Typical *‘Dry’* Products**
<u>Food</u>: Meat, Cheese, Bread and Bakery Products, Fish, Dairy Products, Salads <u>Packaging</u>: Metallized Films <u>Other</u>: Plastic and Rubber products with high carbon black content	<u>Food</u>: Cereal, Crackers, Flour and powders, Biscuits, Frozen Food Products (< 10 Degrees C), Peanut Butter and Margarine (Vegetable oil is not conductive) <u>Other</u>: Wood Products, Plastics and Rubber (Products with high carbon black content may be considered wet’), Textiles, Paper Products

1.3 MetalFreeArea

The Electro-magnetic field is trapped inside the detector's enclosure (shield).
However, some field escapes out of the aperture on both sides and forms the metal free area or MFA.
Generally, the size of the practical leakage is about 1.5 times the (smaller) aperture dimension and no metal should be allowed in this area.
Large moving metal should be kept 2 x away.

Where applications demand a smaller MFA, special detectors are available which can substantially reduce the total area required.

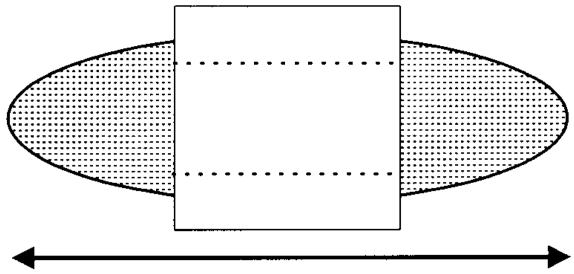


Figure 4

1.4 Sensitivity

The *theoretical* sensitivity of a given metal detector is determined by the aperture size. The smaller the aperture, the smaller the piece of metal that can be detected. The smaller dimension of rectangular apertures is used to calculate the sensitivity, although the length also contributes.

To maximize sensitivity a detector the smallest size aperture should be selected. However there are some exceptions:
- Metallised Film
- Oxygen Scavengers
- Highly Conductive product (large blocks of cheese)

Product effect, metal free area, type and orientation of contaminant and other factors can effect the *practical* sensitivity in any application.

The position in the aperture also effects the sensitivity (see figure 6).
The centerline axis is the least sensitive point and therefore this is where performance testing should take place. As metal gets closer to the sides (and coils), the signal it generates gets larger, making it easier to detect.

Regular testing of the detector should be done so that the test sphere passes close to the center of the aperture. If this is not easily done, then a consistent position should be used so that the test results will be consistent (see figure 7).

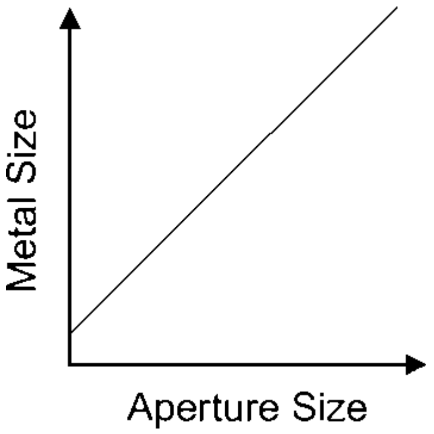


Figure 5

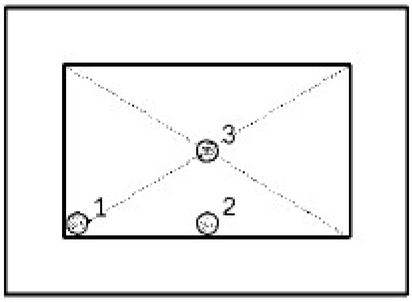


Figure 6

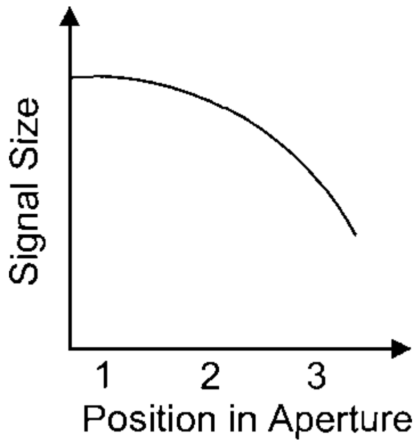


Figure 7

1.5 Types of Metal

The sensitivity of a metal detector is not the same for all types of metal. For simplicity, we tend to categorize all metals into three types:

- **Ferrous:**
  Any metal that can easily be attracted to a magnet (Steel, iron, etc.).

  Typically the easiest metal to detect and usually the most common contaminant.

- **Non-Ferrous:**
  Highly conductive non-magnetic metals (copper, aluminum, brass, etc.)

  When inspecting dry products these metals produce almost the same signal size as ferrous due to the fact that they are good conductors.

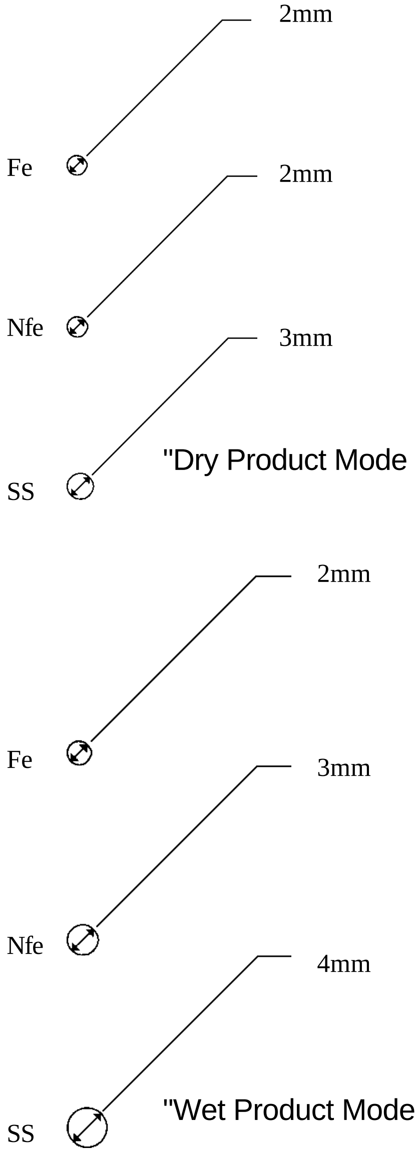
  When inspecting wet products, de-rate the sphere size by at least 50%.

- **Non-Magnetic Stainless Steel:**
  High quality 300 series stainless steels (Type 304, 316).

  These are always the most difficult metals to detect due to their poor electrical conductive qualities and by definition are have low magnetic permeability.

  When inspecting dry products a stainless sphere will have to be 50% larger than a ferrous sphere to produce the same signal size.

  When inspecting wet products a stainless sphere would have to be 200 to 300 % larger than a ferrous sphere to produce the same signal size.



Example of Ratios ONLY

Figure 8

1.6 Shapes & Orientation of Metal

Metal detection standards are measured in spheres because a sphere is the same shape from any aspect. Real contaminants are rarely spherical and may produce a different signal depending on its orientation when it passes through the detector. The most dramatic example of this is shown by wire contaminants.

With wire shapes, the signal produced will vary greatly depending on the type of metal and its orientation as it passes through the aperture (see figure 9). In the worst case a wire may produce a signal no bigger than a sphere of the same size as the diameter of the wire.

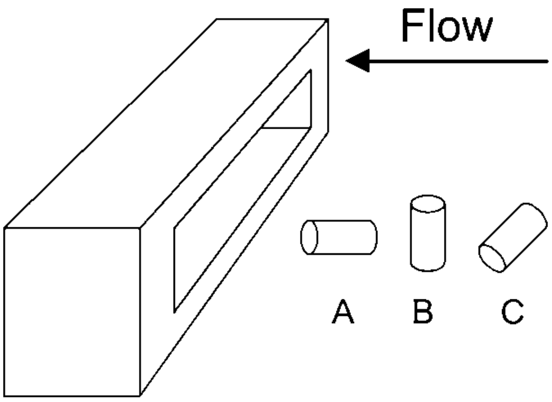


Figure 9

In Figure 9:

Ferrous Wires:
- **A** – Easiest position, biggest signal.
- **B, C** – Hardest Position, smallest signal.

Non-Ferrous and Stainless Steel Wires:
- **B, C** – Easiest position, biggest signal.
- **A** – Hardest position, smallest signal.