SAFELINE
Metal Detection & X-ray Inspection

Metal Detection

Reduction of Metal Contamination

Building an Effective Programme

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METTLER TOLEDO

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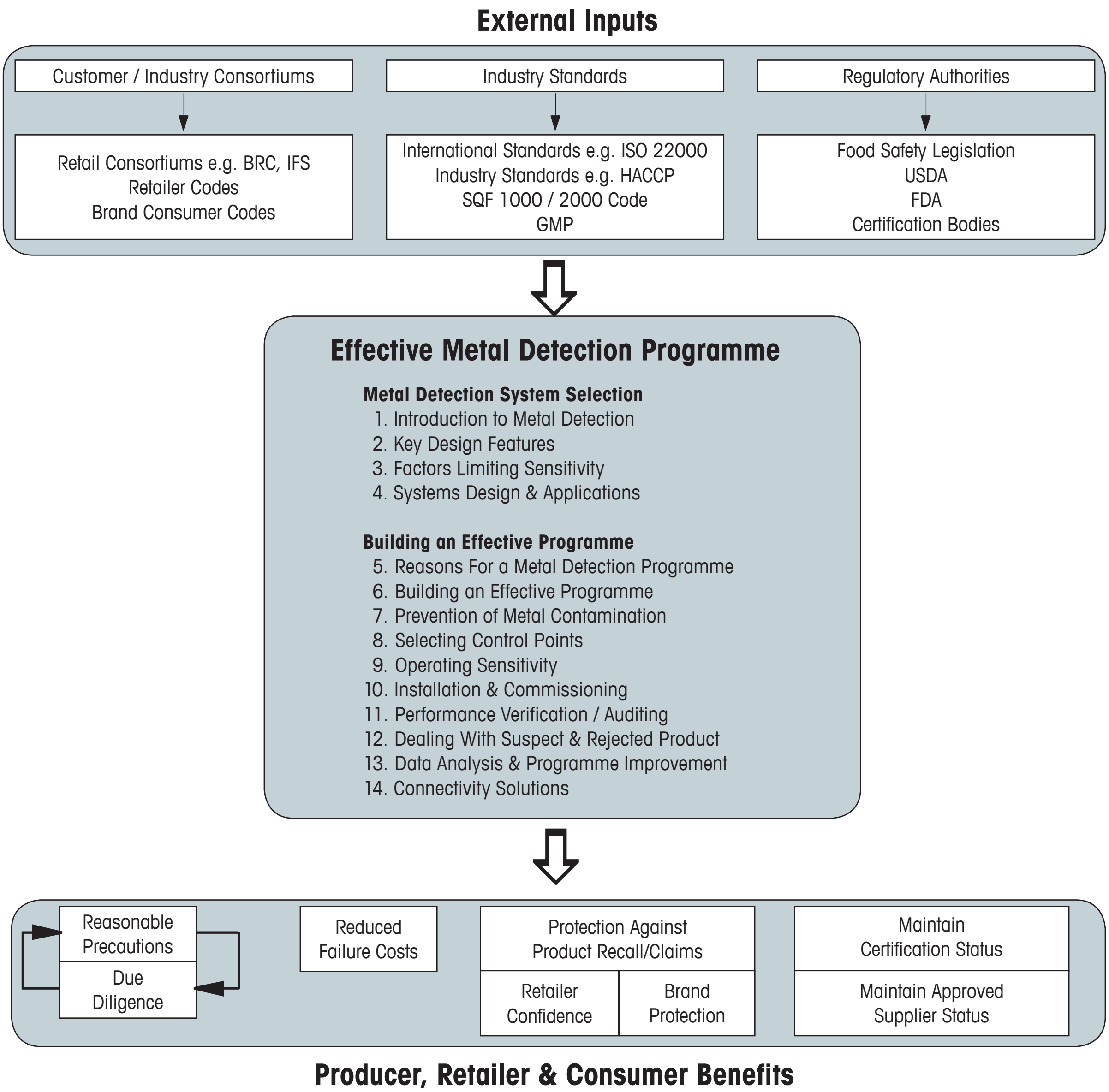
Introduction

The need for metal detection systems in the food and pharmaceutical industry is recognized by most manufacturers and processors as an essential area for focus in any efficient quality regime. In an increasingly competitive market place, driven by ever-changing customer needs, tightening of industry standards and the growth of regulatory and legislative bodies, the importance of effective metal detection has been escalated in recent years.

However, merely installing metal detectors alone will not necessarily guarantee that a metal-free product is produced unless the installations form part of an effective overall metal detection programme. This guide has been written to assist manufacturers in the setting up of such a programme.

An effective metal detection programme can provide protection against product failure and recalls, help to maintain hard fought supplier certification status and reduce overall operating costs. The programme can also support the ability to prove that reasonable precautions and due diligence have been applied in the manufacturing process in the event of a legal claim situation. The requirements for and the benefits of adopting a programme are summarized in the diagram below.



This guide provides a comprehensive reference point for those involved in food safety, giving an insight into all aspects from basic principles through to implementing a comprehensive metal detection programme.

Chapters 1 to 4 provide an overview of how metal detectors work, an explanation of important design features, an insight into factors which potentially limit performance of the equipment and the integration of metal detectors with effective rejection systems.

Chapters 5 to 14 go on to explain that simply installing a metal detection system alone is not enough. A comprehensive metal detection programme is required and the key elements of such a programme are explained in detail.

Margin assists are used throughout the guide to draw attention to points of particular note. The symbols used and their meanings are described below:

Symbol	Meaning
	**Warning** - An operating practice that could result in the incorrect operation or use of the metal detection system
	**Best Practice** - An operating practice that can be considered best practice at time of publication
	**Record** - Highlights pertinent records that should be generated and maintained in order to demonstrate the effective operation of the metal detection programme

Chapter 1
Introduction to Metal Detection

In order to make informed decisions about metal detection systems, it is important to gain an understanding of the main system components and principles of operation. This chapter aims to deliver a basic overview and develop an understanding which can be built upon in subsequent chapters to gain a greater understanding of metal detection technology, equipment capabilities and performance.

1.1 Sources of Metal Contamination

The sources of contamination are numerous and even the most stringent controls cannot prevent the occasional incident. Good working practices will minimize the likelihood of metal particles entering the production flow and correct equipment design and appropriate selection will maximize the likelihood of reliably detecting and rejecting any that do.

Contamination normally comes from one of four sources:

- **Raw Materials**
  Typical examples include metal tags and lead shot in meat, wire in wheat, screen wire in powder material, tractor parts in vegetables, hooks in fish, staples and wire strapping from material containers.
- **Personal Effects**
  Buttons, pens, jewelry, coins, keys, hair clips, thumb tacks, pins, paper clips, etc.
- **Maintenance**
  Screwdrivers and similar tools, swarf and welding slag following repairs, copper wire off cuts following electrical repairs, miscellaneous items resulting from inefficient cleanup or carelessness and metal shavings from pipe repair.
- **In-plant Processing**
  The danger of contamination exists every time the product is handled or passes through a process. Crushers, mixers, blenders, slicers and transport systems all contribute. Examples include broken screens, metal slivers from milling machines and foil from reclaimed products.

Identifying the likely source of contamination is an important stage in developing an overall metal detection program.

1.2 What is a Metal Detection System?

An industrial metal detection system is a sophisticated piece of equipment used to detect and reject unwanted metal contamination. When properly installed and operated, it will help to reduce metal contamination and improve food safety. A typical metal detection system consists of four main parts as follows:

Detector Coil or Search "Head"
Most modern metal detectors fall into one of two main categories. The first type utilizes a "balanced coil" search head. Detectors of this design are capable of detecting all metal contaminant types including ferrous, non-ferrous and stainless steels, in fresh and frozen products. The products being inspected can be either unwrapped or wrapped and can include those wrapped in metallized films. The second detector type utilizes permanent magnets in a "Ferrous-in-Foil" search head. These search heads are capable of detecting ferrous metals and magnetic stainless steels only within fresh or frozen products which are packed in an aluminium foil wrapping.

While it is recognized that other technologies exist, this guide concentrates mainly on the "balanced coil" detector type and to a much lesser extent on the Ferrous-in-Foil (FIF) technologies.

The search heads are manufactured in virtually any size to suit the product being inspected. They may be rectangular or round and may be mounted horizontally, vertically or on an incline. Each has an opening through which product passes. This is called the "aperture." When a piece of metal contamination is detected by the detector search head, a signal is sent to the electronic control system.

User Interface/Control Panel

The user interface is the front-end of the electronic control system and is often mounted directly on the search head. However, it can be mounted remotely with connecting cables if the search head is too small or if it is installed in an inconvenient or inaccessible location.

Transport System

The transport system is used to pass the product through the aperture. The most common is a conveyor. Alternatives include a plastic chute with the detector mounted on an incline, and a non-metallic pipe, mounted horizontally or vertically for inspecting powders and liquids.

Automatic Rejection System

An automatic reject device is frequently fitted to the transport system in order to remove any contaminated product from the production line. There are many different styles available including air blasts, push arms, drop flaps, etc. The style of the reject device installed will depend on the type of product being inspected (see Chapter 4 of this guide).

Other Features

In addition to the four main parts of a metal detection system, other important items may include:

- A container (preferably lockable) fixed to the side of the conveyor to collect and hold rejected product
- A full-length cover between detector and reject device
- A failsafe alarm which operates if the metal detector becomes faulty
- A reject confirmation device, with sensors and timers, to confirm contaminated product is actually rejected from the line
- A beacon and/or audible alarm to alert operators to various other events such as an automated warning that a detector is due to be tested or that the reject bin is full

1.3 Where Can a Metal Detection System Be Used?

Metal detectors may be used at various stages of a production process:

- **Bulk "In-Process" Inspection**
  - Eliminates metal before it can be broken into smaller pieces
  - Protects processing machinery from damage
  - Avoids product and packaging waste by subsequently rejecting a finished higher value product

Typical examples include bulk inspection of meat blocks prior to grinding, ingredients for pizza toppings and grain products.

- **Finished Product Inspection**
  - No danger of subsequent contamination
  - Ensures compliance to retailer and consumer brand quality standards

A combination of bulk and finished product inspection will provide optimum protection.

The most common types of metallic contamination in a broad range of industries include ferrous (iron), non-ferrous (brass, copper, aluminium, lead) and various types of stainless steel. Of these, ferrous metal is the easiest to detect and relatively simple detectors, or even magnetic separators, can perform this task well.

Stainless steel alloys are extensively used in the food industry, but are often the most difficult to detect, especially common non-magnetic grades such as 316 and 304. The non-ferrous metals such as brass, copper and lead usually fall between these two extremes, although in larger metal detectors operated at higher frequencies, non-ferrous may be harder to find than non-magnetic stainless steel. Only metal detectors using an alternating current "balanced coil" system have the capability to detect small particles of non-ferrous and non-magnetic stainless steel.

1.4 Balanced Coil System

1.4.1 Basic Principles of Operation

Three coils are wound onto a non metallic frame or former, each exactly parallel with the other (Figure 1.1). The center coil (transmitter) is energized with a high frequency electric current that generates a magnetic field. The two coils on each side of the center coil act as receivers. Since these two coils are identical and the same distance from the transmitter, an identical voltage is induced in each. When the coils are connected in opposition, these voltages cancel out resulting in "zero output."

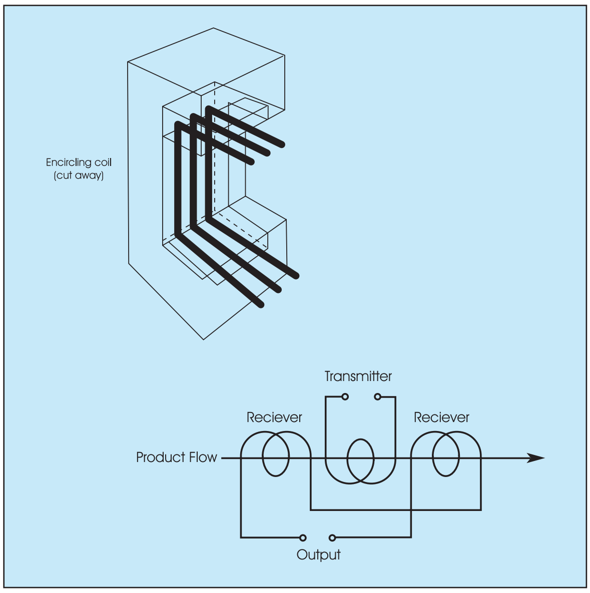


Figure 1.1

As a particle of metal passes through the coil arrangement, the high frequency field is disturbed first near one receiver coil and then near the other. This action changes the voltage generated in each receiver (by nano-volts). This change in balance gives a signal that can be processed, amplified and subsequently used to detect the presence of unwanted metal (Figure 1.2).

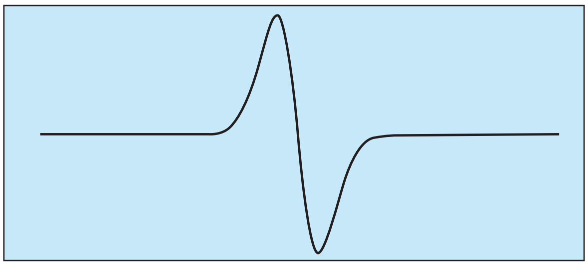


Figure 1.2

The control electronics actually split the received signal into two separate components, magnetic and conductive which are at 90° to each other. The resultant vector, which is referred to as the "product signal" has a magnitude and a phase angle. Many products to be inspected inherently have one or both of these characteristics referred to as "product effects" which the detector must remove or reduce in order to identify a metal contaminant. Most modern metal detectors will have a means of achieving this; it is often referred to as "phase control."

To prevent airborne electrical signals, or nearby metal items and machinery from disturbing the detector, the complete coil arrangement is mounted inside a metal case with an opening through the center to allow passage of the product. The case is normally constructed of aluminium (dry applications) or stainless steel (wash-down applications). In addition to creating a screen, the metal case adds strength and rigidity to the assembly. This is crucial for satisfactory operation of the detector.

Several special mechanical and electrical techniques are essential to the design of stable reliable metal detectors.

1.4.2 Mechanical Techniques

The metal case has an effect on the state of balance of the magnetic field and any movement relative to the coils can cause a false detection signal. Also, microscopic movements of the coils relative to each other, as small as 1 micron, can cause a signal sufficient to result in a false rejection. One of the major design problems for metal detector manufacturers is to design a totally rigid and stable system, unaffected by vibration from motors, pulleys, auto-reject devices, temperature changes, transportation and machinery located in close proximity.

The selection of former material, coil specifications, and case design are crucial. To increase mechanical rigidity further, most manufacturers fill the detector case with a material to prevent relative movement of the metal case to the coils (frequently referred to as potting). This helps produce a unit that is able to operate at maximum sensitivity under typical factory conditions. The quality of the potting is critical to the performance of the metal detector.

1.4.3 Electronic Techniques

Mechanical construction methods will minimize false signals from coil and case movements and provide long-term stability in harsh environments. However, temperature changes, build-up of product in the aperture, ageing of electric components and slow changes in the mechanical structure, will also contribute to an out-of-balance voltage. These can be eliminated by various electronic techniques. Automatic Balance Control continuously monitors this out of balance voltage and automatically corrects it to zero. This removes the need for periodic fine-tuning by an operator and ensures the detector is always operating at the optimum level.

Quartz crystal control, now standard on metal detectors, controls the frequency of the oscillator with great accuracy in order to prevent drift. However, to combat electronic component changes which occur with changes in temperature, further electronic compensation is necessary.

Automatic balance control and quartz crystal control will not, themselves, enable the detector to detect smaller pieces of metal. They will, however, enable the detector to permanently maintain this sensitivity without operator attention and without the generation of false reject signals. For high performance over an extended period, automatic balance control, quartz control, temperature compensation and potting of heads are all essential.

1.4.4 Metal Free Zone (MFZ)

Most of the detector's high frequency magnetic field is contained within the metal case of the detector unit. Unavoidably, there is some leakage of the magnetic field from the aperture of the detector. It is the effect of the leakage of the magnetic field on the surrounding metalwork that may influence the detector's performance and can give rise to inconsistencies in detection capability.

To achieve optimum metal detection results, an area surrounding the aperture of the detector known as the "Metal Free Zone" (MFZ) should be kept free of all metals. The size of the MFZ is dependent upon the aperture height (Figure 1.3), the type of detector and the operating sensitivity. Stationary metal can be positioned closer to the detector than moving metal.

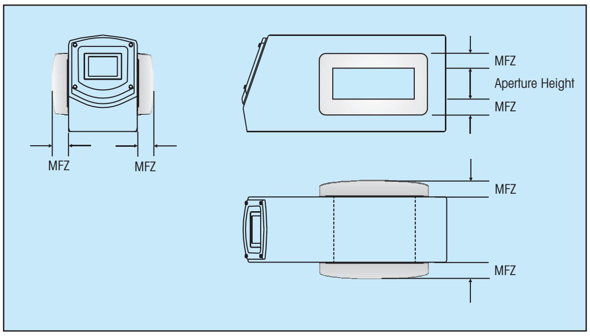


Figure 1.3

The MFZ will normally be specified within the manufacturer's installation instructions. Typical quoted values are 1.5 x aperture height for stationary metal and 2.0 x aperture height for moving metal. Due consideration of this during installation will provide consistent reliable, metal detection performance.

When space is restricted, such as with a short conveyor system or when installation is between a weighing machine and a vertical form fill seal bag maker, a special unit may need to be used where the metal free zone is much smaller. This is referred to as "Zero Metal Free Zone" (ZMFZ) technology.

1.5 Ferrous-in-Foil (FIF) Detection

When the product to be inspected is packaged inside an aluminium foil pack or dish, a metal detector using a balanced coil system cannot be used. However, a detector design is available, which suppresses the effect of the aluminium foil but is still sensitive to small pieces of ferrous and magnetic stainless steel contamination. Figures 1.4 and 1.5 show the basic operating principle.

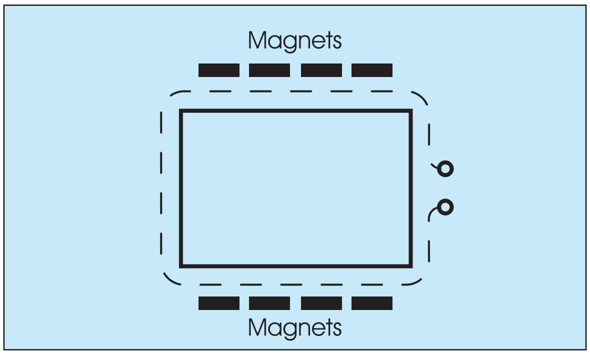


Figure 1.4

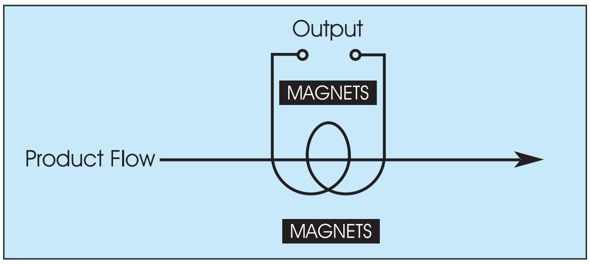


Figure 1.5

As a metal particle approaches the detector, it moves into a powerful magnetic field that magnetizes the particle. As this magnetized particle passes through the single coil, wound around the former, a small voltage is generated, which is subsequently amplified. Ferrous-in-Foil metal detectors show much greater sensitivity to magnetic material than to non-magnetic, but in practice, the sensitivity of the detector may have to be reduced due to some product signal from the aluminium foil and this is often a limit to performance.

1.6 Detection Modes

As a metal particle passes through a balanced coil detector, an output signal is generated which increases to a maximum as it passes under the first coil, falls to zero as it reaches the center coil, and increases again to a maximum again as it passes under the third coil. The signal will start to build up when the metal is some distance from the coil. With a large metal piece, it could be influencing the coil before it even arrives at the detector. Figure 1.6 shows the signal generated by a small and a large metal piece. This will be true for all types of detectors.

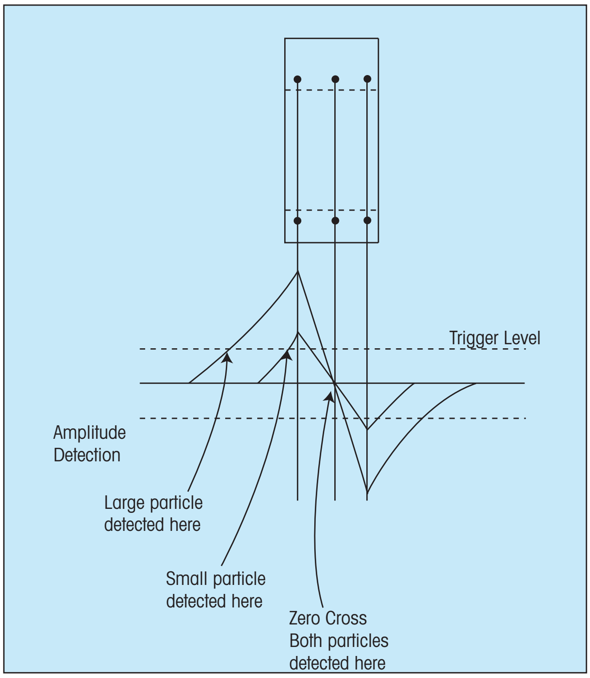


Figure 1.6

There are, however, two alternative methods of interpreting or processing this output signal, which result in different detector characteristics. One is known as Amplitude Detection, the other is known as Zero Crossover (or Narrow Zone) Detection.

1.6.1 Amplitude Detection

When the signal from the metal particle exceeds a predetermined 'trigger' level, the detector operates. Figure 1.6 shows that a large metal piece breaks the trigger level and so is detected earlier than a small metal piece. With Amplitude Detection, a large metal piece is detected earlier and so a greater amount of good product is rejected.

1.6.2 Zero Crossover Detection

This method gives a detect signal from the metal, when the signal changes polarity, from a +ve to -ve or vice-versa. Figure 1.6 shows that this always occurs at the same point, under the center coil, independent of metal size. With this method, the point of detection can be accurately determined, regardless of metal size, and the volume of rejected product can therefore be minimized.

1.6.3 Multiple Metal Pieces

The major drawback of the Zero Crossover method is that it is not foolproof. In a typical production line, it is common for no contamination to occur for a long period and then several pieces to pass together, such as when a sieve or mincer breaks up. If one metal piece follows a second piece and the metals are of a different size, then the Zero Crossover detector can be 'fooled' and the smaller piece may not be detected.

Figure 1.7 shows the signal from a small piece 'A' followed by a larger piece 'B'. The detector does not see the two separate signals but the combined resultant signal 'C'. It can be seen that before this signal 'C' has a chance to change polarity, and be detected, the effects from the second piece over-powers it. The first piece is therefore not detected. If a third large piece arrives, the first two may not be detected and so on. This is a serious limitation of the Zero Crossover method.

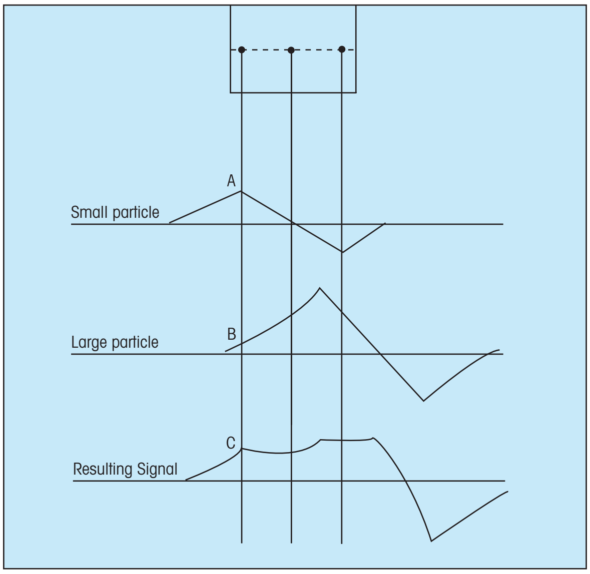


Figure 1.7

1.6.4 Inverse Detection

Metal detectors can also be used to verify that a "required" metal object is present in a packaged product. For example, a specific metal "product component" or a "free gift." This is usually achieved by reversing the action of the reject timer, such that, product containing no metal is rejected while product containing metal is accepted. With this type of application it is important to monitor the product both before and after the process at which the metal item is introduced. This is to be certain that the detected metal item at the output point is the desired object and not a metal contaminant.

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