High-Sensitivity and High-Stability Metal Contaminant Detection using M6-h Series Metal Detector

Hidekazu Kitajima, Yuki Hayakawa, Satoshi Yamashita, Eiji Taniguchi, Tomohiko Yamaguchi, Natsuko Oishi

[Summary] We have developed the M6-h Series Metal Detector using new technologies and functions, such as auto-setting with digital signal processing and a new built-in algorithm as well as a smart guide, while building on the excellent reputation of previous models including simultaneous dual-frequency detection, easy production-line integration, and one-touch maintenance. The M6-h Series detection of magnetic and non-magnetic contaminants even in evaporated-aluminum packaging is based on the concept of "easy-to-operate, high-sensitivity and high-stability detection by anyone" and can detect 1 to 2 times smaller test pieces than its predecessor model.

1 Introduction

General consumers' awareness about food safety and security problems is becoming increasingly strict. In particular, the health dangers and concerns about contamination of foodstuffs has caused voluntary recalls and manufacturing stoppages of products, resulting in large damages for food manufacturers. Furthermore, loss of consumer trust presents a serious risk to continuation of a company's business.

On the other hand, against the background of the 2020 Tokyo Olympics, in 2016, the Ministry of Health, Welfare and Labour defined a strategy for staged implementation of the Hazard Analysis and Critical Control Point (HACCP) International standard for food hygiene to protect Japanese food-related businesses. The HACCP standard analyzes the biological, chemical, physical risks at manufacturing stages and establishes Critical Control Points for manufacturing processes based on the results to assure product safety and hygiene management using continuous monitoring. On receiving this Ministry guidance, food manufacturers have re-examined their production facilities and management systems, focusing on securing better quality management and especially on prevention of contamination by foreign materials.

The main contaminants of foods are metals, stones, glass, bone, plastic, hair, insects, etc. Detection and removal of large metal contaminants presenting a high health risk is generally performed using metal detectors and X-ray inspection systems. In comparison to X-ray inspection systems, metal detectors are less expensive to purchase, have lower maintenance costs, and are relatively easier to handle. As a result, against this background, not only are developed countries, such as Japan and North America, introducing metal detectors, but newly industrializing economies, such as ASEAN, where there are increasing consumer concerns about food safety and stability, are also introducing metal detectors for widespread applications.

Since these metal detectors detect contaminants using very small changes in magnetic fields, they are easily affected by food components and temperature changes, risking detection errors and lower production-line productivity. As a result, error-free operation with high sensitivity and stability has required optimized settings based on the experience and knowledge of specialists. However, due to declining workforces in aging societies, it is becoming harder to train and hold on to experienced workers with the necessary knowledge. As a result, there is increasing need for metal detectors that can be set and operated easily by almost anyone.

To meet this need, we have developed the M6-h Series Metal Detector based on the concept of "easy-to-operate, high-sensitivity and high-stability detection by anyone". An external view of the M6-h Series is shown in Figure 1.

Figure 1 External View of M6-h Series Metal Detector

2 Metal Detection

2.1 About Metal Detectors

A metal detector is composed of a metal detection sensor head with an opening, a belt conveyor for carrying inspected products, and a display for controlling the metal detector functions and displaying the detection results. The metal detection sensor head detects changes in the magnetic field caused by the passage of products through the head as a detection signal and displays the presence of metal contaminants as a NG evaluation when the set value detection threshold limit is exceeded. Since even uncontaminated products can cause changes in the magnetic field due to inspected-product components and temperature, there is always some randomness in the detection signal for each inspected product. Figure 2 shows the randomness of the detection signals for a series of 10 inspected products. Many of the detection signals are yellow, meaning that it is easy to misidentify normal products as NG Products, and requiring a NG threshold setting with some leeway.

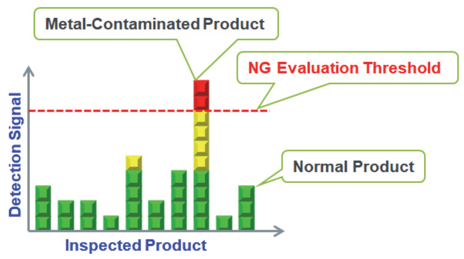

Figure 2 Metal Detector Sensing Image

2.2 Principle of Metal Detector Sensor Head

2.2.1 Metal Detection Basic Principles

This section explains the basic principles of metal detection using the coaxial alternating method used by the M6-h Series. The metal detector sensor head contains one transmission (Tx) coil to generate an alternating magnetic field, and two differentially connected reception (Rx) coils; these coils are wound coaxially at right angles to the conveyance direction of inspected products (Figure 3).

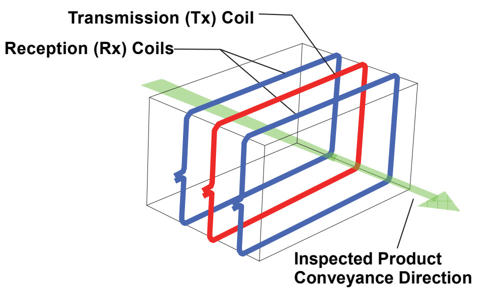

Figure 3 Detection Head Coil

As shown in Figure 4(a), under normal conditions, the magnetic flux generated from the Tx coil forms a balanced magnetic field intersecting the two Rx coils equally and there is no induced voltage from the Rx coils.

When an inspected product passes through the interior of the metal detection sensor head, if there is a magnetic metal, such as iron in the product, the magnetic flux is pulled by the metal contaminant as shown in Figure 4(b) and becomes unbalanced at the two Rx coils. Specifically, the imbalance becomes larger with the passage of larger magnetic metals through the head as the magnetic field strength generated by the Tx coil becomes larger. Similarly, passage of an inspected product containing non-magnetic metal such as stainless steel, repels the magnetic flux as shown in Figure 4(c), resulting in a flux imbalance in the opposite direction to that caused by a magnetic metal. Specifically, the imbalance becomes larger as the magnetic field strength generated by the Tx coil become stronger and the size of the non-magnetic metal passing through the head becomes larger and the magnetic field frequency becomes higher.

Since the metal detector detects the size of these imbalances, smaller metal contaminants are harder to detect because they cause smaller imbalances.

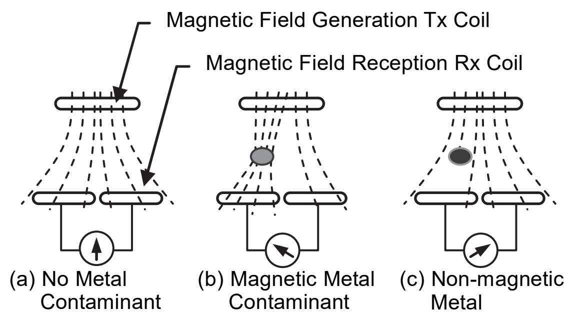

Figure 4 Magnetic and Non-Magnetic Metals in AC Magnetic Field

2.2.2 Characteristics of Metals in Inspected Products

Since inspected products, such as foods, include a variety of components such as iron, salt, water, etc., the inspected product itself has an effect on the metal detector sensor magnetic fields. Moreover, food packagings using evaporated-aluminum wrappings have a large effect on the magnetic fields even when there is no actual foreign metal contaminant. Normally, a high magnetic frequency is set to detect non-magnetic metals with high sensitivity, but this increases the adverse impact of food components and wrapping materials on the inspected product magnetic field. As a result, it is better to set a low magnetic frequency, which also reduces the metal detector relative detection sensitivity.

2.2.3 Detection using Two Magnetic Field Frequencies

As a countermeasure to inspected food products with a large product effect due to food components and wrappings, there is a method (Figure 5) using two magnetic field frequencies each with a different effect. Using this method, one Tx generates two magnetic field frequencies one of which is a high frequency for detecting magnetic metals, and the other of which is a low frequency for detecting non-magnetic metals. Consequently the imbalance in the magnetic flux captured by the Rx coils can be used to evaluate the presence of separate metal contaminants discriminated by a magnetic metal detection circuit and a non-magnetic metal detection circuit.

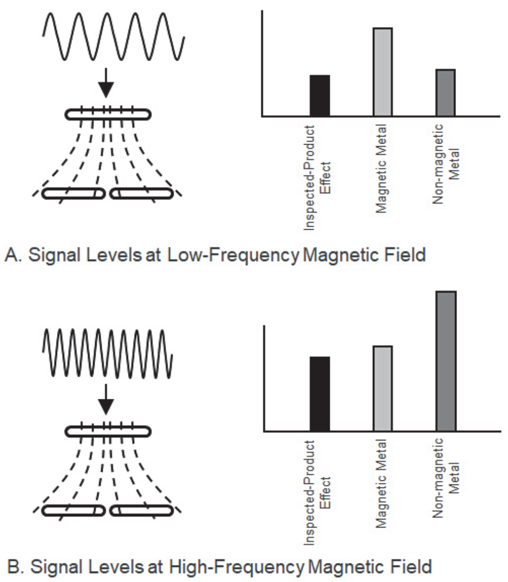

Figure 5 Relationship between Magnetic Frequency and Signal Level

3 Development Concept and Implementation

3.1 M6-h Series Concept

We developed the M6-h Series Metal Detector to solve the following three important issues for the foodstuffs market.

(1) High Sensitivity
- Implement higher sensitivity metal detection without complex operation

(2) High Stability
- Strengthen resistance to environmental noise
- Shorten warm-up time and stabilize temperature

(3) Easy Operation
- Support HACCP-compliant operation
- Simplify production-line integration and maintenance

3.1.1 Implementing High Sensitivity

(1) Redesigning High-Sensitivity Rx Section

As shown in Figure 6(a), previous metal detectors performed Analog/Digital (A/D) conversion after decoding the differential output from the two Rx coils. As a result, the captured digital signal contained less information, preventing improvement by signal processing. However, as shown in Figure 6(b), the M6-h Series performs A/D conversion on the differential output from the Rx coils at an earlier stage and is constructed with a digital decoding circuit. As a result, various signal processings (algorithms) can be performed on larger data volumes to separate the contaminant signal from the product-effect signal.

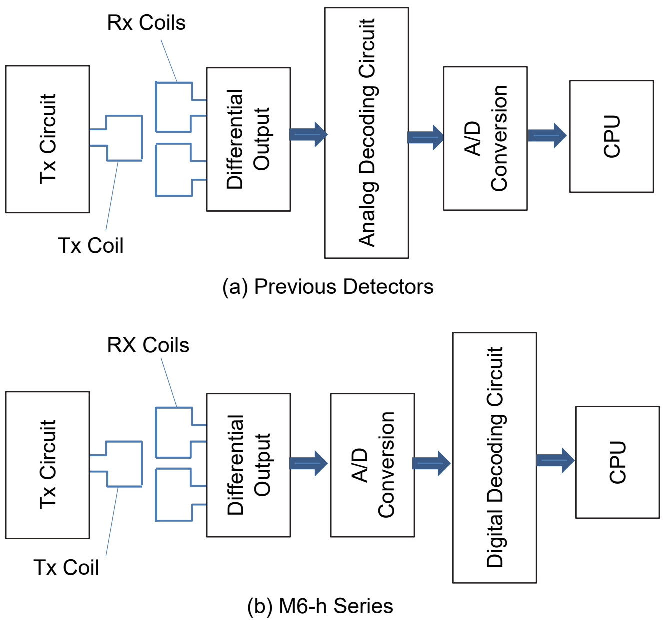

Figure 6 Metal Detector Sensor Circuit

(2) Simultaneous Dual-Frequency Magnetic Field Detection

Using a time-sharing system for generating two magnetic field frequencies alternately, when the inspected- product conveyance speed is high, there may be problems with out-of-sequence detection data. Consequently, the M6-h Series uses Anritsu-patented technology developed for the previous Mepoli III series with simultaneous dual-frequency magnetic field detection and signal processing to prevent loss of detection results.

(3) New Algorithm to Reduce Inspected-Product Effect

We used big data collected from previous metal detector deliveries to statistically analyze the impact of items such as size of the sensor head opening, impact of product effect, and impact of contaminant effect on metal detection. As a result, we were able to establish a method for separating the product-effect and contaminant signals. We developed a new algorithm for separating the product effect (N) from the received signal to lower its impact when extracting the metal-contaminant effect (S) and applied this new method to the M6-h Series. This new algorithm can detect smaller metal contaminants by increasing the relative S/N (Figure 7). It is especially effective when inspecting products with high salt and water contents, such as processed meats and prepared meals, as well as inspected products with a large product effect, such as evaporated-aluminum wrapped products.

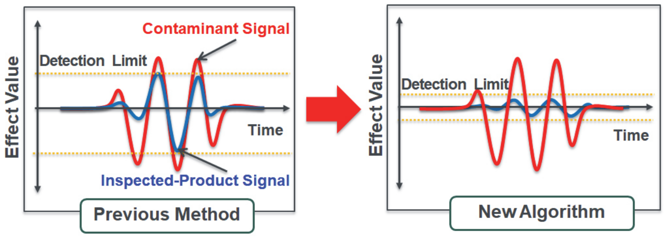

Figure 7 Concept of new algorithm

(4) Metal Contaminant Detection using Multi-signal Processing

Previous metal detectors used the simultaneous dual-frequency magnetic field detection method and dual-signal processing of the magnetic and non-magnetic metal signals described above to detect contaminants in products with a large product effect. The M6-h Series performs a different processing on a total of four signals obtained using the previously described new algorithm. This multi-detection (Figure 8) based on more characteristics supports wider metal contaminant inspection.

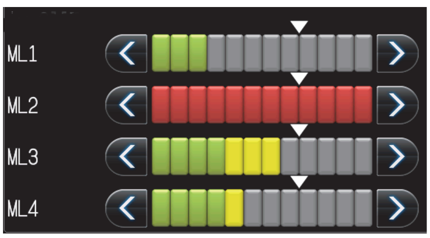

Figure 8 Multi-limit Metal Contaminant Detection

(5) Simple and Fast Auto-setting

The auto-setting function of previous metal detectors automatically sets the frequency and phase to improve the detection sensitivity matching the inspected product. In addition, in the M6-h Series, a new algorithm matching the expected product has been chosen by adding analysis procedures matching product features (Figure 9). The M6-h Series auto-setting function automatically selects the best settings using a combination of phase, frequency and algorithm values for 10,000 or more passes of the inspected product simply by passing the inspected product through the sensor head in accordance with screen navigation displays. As a result, almost anyone can easily make high-sensitivity settings.

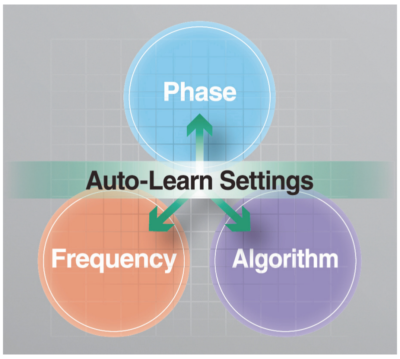

Figure 9 Auto-Setting Configuration Components

3.1.2 Implementing High Stability

(1) Strengthened Noise Tolerance using Digital Circuits

Metal detectors can suffer misdetection errors due to the effects of interference signals (including harmonic frequencies) radiated from equipment using inverters, heavy-current machinery with large motors switching on and off, fluorescent tubes approaching the end of life, etc. Since many of these facilities are used on food-production lines, the effect of noise can cause problems with evaluation of passing products as NG products.

The signal output from the metal detector sensor is easily affected by very small noise. However, the M6-h Series has been developed with better noise tolerance using high-sensitivity Rx circuits described in section 3.1.1. As a result, it supports stable operation on food-production lines.

(2) Temperature Stabilization using Power-Saving Circuit Design

The power consumption of the M6-h Series of metal detectors has been reduced by 20% compared to previous models by using parts selection and optimized circuit design for printed circuit boards built into the metal detector sensor. Consequently, the internal temperature of the metal detector sensor has also been reduced by 20% compared to previous models.

Moreover, re-examination of the circuit configurations to strengthen resistance to temperature change has improved warm-up times from 60 minutes for earlier models to 10 minutes for the M6-h Series, resulting in large cuts in dead time when starting the production line.

3.1.3 Implementing Simple Operation

(1) HACCP Support using Smart Guide

A navigation function called Smart Guide (Figure 10) has been added to support rejection of metal-contaminated products as required by HACCP. The Smart Guide provides operational guidance from the beginning to end of work to prevent production without confirmation of normal operating conditions. The operator simply follows messages displayed in orange at the right side of the screen, making it easy for almost anybody to operate the metal detector correctly and assure production with constant quality irrespective of who is running the operation. Moreover, since daily operation reports are stored automatically in the metal detector built-in memory, the risk of lost records is prevented. Daily reports can also be transferred over a network and saved to USB memory. There are plans to improve usability by using barcodes to record changes in products and operators.

Figure 10 Smart Guide Help

(2) Line Integration using Variable-Speed Function

Metal detectors are installed in production plants with a variety of usage conditions and there is no standard specification. Belt conveyor speeds vary considerably depending on the plant equipment and production lines. Plants using multiple production lines may want to change conveyor speeds. Like earlier models, the M6-h Series has a built-in variable speed function and the belt speed can be changed in the ranges from 5 to 90 m/minute or 5 to 73 m/minute using the operation panel.

(3) Easy Maintenance

The belt conveyors on production lines handling unpackaged foods must be cleaned daily to prevent bacterial contamination, which requires removal of the belts to clean inside surfaces. As a result, line operators require a structure making it easy to remove and fit belts. In particular, refitting belts after washing requires adjustment to prevent belt wander. This adjustment requires both skill and time. Incorrect adjustment can result in belts touching the conveyor sides, causing wear and damage.

Like earlier models, the M6-h Series uses direct-driven belt conveyors allowing one-touch removal of the driven rollers and motor to simplify belt conveyor disassembly and assembly. Use of v-guide belts and automatic tensioning function assure a fixed belt tension, eliminating the need for belt wander adjustment. As a result, the cleaning time is shortened and the risk of worn belts is reduced (Figure 11).

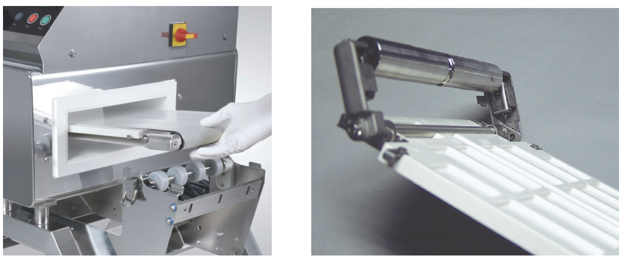

Figure 11 One-Touch Easy Disassembly/Assembly Maintenance

4 Detection Sensitivity Test

High-sensitivity detection of foreign metal contaminants in inspected products is the key function of a metal detector. Table 1 lists the test-piece data comparison between the previous Super Mepoli IIIS metal detector and the M6-h Series. Under the same comparison conditions with a 300-mm wide sensor opening and a 75-mm wide pass height, when detecting the same inspected products, the M6-h Series has much higher sensitivity and can detect 1 to 2 times smaller test pieces than its predecessor.

Table 1 Sensitivity Calibration Data

Inspected Product	M6-h (KDS3008ABW)		Previous KDS8113BW	
	Fe Sphere	SUS304 Sphere	Fe Sphere	SUS304 Sphere
Evaporated Aluminum Wrapped Candies	φ0.8	φ2.8	φ1.5	φ3.5
Ham	φ0.8	φ1.7	φ1.0	φ2.0
Rice Crackers	φ0.6	φ0.8	φ0.7	φ1.0
Bread	φ0.7	φ1.7	φ1.5	φ2.4

5 Conclusion

We have developed the M6-h Series Metal Detector based on the concept of "easy-to-operate, high-sensitivity and high-stability detection by anyone" by implementing simultaneous dual-frequency magnetic field detection, high-sensitivity Rx circuits, and new auto-setting software with an exceptional new algorithm. In addition, various ease-of-use improvements and simple operability have been achieved by adding a new Smart Guide along with variable-speed and easy maintenance functions. The main specifications of the M6-h Series are listed in Table 2. Additionally, we have also developed vertical models with a high bin, as well as combination-type detectors with a built-in checkweigher.

For the future, we continue to develop high-sensitivity and high-stability metal detectors and sensors for various applications to help play a role is securing safe and stable foods.

References

1) Shigeru Kubotera et al., "KD8013/15/16 A/AW Metal Detector", Anritsu Technical Bulletin No.78 (1999) (in Japanese)

2) Shigeru Kubotera et al., "Development of High-sensitivity duw and M Series Metal Detectors", Anritsu Technical Bulletin No.85 (2007) (in Japanese)

3) Takashi Kanai, "Principle and Use of Inspection Systems for Food Contaminants", Anritsu Technical Review No.22 (2014)

Authors

Hidekazu Kitajima
3rd Development Dept.
Development Division
Anritsu Infivis Co., Ltd.

Yuki Hayakawa
3rd Development Dept.
Development Division
Anritsu Infivis Co., Ltd.

Satoshi Yamashita
3rd Development Dept.
Development Division
Anritsu Infivis Co., Ltd.

Eiji Taniguchi
Common Technology Development Dept.
Development Division
Anritsu Infivis Co., Ltd.

Tomohiko Yamaguchi
Advanced Technology Development Dept.
Development Division
Anritsu Infivis Co., Ltd.

Natsuko Oishi
Sales Promotion Sec.
Marketing Division
Anritsu Infivis Co., Ltd.

Table 2 Main Specifications of M6-h Series Metal Detector

Model			KDS2105ABF/W	KDS2108ABF/W	KDS2110ABF/W
Maximum pass width			210 mm		
Belt width			160 / 140 mm		
Belt speed			5 to 90 m/min variable speed		
Detection sensitivity	Pass height		50 / 45 mm	80 / 75 mm	100 / 95 mm
	Φ Sphere	Fe	φ0.25 mm	φ0.3 mm	φ0.35 mm
		SUS304	φ0.6 mm	φ0.6 mm	φ0.7 mm
Metal detection			Rejection, or belt stop and beep		
Protection class			IP30 / IP66		
Power requirements			100 to 240 Vac+10%−15%, single phase, 50 / 60 Hz, 200 VA, rush current 50 A(typ) (20 ms or less)		
Mass			90 / 92 kg	90 / 92 kg	91 / 93 kg
Machine length			800 mm		

Model			KDS3005ABF/W	KDS3008ABF/W	KDS3010ABF/W	KDS3012ABF/W	KDS3015ABF/W	KDS3018ABF/W
Maximum pass width			300 mm					
Belt width			250 / 230 mm					
Belt speed			5 to 90 m/min variable speed					
Detection sensitivity	Pass height		50 / 45 mm	80 / 75 mm	100 / 95 mm	120 / 115 mm	150 / 145 mm	180 / 175 mm
	Φ Sphere	Fe	φ0.3 mm	φ0.3 mm	φ0.35 mm	φ0.4 mm	φ0.4 mm	φ0.45 mm
		SUS304	φ0.6 mm	φ0.6 mm	φ0.7 mm	φ0.7 mm	φ0.8 mm	φ0.85 mm
Metal detection			Rejection, or belt stop and beep					
Protection class			IP30 / IP66					
Power requirements			100 to 240 Vac+10%−15%, single phase, 50 / 60 Hz, 200 VA, rush current 50 A(typ) (20 ms or less)					
Mass			94 / 97 kg	94 / 97 kg	96 / 99 kg	97 / 100 kg	98 / 101 kg	100 / 103 kg
Machine length			800 mm					

Model			KDS4505ABF/W	KDS4510ABF/W	KDS4513ABF/W	KDS4515ABF/W	KDS4518ABF/W
Maximum pass width			450 mm				
Belt width			350 mm				
Belt speed			5 to 73 m/min variable speed				
Detection sensitivity	Pass height		50 / 45 mm	100 / 95 mm	130 / 125 mm	150 / 145 mm	180 / 175 mm
	Φ Sphere	Fe	φ0.35 mm	φ0.4 mm	φ0.45 mm	φ0.5 mm	φ0.5 mm
		SUS304	φ0.75 mm	φ0.85 mm	φ0.9 mm	φ0.9 mm	φ1.0 mm
Metal detection			Rejection, or belt stop and beep				
Protection class			IP30 / IP66				
Power requirements			100 to 240 Vac+10%−15%, single phase, 50 / 60 Hz, 200 VA, rush current 50 A(typ) (20 ms or less)				
Mass			103 / 108 kg	105 / 110 kg	108 / 113 kg	109 / 114 kg	114 / 119 kg
Machine length			800 mm				