Detection of Contaminants in Food and Drug by High Sensitive SQUID Magnetometer

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Abstract

There is a chance of individuals ingesting contaminants, which have been accidentally mixed with food, because processed foodstuffs have become very common. Therefore a detection method of small contaminants in food and pharmaceutical medicines is required. High-Tc SQUID detection systems for a metallic contaminant in foodstuffs and drugs are developed for safety. We developed two systems; one large system is for meat blocks and the other small system is for powdered drugs or packaged foodstuffs. The both systems consist of SQUID magnetometers, a permanent magnet for magnetization and a belt conveyer. All the samples were magnetized before measurements and measured by high Tc SQUIDs. As a result, we successfully measured small syringe needles with length of 2mm in a meat block and a stainless steel ball as small as 0.3mm in diameter.

Keywords: SQUID, Food safety, contaminant, detection, inspection

1 INTRODUCTION

Recently, opportunities to eat processed foodstuffs are increasing in our daily life. Therefore there is a chance to eat unfavorable contaminants, which are accidentally mixed with food. For example, they are small chips of processing machines and also broken syringe needles used for immunization shot or hormone injections. According to the increase of international concern regarding food safety, we should develop a high sensitive detector to ensure the safety. Although an iron particle detection system has been already developed, there is a few reports for food contaminants and no system for factory use [1-3]. Our target is fabrication of detection system for factory use. Since the electric conductivity of the austenitic stainless steel is low, it is difficult to detect it using a conventional eddy current method. An austenitic stainless steel material is originally non-magnetic. However it shows properties like a ferromagnetic material after martensitic transformation during its manufacturing process. Therefore it is possible to detect it by SQUID magnetometer [4-8].

In this paper, we describe the system for small stainless steel contaminants in foodstuffs or pharmaceutical drugs by using high-Tc SQUID magnetometer.

2 PRINCIPLES

The block diagram of the detection system is shown in Fig.1. It consists of a permanent magnet, a conveyer, a magnetically shielded box and SQUIDs. All of the sample moves from left to right and passes under the magnet tunnel before the detection. An austenitic stainless steel material is originally non-magnetic. However it shows properties like a ferromagnetic material after martensitic transformation by work hardening during its manufacturing process [9]. Therefore the magnetization prior to the detection is effective also for austenitic stainless steel contaminants. The magnetic field from a metallic contaminant in food is detected by the SQUID magnetometers when it passes under the magnetometer.

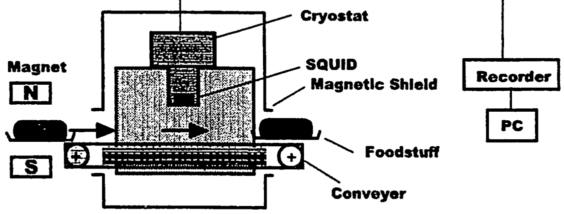

Fig. 1. Block diagram of food contaminant detection system. It consists of a permanent magnet, a conveyer, a magnetically shielded box and SQUIDs.

3 DETECTION SYSTEM FOR MEAT BLOCK

3.1 System design

The target detected by the system is piece of stainless steal syringe needle ϕ0.9mm x 2mm L. The size of the meat block which is currently processed at a factory in Japan is 640L x 400W x 200H. Thus we decided the size of the conveyer to meet its size. It is fairly large and 500mm in width. The conveyer speed is also determined by the real speed in a factory and is 15 m per minute.

Firstly, we calculated the distribution of the sensitivity of a SQUID sensor to know the best configuration of the sensors to cover the width of the conveyer. As shown in Fig.2, we supposed a magnetic dipole and simulated the magnetic field of z-axis $\mathbf{H_z}$ at the position of the sensor. The simulated results are shown in Fig.3. This shows that if three SQUIDs are positioned with separation of 170 mm, you can keep the sensitivity at least more than 60% of maximum value in any place on the conveyer with width of 500mm. Therefore, we determined that three SQUIDs are needed for this system. The SQUID and its driving electronics we employed here are Sumitomo Electric Hightechs made. The size of the pickup loop is 10mm x 10 mm square and high Tc direct coupled type. The sensitivity of the SQUID is nominally 300 $fT/Hz^{1/2}$ at 10 Hz. The SQUID driving electronics is non-modulation type and its bandwidth is 300 kHz. The detail of the specification is shown in the web [10].

Figure 4 shows the design drawing of the whole system. The size is 3305L x 1290W x 1610H. The magnet is made of Nd base alloy and its magnetic field is 0.2 T. The LN_2 cryostat to keep the temperature of the SQUIDs at 77K is made of G-10 glass epoxy resin and its size is 620W x 200D x 312H. The volume of the cryostat is 7 litters and the liquid nitrogen can be kept for 7 hrs without filling. The magnetic shield covering the cryostat consists of two layers of permalloy with thickness of 1mm. Most of the frame was made of stainless steal sus304. Although the rollers were originally made of steal, they were replaced with the aluminum alloy to prevent from magnetic noise. The system was totally controlled by a PC and you can operate the system by touching the display panel in front of the system. All the electronics and the vacuum pump for evacuation of the cryostat were installed underneath the magnetic shield. The signal was passed through a low-pass filter (LPF) at a frequency of 5 Hz or 10 Hz.

$$H_1 = q_m / 4\pi\mu_0 r_1^2$$
$$H_2 = -q_m / 4\pi\mu_0 r_1^2$$
$$r_1 = (r-(L/2))/\cos\theta_1$$
$$r_2 = (r+(L/2))/\cos\theta_2$$
$$\theta_1 = \mathrm{Tan}^{-1}[X/(r-(L/2))]$$
$$\theta_2 = \mathrm{Tan}^{-1}[X/(r+(L/2))]$$
$$H_Z = H_1\cos\theta_1 + H_2\cos\theta_2$$

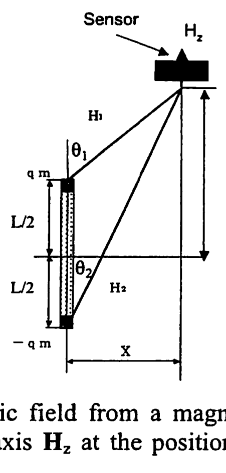

Fig. 2. Calculation of magnetic field from a magnetic dipole. Magnetic field of z-axis $\mathbf{H_z}$ at the position of the sensor was calculated.

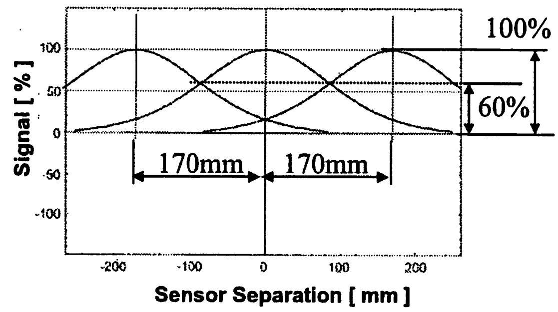

Fig.3. Distribution of SQUID sensitivity. Sensitivity more than 60% of maximum value can be obtained in any place on the conveyer with 500mm width if three SQUIDs are employed.

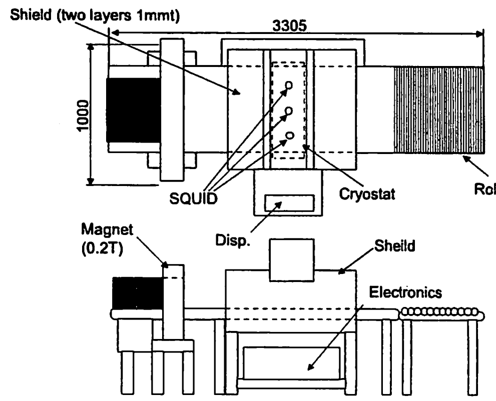

Fig. 4. Design drawing of the large system for meat block. The size is 3305L x 1290W x 1610H.

3.2 Performances

we have measured the magnetic field noise of the system without filter. The signal of the SQUID was measured by dynamic signal analyzer Agilent Technologies 35670A. The noise spectra are shown in Fig. 5. Several peaks around 1 to 5 Hz are due to the environmental noise at the laboratory. It may come from a voltage stabilizer in the power system. The peak at 60 Hz is from the appliance frequency. The magnetic field noise level at 10 Hz is 300-400 $fT/Hz^{1/2}$.

For the performance test, a cut stainless steal syringe needle with dimension of ϕ0.9 x 2mm as a test piece was put vertically on the conveyer. The distance between the test piece and the SQUID sensor was set at 200 mm. The sample was moved by the conveyer with speed of 15 m/min. It was magnetized by the magnet when it passed thorough the magnet tunnel. And then it was measured when it passed under the SQUID. The time trace of the signal is shown in Fig. 6. One peak as large as 150 pT can be seen in the middle of the trace. This peak is corresponding to the test piece. We could successfully measure the piece of needle as small as 2mm with distance of 200mm.

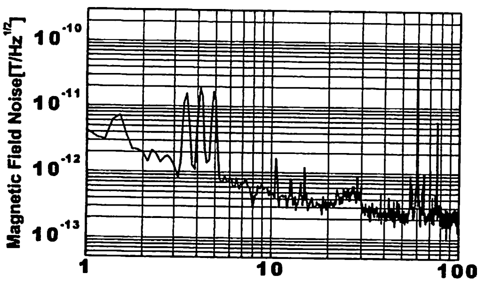

Fig. 5. Noise spectra of the system. Several peaks around 3 to 5 Hz are due to the environmental noise at the laboratory. The peak at 60Hz is from the appliance frequency. The noise at 10 Hz is 300-400 $fT/Hz^{1/2}$.

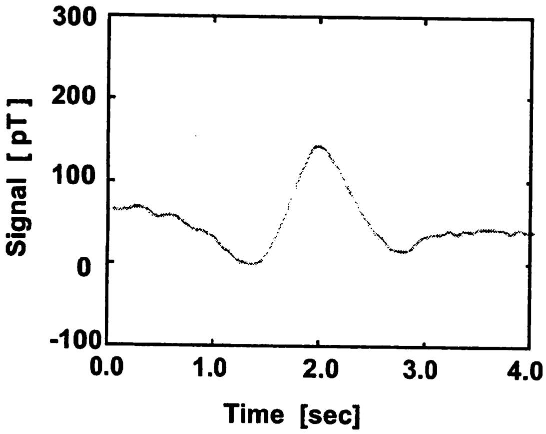

Fig.6. Time trace of the detected signal. A cut stainless steal syringe needle with dimension of ϕ0.9 x 2mm was measured. The distance between the test piece and the SQUID sensor was set at 200 mm.

4 DETECTION SYSTEM FOR DRUG

4.1 System design

We also designed a smaller system, which detects contaminants in a drug or a small packaged food. The target to be detected is small stainless steal ball as small as 0.3mm in diameter. Since the expected dimension of the drug or the packaged food is 150W x 80H in maximum, the width of the belt conveyer was determined as 200mm and the height from the conveyer to the bottom of the cryostat was 80 mm. The conveyer speed is the same as the large system and is 15 m/minute. Following the same manner as our large system, we simulated the distribution of the sensing area of the SQUID. As a result, it was found that not one but three SQUIDs are needed with separation of 35mm because the sensing area becomes smaller as decrease of the distance.

4.2 Magnetic Shield Design

The magnetic shield is expensive and one of important components in the detection system because high sensitive magnetometers are used in a factory where environmental noise is considerably higher. Thus, before the design we performed the 2D simulation of magnetic field using four models as shown in Fig. 7. Simulation software *Maxwell* of Ansoft Corporation was used. Magnetic field of 50μT was applied from the Y-direction for each model and the field distribution inside was calculated by FEM. The thickness of the permalloy layer was 1mm. The summary of the simulation results is shown in Table 1. The most attenuated result could be obtained at the model (d). Thus we employed three layers with flange as a magnetic shield. Figure 8 depicts the design drawing of the small system we constructed. The size is 2500L x 235W x 800H. The magnet is made of Nd base alloy and its magnetic field is 0.1T, which is half an intensity of the large system. The LN_2 cryostat to keep the temperature of the SQUIDs at 77K is made of G-10 glass epoxy. The system was totally controlled by a PC. The electronic system is almost the same as the large system for meat as we described in the section 3.

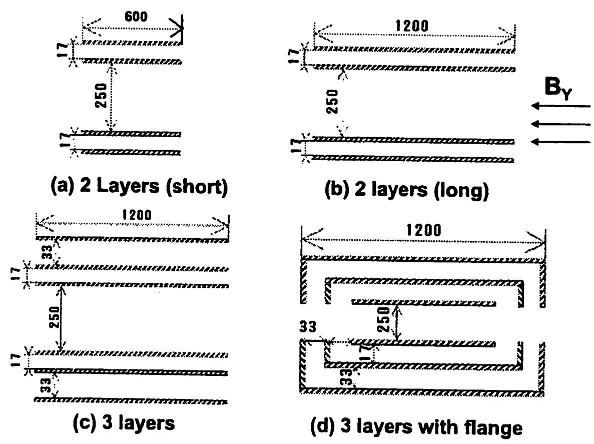

Fig.7. Simulation model of magnetic shield. Magnetic field of 50mT was applied from the Y-direction for each model and the field distribution inside was calculated by FEM.

Table 1.

Applied field: 50μT

Number of layer (Model No.)		Length [mm]	Flux density at Center [μT]	Attenuation [dB]
2	(a)	600	3.20	-23.9
2	(b)	1200	0.21	-47.5
3	(c)	1200	0.19	-48.6
3	(d)	1200 with flange	0.10	-53.8

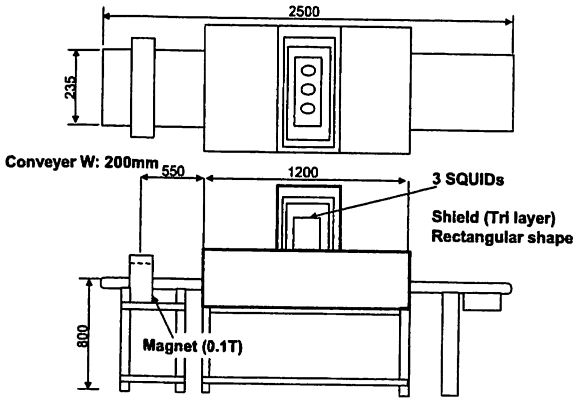

Fig. 8. Design drawing of the small system. The size is 2500L x 235W x 800H.

4.3 Performances

We prepared a sus304 stainless steal ball of ϕ0.3mm. It was magnetized by the permanent magnet and detected by the SQUIDs. The Distance dependence of the signal is shown in Fig. 9. It is demonstrated that the signal intensity is inversely proportional to the cubic of distance. The laboratory noise level is indicated at the same time for the comparison. Although the signal at the distance of 50 mm is six times larger than the noise level, the signal at 80mm is just 1.5 times larger than the noise. Therefore this system should be used within the distance of 50mm to obtain a better signal noise ratio.
Detection using a stainless steal ball in an aluminum bag was also performed. The result was the same as without the bag. It means that the aluminum bag is invisible for the SQUID.

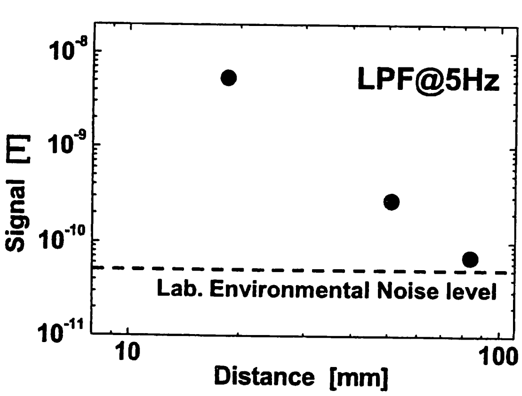

Fig. 9. Magnetic signal vs. distance. The signal intensity is inversely proportional to the cubic of distance.

5 SUMMARY

We have constructed and demonstrated two types of detection systems for metallic contaminants in a food or drug. One is for large meat block and the other is for a pharmaceutical drug or a small packaged food. Former system could successfully detect a stainless steel needle of ϕ0.9 x 2mm and latter system could detect a stainless steal ball as small as 0.3mm in diameter. These detectable levels are above the requirement at a factory.

ACKNOWLIDGMENT

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Biographies

Saburo Tanaka received his B.E. and M.E. from Toyohashi University of Technology in 1981, and 1983, respectively. He received his Doctoral Degree in engineering from Osaka University in 1991. Since 1987 he has been involved in the research of high temperature superconductors at Sumitomo Electric Itami Research Lab. He was engaged in the development of multi-channel high-Tc SQUID systems at the Superconducting sensor laboratory from 1991 to 1995. He was a visiti ng research associate at the Dept. of Physics, University of California at Berkeley from 1996 to 1997. Currently he is a professor at Toyohashi University of Technology. He is a member of the Japan Society of Applied Physics, the Institute of Electronics, Information and Communication Engineers, the Institute of Electrical Engineers of Japan, and the Institute of Electrostatics Japan.