Measurement of a metallic inclusion in food by high-Tc SQUID

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Abstract—**We have proposed and demonstrated a high-Tc SQUID detection system for a metallic inclusion in foodstuffs. There is a demand for development of detection system for not only a magnetic material but also non-magnetic material such as Cu or aluminum in foodstuffs to ensure food safety. The system consists of a SQUID magnetometer, an excitation coil and a permanent magnet. A metallic sample was slide in the existence of AC magnetic field after magnetized by a permanent magnet. For the non-magnetic sample signal from the SQUID was demodulated by a lock-in-amplifier and recorded. For the magnetic sample the direct output signal of the SQUID was recorded through the low pass filter to eliminate the AC field component. As a result, we could detect a stainless steel ball with diameter of 0.1mm and an Cu ball of less than 1 mm in diameter for example**

I. INTRODUCTION

Recently, opportunities to eat processed foodstuffs are increasing in our daily life. Therefore there is a chance that unfavorable inclusions 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, which are mostly metallic materials. According to the increase of international concern regarding food safety, we should develop a high sensitive detector to ensure the safety. It is difficult to detect all the materials by one detection system. However, if targets are limited to metallic inclusions, high-Tc SQUID is one candidate as a sensitive detector for inclusions in foodstuffs.

In this paper, we describe a detection system for a small metallic substance by using high-Tc SQUID magnetometer. Two methods are proposed: One is for a non-magnetic sample such as Cu or Silver. The other is for a sample with ferromagnetism. For a non-magnetic sample, an AC magnetic field is applied during detection. The SQUID signal is lock-in amplified and recorded. For a sample with ferromagnetism, a strong magnetic field is applied to the sample prior to detection. The signal is recorded through the low pass filter to eliminate the AC field component.

II. EXPERIMENTAL

A. SQUID

The SQUID is made of $Y_1Ba_2Cu_3O_{7-y}$ thin film [1-2]. The junctions utilized in the SQUID are of the step-edge type. The washer size of the SQUID is about 5.5 x 5.0 mm^2 and the effective area is about 0.1 mm^2. When the SQUID was operated in a flux-locked loop with a flux modulation frequency of 256 kHz, magnetic flux noise in the white noise region was about 20 $\mu\phi_0/Hz^{1/2}$.

B. System

The detection system was constructed in a magnetically shielded room at our laboratory. Figure 1 shows the schematic drawing of the detection system. The cryostat, which was specially designed for a SQUID microscope was employed. The SQUID was located inside a vacuum in face up and separated by a 200 μm thick sapphire window. A more detailed description can be found elsewhere [3]. A rectangular shape Helmholtz coil (1000Turns x 2, bore: 80x50mm) was located above the cryostat via an engineering plastic made robust table. A sample was slide on the surface of the rectangular coil tube with constant speed. In this condition the spacing between the sample and the SQUID was 10-40mm. A sinusoidal AC current with a frequency of 900Hz to 2kHz was directed to the coils; the peak to peak amplitude of magnetic field generated from the coil was 2.5 x 10^{-4} $T_{(peak-peak)}$. The modulated signal associated with the metallic sample was then demodulated by the lock-in-amplifier. The AC magnetic field was applied to the samples regardless of magnetic properties, such as non-magnetic or ferromagnetic. For a non-magnetic sample, the output signal from the lock-in amplifier was directed to the A/D converter of PC through a high pass filter with frequency of 0.1Hz to eliminate a dc offset. For a ferromagnetic sample, a modulation component of AC frequency was eliminated from SQUID output signals by low pass filter. We note that magnetic sample was magnetized by a 0.5 T permanent magnet prior to

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the measurement.

The z-component of the magnetic field at the center of the coils canceled each other in principle when there is no sample. Therefore the SQUID position was carefully adjusted before measurement, so that the SQUID output signal without sample became zero [4-5].

C. Samples

Copper small balls and austenitic stainless steel balls with different sizes were prepared as samples. The size range of the sample was from 0.1 to 1.5 mm in diameter. 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. Therefore the stainless steel ball sample can be magnetized. So the samples were magnetized for five sec by a strong permanent magnet (0.5T) before measurement. The magnetic field density was large enough to attract the samples.

III. RESULTS AND DISCUSSIONS

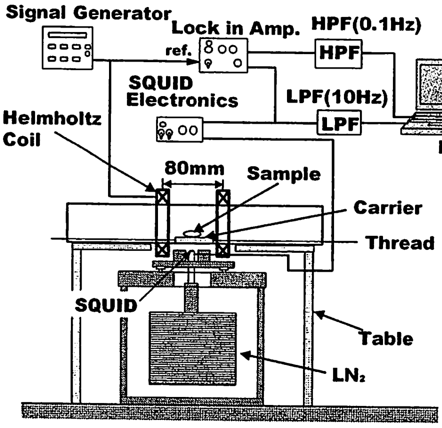

Fig. 1. Schematic drawing of the detection system. A rectangular shape Helmholtz coil was located above the cryostat via an engineering plastic made robust table. A sample was slide on the surface of rectangular coil tube with constant speed.

Firstly, we measured copper ball samples under the modulation scheme. The size dependence of the signal is shown in Fig. 2. At the distance of 15 mm, the detectable minimum size of the Cu ball was 1.0mm.

Secondly, Stainless steel ball was measured. After magnetization the sample was slide above the SQUID with distance of 30mm. A recorded raw data for 0.3 mm stainless steel ball is shown in Fig. 3. Peak of 0.9nT was observed. Even if the distance became wider to 40 mm, still substantial signal peak could be detected. The detectable minimum size was 0.1mm in diameter with distance of 10mm. This value is also the same as reported before [6]. We also successfully detected the sample in chicken meat.

IV. CONCLUSION

We have proposed and demonstrated a high-Tc SQUID detection system for a metallic inclusion in foodstuffs. It could successfully detect 0.1mm of stainless steel ball. For the detection of non-metallic substances, Cu ball of 1.0mm was detected. This value can be improved by increasing the frequency of the magnetic field.

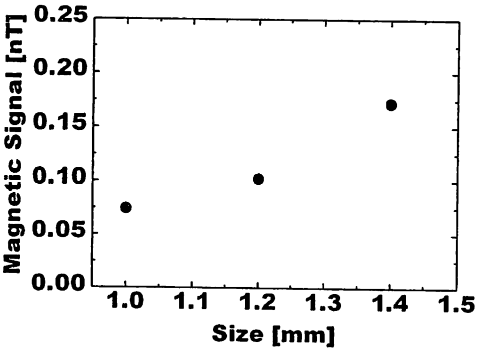

Fig. 2. The size dependence of the signal for Cu ball. At the distance of 15 mm, the detectable minimum size of the Cu ball was 1.0mm.

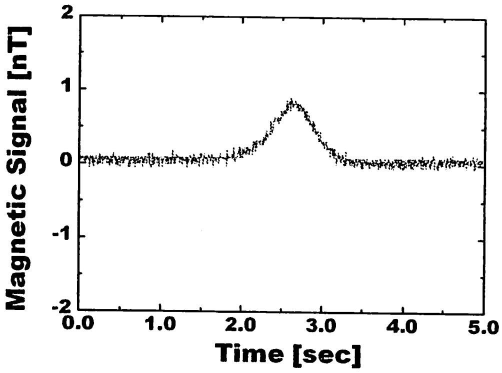

Fig. 3. A recorded raw data for 0.3 mm stainless steel ball with spacing of 30mm. Stainless steel ball sample was magnetized by a strong permanent magnet (0.5T) before measurement. Then the sample was

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