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Ultra-low field MRI food inspection system prototype

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ABSTRACT

We develop an ultra-low field (ULF) magnetic resonance imaging (MRI) system using a high-temperature superconducting quantum interference device (HTS-SQUID) for food inspection. A two-dimensional (2D)-MR image is reconstructed from the grid processing raw data using the 2D fast Fourier transform method. In a previous study, we combined an *LC* resonator with the ULF-MRI system to improve the detection area of the HTS-SQUID. The sensitivity was improved, but since the experiments were performed in a semi-open magnetically shielded room (MSR), external noise was a problem. In this study, we develop a compact magnetically shielded box (CMSB), which has a small open window for transfer of a pre-polarized sample. Experiments were performed in the CMSB and 2D-MR images were compared with images taken in the semi-open MSR. A clear image of a disk-shaped water sample is obtained, with an outer dimension closer to that of the real sample than in the image taken in the semi-open MSR. Furthermore, the 2D-MR image of a multiple cell water sample is clearly reconstructed. These results show the applicability of the ULF-MRI system in food inspection.

1. Introduction

In recent years, ultra-low field magnetic resonance imaging (ULF-MRI) has attracted attention because it is compact, easy to handle, and inexpensive. Conventionally, Faraday coils have been used for the detection of magnetic fields. However, the sensitivity decreases with decreasing magnetic resonance signal frequency. A high-temperature superconducting quantum interference device (HTS-SQUID) with frequency independence provides an alternative for constructing a high-sensitivity ULF-MRI system [1–8].

We develop a ULF-MRI system with HTS-SQUID for food inspection targeted at food which contains a lot of water [9,10]. However, the detection area of this device is not sufficient for food inspection and can be expanded using an *LC* resonator with the HTS-SQUID, as proposed by Qiu et al. [11]. In a previous study, we combined an *LC* resonator with the ULF-MRI system, and could expand the detection area and improve the sensitivity [12]. However, the influence of environmental magnetic noise became a problem because the system was located in a magnetically shielded room (MSR) with the door open. To overcome this problem, we develop a compact magnetically shielded box (CMSB), which has a small open window for transfer of a pre-polarized sample. In this study, we discuss the two-dimensional (2D)-MR images reconstructed from the grid processing raw data by the 2D fast Fourier transform method, which are taken in the CMSB.

2. Experimental setup and method

2.1. ULF-MRI system using HTS-SQUID

Fig. 1(a) and (b) show the schematic and the image of the ULF-MRI system, respectively. The system consists of the following ten units: an HTS-SQUID, an *LC* resonator, a CMSB, a cryostat, SQUID electronics, a measurement coil (B_m), three sets of gradient field coils (G_x, G_y, G_z), an AC pulse coil (B_{AC}), a permanent magnet (B_p) at 1.1 T, and a nuclear magnetic resonance (NMR) spectrometer Kea^2 (Magritek Ltd., New Zealand) [13]. A sample is pre-polarized by the permanent magnet located outside the CMSB. When a trigger signal is supplied from the main pulse generator, the pre-polarized sample is then transferred to the appropriate position under the SQUID by compressed air, and exposed to B_m of 93.7 µT from the measurement coil in the z direction. Subsequently, by applying a gradient field and an AC pulse field, an MR signal is detected by the *LC* resonator, and detected by the SQUID. Finally, the MR signal is acquired by the Kea^2.

2.2. Pulse sequence

The detailed pulse sequence used for the measurement is shown in Fig. 2. Firstly, the sample is pre-polarized using the B_p for more than 5 s. Then, the sample is positioned under the SQUID

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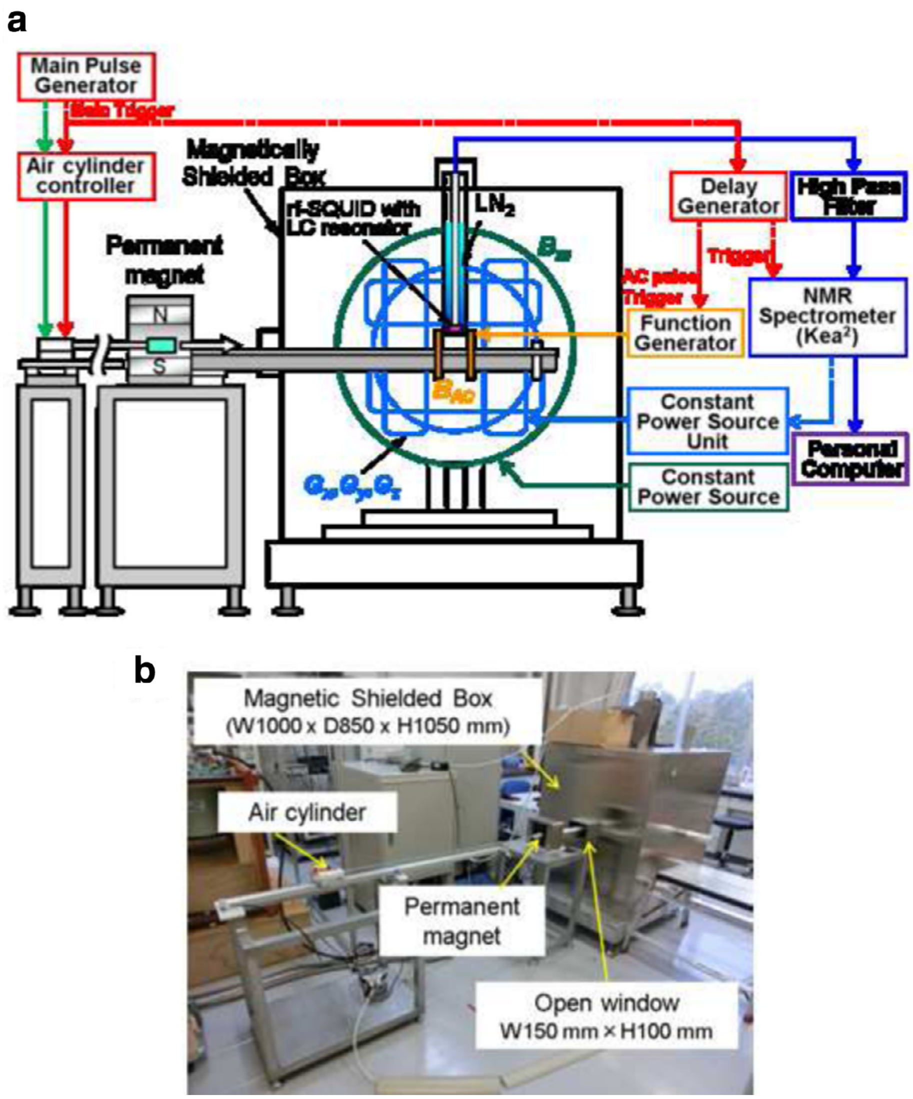

Fig. 1. The ultra-low field magnetic resonance imaging system using HTS-SQUID. (a) Schematic diagram of the system. (b) Appearance of the system.

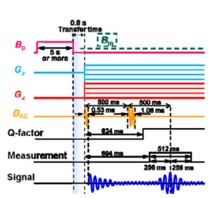

Fig. 2. Pulse sequence of measurement.

within about 0.8 s. After the transfer, the gradient coil and AC pulse coil apply a gradient field of 27.7 μT/m, the absolute value of the y and z components, and a 90° pulse field B_{AC}, respectively. The echo time (t_E) of the 90° and 180° pulses is 500 ms. After the 180° pulse, the *LC* resonator becomes high Q-factor state by turning on the control signal of TTL logic. The high level of TTL logic corresponds to the low level of FET input of the Q-switch. Information regarding the Q-switch is described elsewhere [12,14]. The sensitivity is improved and the detection area is enlarged at the resonant condition. Then, 512 points are acquired during an acquisition time (t_{acq}) of 512 ms. In this study, radial scanning with a spin echo technique is used. The number of projection angles is 24, because the gradient field directions are rotated for 7.5° step-by-step to cover 180°.

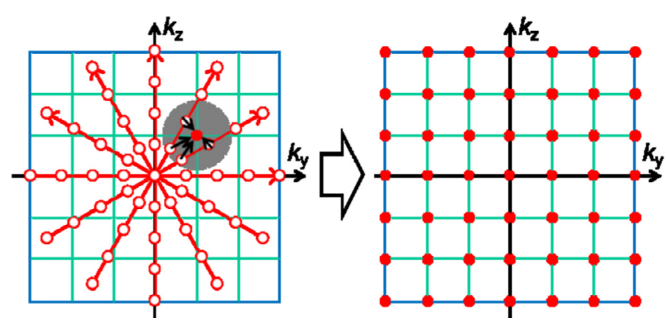

Fig. 3. Principle of gridding.

2.3. Data processing

The MR signal acquired by radial scanning was processed by decimation and filtering to reduce the noise. Data processing was combined with a gridding process using the software "MATLAB". This gridding process involves locating the data on the grid from the data in the vicinity of the measurement space (k-space), as shown in Fig. 3. The number of data acquired by Kea^2 was reduced to 52 points by using decimation. We set the total number of data

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