# Mobile high-$T_c$ dc SQUID magnetometer

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**Abstract**

By optimizing the designing, we made a small size and low noise high-$T_c$ dc SQUID readout electronics with the modulation freqency of 80 kHz. The white flux noise was about 30 $\mu\Phi_0/\sqrt{Hz}$ when Sumitomo high-$T_c$ dc SQUID sensor was used. We also proved mobile high-$T_c$ dc SQUID magnetometer was feasible. By using a special compensation method, the SQUID magnetometer could keep locking when it swung about 20 degree in the earth field. Using this system and eddy-current NDE method, we successfully detected the defect in ferromagnetic material.

*Key words:* SQUID; mobile; eddy-current; NDE

## 1. Introduction

In SQUID-based eddy-current NDE, for the object made of ferromagnetic material or the object with big size, the SQUID system with large dynamic range, which can move in the earth field, is necessary. Planar SQUID gradiometer is a way to solve this problem [1], but its small baseline limits its applications. M.v.Kreutzbruck, A.Theiss et al. developed a background field compensation scheme [2]. If the dc field approaches the saturation value of the sensor, a low-pass-filtered counter field controlled by an 8-bit counter is applied to compensate the slowly varying (below 30 Hz) background field, thus enhancing the dynamic range at low frequency. We think this system is too complex, which includes so many parts: low-pass filter, comparator, impulse shaper, counter, DAC, amplifier. We developed a very simple background field compensation scheme. The compensation circuit was very small and could be put into the box of dc SQUID readout electronics designed by us. The dynamic range of 100 $\mu$T at low frequency (below 20 Hz) could be easily achieved and the flux noise at higher frequency was not increased.

## 2. The operation of mobile dc SQUID magnetometer

Fig.1 shows the schematic block of our compensation system. The compensation coil is 50 turns wound outside of the cryostat. Increasing the turns of the compensation coil can easily increase the dynamic range of low frequency field compensation. In our case, the dynamic range for low frequency magnetic field is about 100 $\mu$T, which is enough to keep the SQUID locking when it moves in the earth field.

The high-$T_c$ YBCO dc SQUID magnetometer was from Sumitomo Electric Hightecs co. Ltd. [3] and the effective area of SQUID was about 0.2 $mm^2$. We made the readout electronics by ourselves with the modulation frequency of 80 kHz. The box size of the readout electronics was about $13 \times 9 \times 3$ $cm^3$ and the compensation circuit could also be put in the box. Using our readout electronics, the white flux noise, measured in a simple shielding, was about 30 $\mu\Phi_0/\sqrt{Hz}$ with the 1/f

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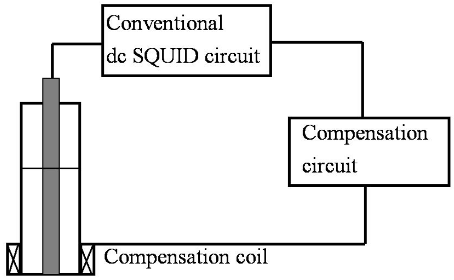


Fig. 1. The schematic diagram of the mobile dc SQUID magnetometer.

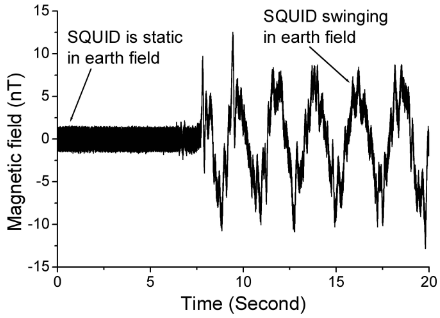


Fig. 2. The output signal of mobile dc SQUID when it was static and swung in the earth field.

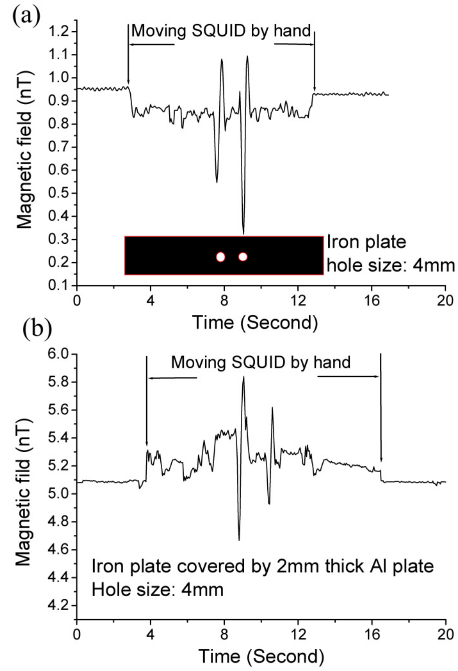


Fig. 3. The signal of artificial hole defect in iron plate measured by mobile dc SQUID moved by hand. (a) the signal of defect when the iron plate was not covered by any other things. (b) the signal of defect when the iron plate was covered by a 2mm thick aluminum plate.

corner frequency lower than 10 Hz. We measured the flux noise spectrum in unshielded environment with and without compensation. The result proved that the flux noise at higher frequency (above 30Hz) was not increased when the compensation was used. Fig.2 shows the SQUID output signal when the SQUID was static and swung about 20 degrees in the earth field. We could see the SQUID could keep locking and the earth magnetic field was dramatically compensated.

## 3. Eddy-current NDE experiments

To do eddy-current NDE experiment, a 5 mm double-D coil was attached on the bottom of the cryostat to produce the excitation field. The frequency of the excitation field is 340 Hz. Using this system; we measured the defect in ferromagnetic material. The defect was 4 mm artificial holes made on an iron plate. When the iron plate moved under the SQUID, it produced magnetic field of about 30 $\mu$T. The dc SQUID without compensation could not keep locking when scanning over it. Using the mobile dc SQUID magnetometer, we could successfully detect the defect with the squid moved by hand. Fig.3 shows the results.

In addition to the application of NDE, the mobile SQUID magnetometer can find many other applications by mounting it in airplane or boat.

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