Evaluation of Noise Reduction Techniques for a SQUID Magnetometer using a Joule-Thomson Cryocooler

Chethasi Kaluarachchi [ab] and Gerard J.J.B. de Groot [a]

[a] *CSIRO Materials Science and Engineering, Lindfield, NSW 2070, Australia.*
[b] *University of Technology, Sydney, NSW 2007, Australia.*

Superconducting quantum interference devices (SQUIDs) can be successfully utilized in the detection of small metal contaminants in food with the use of cryogenic fluids; however when using a Cryotiger® cryocooler, the detection capability deteriorates due to vibration-induced magnetic noise. In order to ensure our cryocooled system is more comparable to liquid nitrogen cooling, we have compared peak frequencies to resonant frequencies within the cold end of the cryocooler and evaluated noise reduction techniques such as magnetic shielding and anti-vibration techniques (AV) such as clamping cryocooler gas lines and spring supports for gas lines. We conclude that the noise level of the SQUID magnetometer can be significantly reduced using a combination of three layers of mu-metal shielding and clamping the cryocooler gas lines. We have also successfully identified some resonant frequencies previously simulated.

1. Introduction

High Temperature Superconducting (HTS) SQUIDs have been successfully used in the detection of small metal contaminants in food with the use of liquid nitrogen [1]; however in order for a SQUID system to be accepted in the food processing industry, the system must be cooled with a cryocooler. This eliminates the hazard of handling and maintenance of cryogenic fluids

The spurious magnetic signals that degrade the performance of a cryocooled SQUID sensor are due to two issues: movement of the SQUID in the residual magnetic field and movement of the magnetised components in the cold end of the cryocooler [1]. While using the Cryotiger® cryocooler, magnetic signals associated with movement of the mechanical components, such as the compressor, heat exchanger and gas lines have been shown to cause spurious magnetic signals that cause false responses and deteriorate the performance of the SQUID [2]. In earlier work [3] we determined the resonant frequencies of the cold end of the cryocooler using Finite Element Analysis (FEA) simulations and experiments with a Laser Vibrometer and a Fluxgate Magnetometer. We also proposed anti-vibration measures to reduce the movement of the SQUID to reduce the spurious magnetic signals.

This report aims to show that the sources of SQUID noise signals, when operating the cryocooler, are related to the movement of the cooler's cold end. Identification of problem components allows us to trial methods of remediation by either changing the cold end component's resonant frequencies or by damping the vibration of these components. We will show that the anti-vibration measures make a considerable improvement to the SQUID noise.

2. Experimental Setup

The SQUID magnetometer was operated over the temperature range 69 K to 71 K with 69 K the lowest attainable temperature for the cryocooler. Over this range there was not a significant fluctuation in SQUID sensitivity.

To reduce ambient noise and interference, the cryocooled SQUID magnetometer was placed in a T-shaped shield that contained three layers of mu-metal shielding. This T-shaped conveyer belt system was previously used with a liquid-nitrogen cooled SQUID [1]. For a conveyer belt speed up to a maximum of 1 m/s, the measurement bandwidth of the conveyer belt system is 1 to 30 Hz.

The two noise reduction techniques evaluated were the clamping of cryocooler gas lines to the sand-filled box and the addition of spring supports to this box, see (Fig 1).

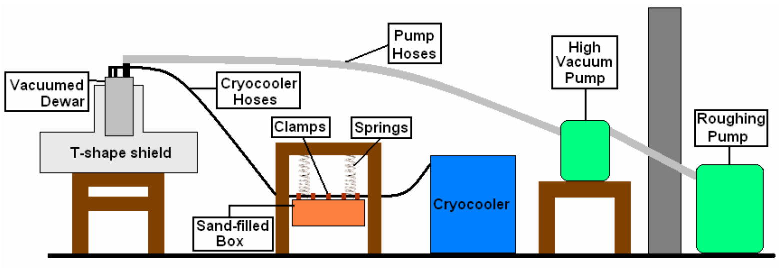

Fig 1. Setup of cryocooled SQUID in the three layered T-shape mu-metal shield, with anti-vibration methods.

3. Resonant Frequencies

Table 1 shows the association between signal peaks observed in our SQUID magnetometer and various components in the cryocooler. The component resonant frequencies were found from data obtained from Laser Vibrometer and Fluxgate Magnetometer experiments, and finite element analysis (FEA) [3]. The SQUID, Vibrometer and Fluxgate measurements all have a resolution of 0.1 Hz. The FEA measurements have an error margin of ±1.5 Hz.

Table 1. Correlated peak frequencies from SQUID data, Laser Vibrometer, Fluxgate Magnetometer and FEA resonant frequencies and their possible causes (modes)

SQUID (Hz)	FEA (Hz) [3]	Laser Vibrometer (Hz) [3]	Fluxgate Magnetometer (Hz) [3]	Cause of Magnetic Interference
15.8	16.5	15.3	15.3, 16.1	Outer part of heat exchanger swinging
22.4	21.4, 21.5	22.6	22.6	Inner part of heat exchanger swinging
24.9	-	-	-	Suspected resonance of the building driven by mains sub-harmonics
26.2	26	-	-	Uncoiling in the base of the outer part of the heat exchanger
29.8	-	31.2	31.3	-
32.9	-	-	-	Suspected resonance of the building driven by mains sub-harmonics
49.1	48	48.6	-	Inner rod swinging & cryocooler compressor
50	-	-	-	Mains power
67.1	-			Suspected to be associated with building resonances mixing with mains second harmonic (100Hz – 32.9Hz)
73.8	73[1]			Second mode of uncoiling in the outer part of the heat exchanger
84.3	85[1]	Not evaluated here		Second mode of swinging of the outer part of the heat exchanger
96.6	-			-
98.3	-			Second harmonic of cryocooler compressor
100	-			Second harmonic of mains power

[1] These values were calculated with the same simulation as the above values; however they were not included in the paper referenced.

Figure 2 shows SQUID noise signals recorded with the cryocooler and pumps operating without any AV mounts. We estimated in [3] that the SQUID noise peaks due to vibration could range from 1 pT - 20 pT. The causes of the 29.8 Hz and 96.6 Hz peaks in the experimental results are not yet understood.

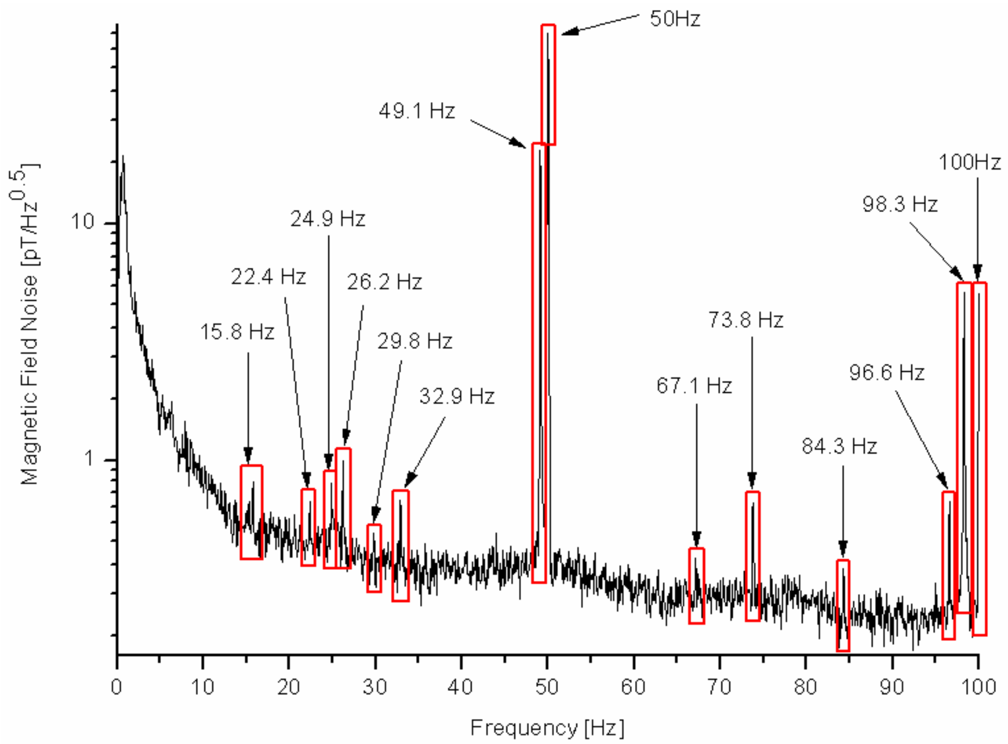

Fig 2. Peak resonant frequencies when the cryocooler and pumps are operating, with no AV.

4. Results and Discussion of Noise Reduction Techniques

4.1. Shielding

The T-shaped three layered mu-metal shield significantly reduces the ambient magnetic noise, from a noise level of 11 pT/√Hz without shielding, to 0.8 pT/√Hz at 10 Hz; at this frequency this noise level is equal to the intrinsic noise of the SQUID. The shields also eliminate the majority of the signal peaks that exist when there is no magnetic shielding.

4.2. Anti-Vibration Techniques

Compared to the noise measured in the T-shape shield (Figure 2), the addition of anti-vibration techniques utilised produced a significant reduction in SQUID noise, see Figure 3.

The clamping of the gas lines reduced the noise to a level of 5.8 pT/√Hz at 1 Hz and 0.4 pT/√Hz at 10Hz. It also reduced most resonant peaks, except for a new peak at 33.3 Hz (Fig 3, trace (b)). Compared to using no AV (Fig 3, trace (a)), combining gas line clamping with spring supports (Fig 3, red trace (c)) reduces the background noise level above 11 Hz and eliminates the 15.8 Hz and 22.4 Hz resonant peak frequencies. However this technique introduces peaks at the 24.6 Hz, 33.3 Hz, 43.6 Hz and 44.1 Hz frequencies. Combining gas line clamping and spring supports does not seem to be as effective as using gas line clamping alone; even though there is a reduction in some noise peaks, the additional spring supports degrades[2] the performance obtained by clamping the gas lines.

[2] This degradation may have been avoided if a vibration absorbing loop was also added to the cryocooler gas lines as proposed in [3].

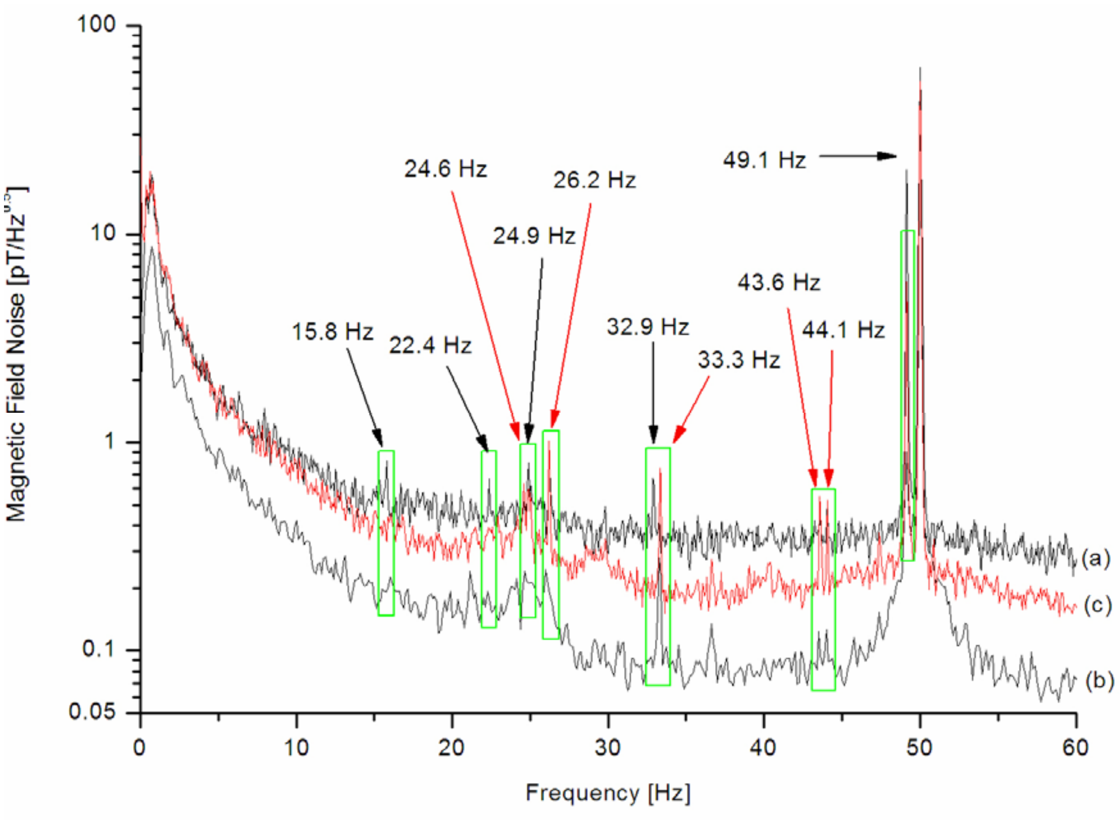

Fig 3. Comparison of anti-vibration techniques used in conjunction with shielding. (a) only three layers of mu-metal shielding (b) clamping of crycooler gas lines (c) clamping of cryocooler gas lines and spring support.

5. Conclusion

The use of the anti-vibration methods reduces the peaks and the noise generated by the mechanical vibrations of the cryocooler and pumps. The clamping of the cryocooler gas lines and shielding offers improved system performance in the application of cryocooled SQUID magnetometers for the detection of metal contaminants in food. The knowledge of the resonant frequencies of the cold end will allow further our ability to change the resonant frequencies and/or introduce damping techniques. Further improvements can be made with the use of gradiometers and electronic filtering techniques.

Acknowledgments

We would like to acknowledge the contributions of Marcel Bick, Keith Leslie, Peter Sullivan, Rex Binks and Bob Thorn.

References

[1] Bick M, Sullivan P, Tilbrook D L, Du J, Gnanarajan S, Leslie K E and Foley C P, *Superconducting Sci. Technol.* **18**, pp. 346-351 (2005)

[2] R. Hohmann, M. L. Lucia, H. Soltner, H. J. Krause, W. Wolf, H. Bousack, M. I Faley, G. Sporl and A. Binneberg, *Integration of HTS SQUIDs with Portable Cooling Devices for the Detection of Materials Defects in Non-Destructive Evaluation,* Cryocoolers 9 pp. 925-934, (1997)

[3] M. A. Santin, G. J. J. B de Groot and T. Thijssen, *Vibration Characterization and reduction of a Joule-Thomson Cryocooler for a SQUID-based Metal Detection System*, Proceedings of the Cryogenic Engineering Conference and International Cryogenic Materials Conference, (2007)