Vibration Characterisation and Reduction of a Joule-Thomson Cryocooler using a High-Temperature Superconducting (HTS) SQUID

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A SQUID (Superconducting Quantum Interference Device) based metal-in-food detection system which is cooled by a Cryotiger® Joule-Thomson cryocooler is evaluated. Previously, it was discussed that the Joule-Thomson cryocooler is noisier than a liquid nitrogen cooled system [1]. We observe large peaks and high 1/f-noise in the noise spectrum of the SQUID. Several noise reduction measures are successfully installed and evaluated in this report.

1. Introduction

The use of SQUIDs to detect metal in food has potential for application in the food industry. The risk of conventional liquid nitrogen cryogen is considered unacceptable in this industrial environment. Cryocoolers offer a means to eliminate this risk. However, they add their own complexity via the introduction of temperature fluctuations and compressor vibrations that add to the SQUID system noise. While the temperature variations affect the internal SQUID performance, the higher noise due to vibrations arises from the translation or rotation of the SQUID in the residual magnetic field and the movement of magnetic components of the cold head. To reduce this noise, the tuning of the SQUID is optimized and anti-vibration (AV) measures like a compressor line wall clamp and an AV table are used. The electromagnetic interference (EMI) of the cryocooler compressor is eliminated by judicious placement of the cooler's compressor.

2. Experimental setup

The SQUID magnetometer, installed in the vacuumed dewar, is placed in a three-layer mumetal shield to reduce the environmental noise. The magnetometer is a 6 mm circular DC SQUID with white noise in the range of 200 fT/Hz$^{1/2}$. The T-shaped shield is located on an AV table to isolate the dewar from ambient vibrations. In comparison to previous AV configurations [2], the damping of the vibrating compressor lines is improved by a timber plate which is rigidly connected to a massive concrete wall.

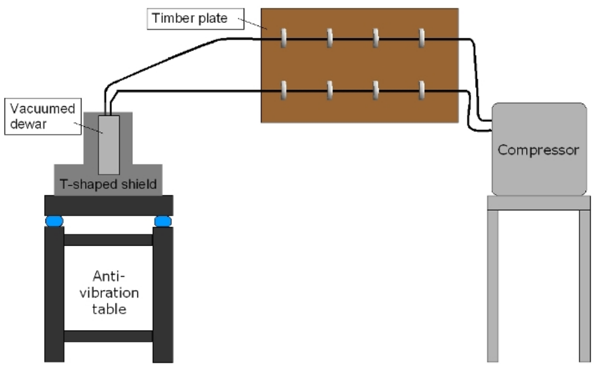

Fig. 1: Experimental setup of cryocooled SQUID with AV techniques

3. Reduction of noise

3.1 EMI of the cryocooler

A standard technique for reducing the effects of any compressor-induced electromagnetic interference on magnetometer sensor signals, is physical separation. Fluxgates were used to determine the minimum separation distance for our Cryotiger® system. Since the low frequencies are of major concern for a metal-in-food detection application, the noise at 1 Hz is used as a reference. A minimum separation of 5 m between the SQUID and the Cryotiger® compressor is required to ensure no noise contamination.

3.2 Internal SQUID noise

3.2.1 Tuning with AC bias and DC bias

To reduce the high internal 1/f-noise of the HTS SQUID, AC biasing is chosen to tune the SQUID. AC biasing clearly improves the sensitivity in comparison to DC biasing. The AC biasing leads to better noise values up to 1400 Hz (Fig. 2). At 28 Hz the noise is reduced to nearly a third of the DC bias value (DC: 570 $fT/Hz^{1/2}$, AC: 200 $fT/Hz^{1/2}$).

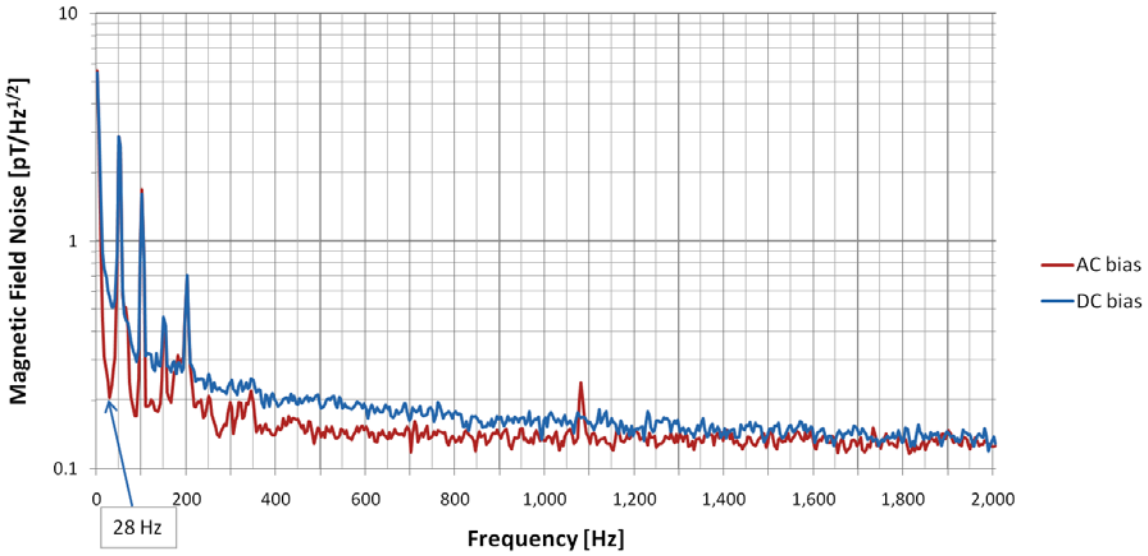

Fig. 2: Difference in noise spectra for DC and AC biasing

3.2.2 Temperature variation

To maintain a good noise performance it is important to consider the temperature fluctuations within a cryocooled system. In contrast to a liquid nitrogen cooled system where the temperature remains fixed, for a cryocooled system the tuning parameters of the SQUID have to be re-adjusted whenever the temperature varies.

Fig. 3 shows that the noise level can vary by more than a factor of two for different AC tuning parameters at the same temperature (71 K) which leads to big differences in sensitivity of the SQUID. (This was also observed in [2].)

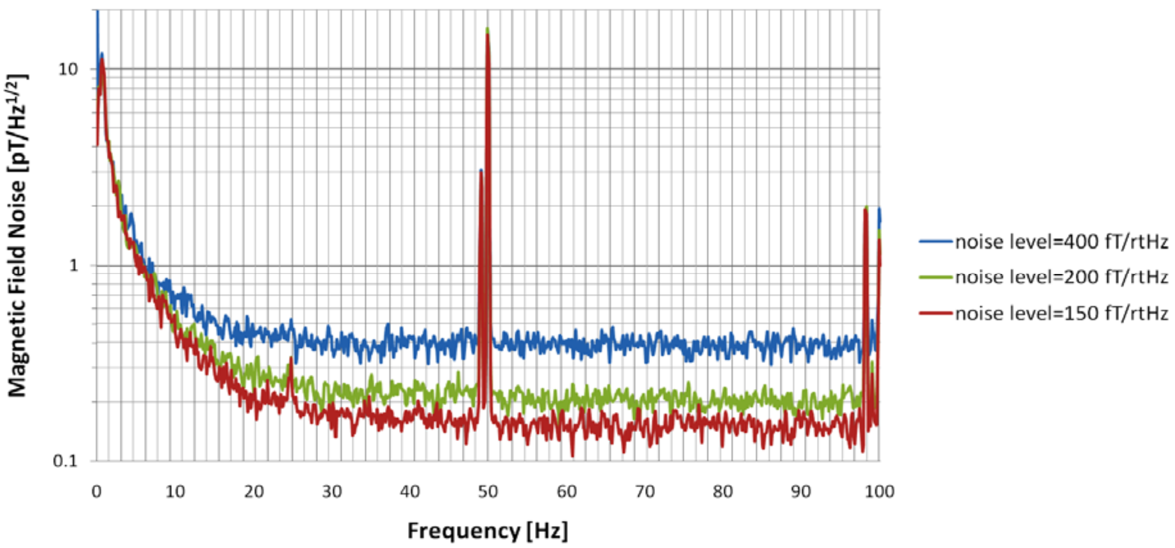

Fig. 3: Different noise levels due to different AC tuning parameters

3.3 External noise sources

In order to reduce the noise caused by vibrations it is important to first determine the external noise sources.

3.3.1 No AV measures

The noise spectrum without any AV measures is recorded and evaluated. Without any AV measures most of the peaks earlier identified [2] are observed.

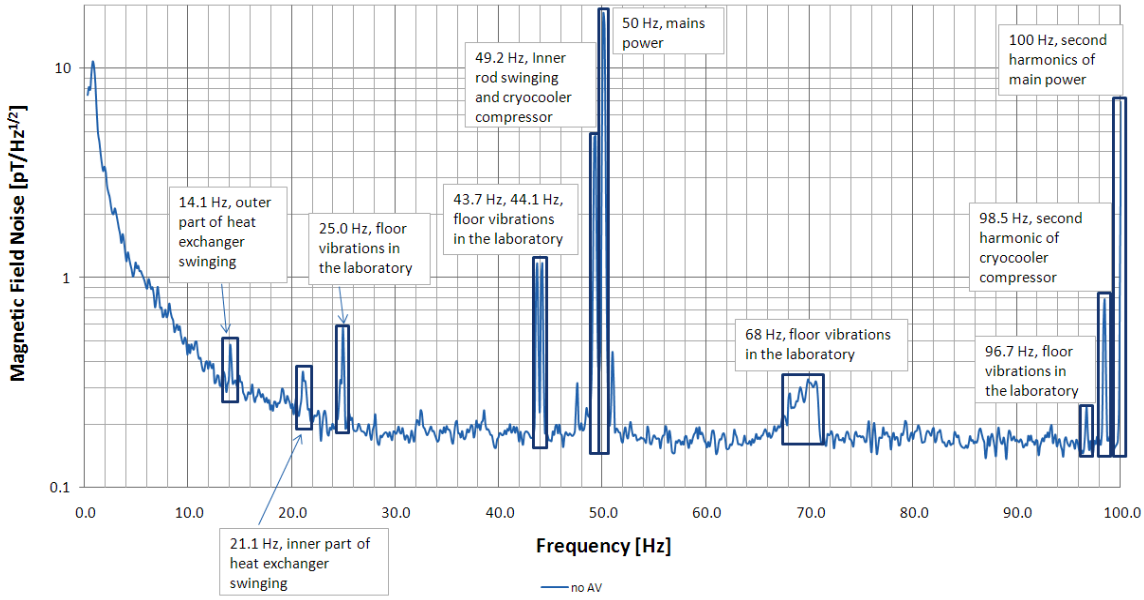

Fig. 4: Noise spectrum measured by the SQUID without any AV measures

3.3.2 Wall clamping of compressor lines

The compressor lines which propagate vibrations from the compressor to the cold head were clamped to a massive wall (see Section 2). By this means, many peaks in the noise spectrum are reduced or are even removed completely. The peaks at 96.7 Hz, 68 Hz and 44 Hz are eliminated and the peak of the outer part of the heat exchanger (14.1 Hz) is reduced.

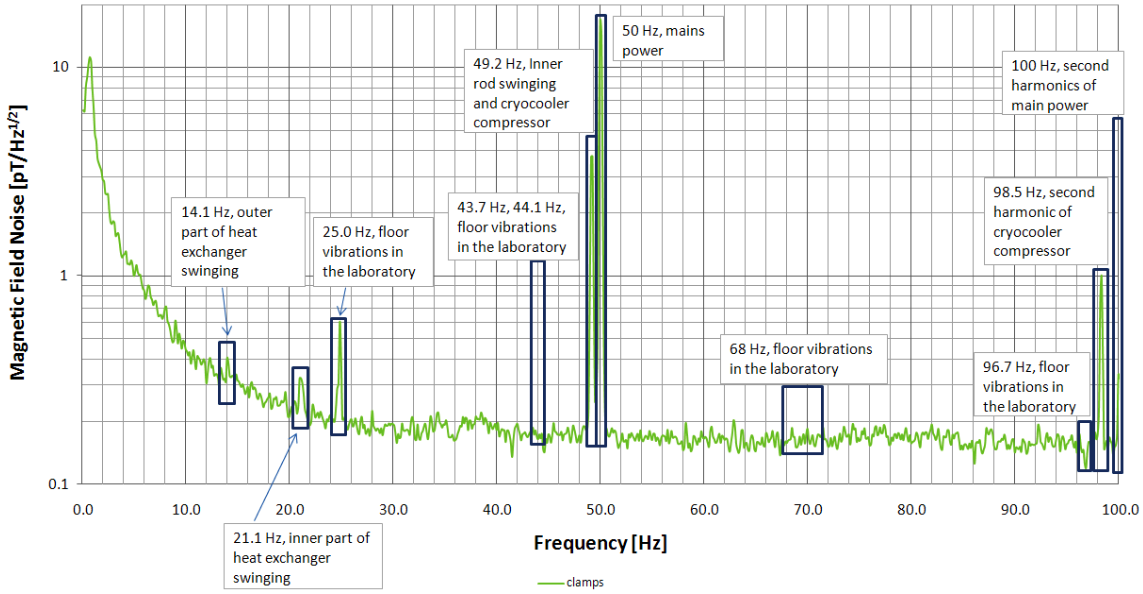

Fig. 5: Noise spectrum measured by the SQUID with wall clamping of the compressor lines

3.3.3 Wall clamping and AV table

To further isolate the SQUID detector from the vibrating environment, an AV table was installed. By this means, the 25 Hz peak is removed and the noise peaks induced by the vibrating compressor are all reduced. The only exception is an increase of the peak at 49.2 Hz, which can so far not be explained.

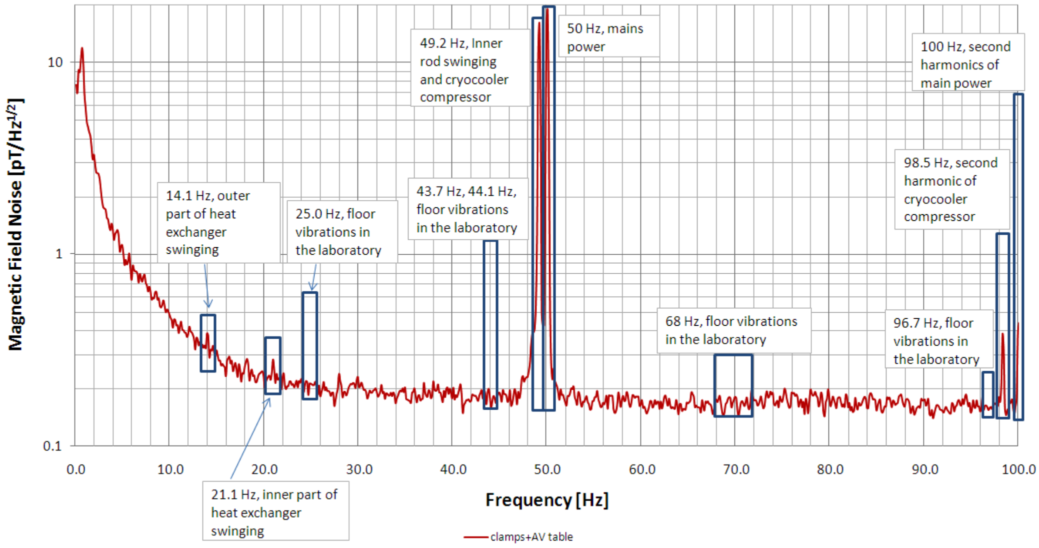

Fig. 6: Noise spectrum measured by the SQUID with wall clamping and AV table

3.3.4 Crycooler off

The effectiveness of the AV measures is demonstrated by measuring the noise spectrum with the cryocooler switched off. Apart from the 49.2 Hz and 98.5 Hz peaks, in Fig. 7 for frequencies above 20 Hz the two spectra are identical. Below 20 Hz, with the cryocooler off, lower noise was observed. This result is suspected to be correlated with further reduced movements of (magnetic) parts in the cold head. Attempts to further improve the 1/f-noise below 20 Hz by inserting washers locking the outer heat exchanger coil proved unsuccessful. More work is required to explain the lower 1/f-noise when the cooler is switched off.

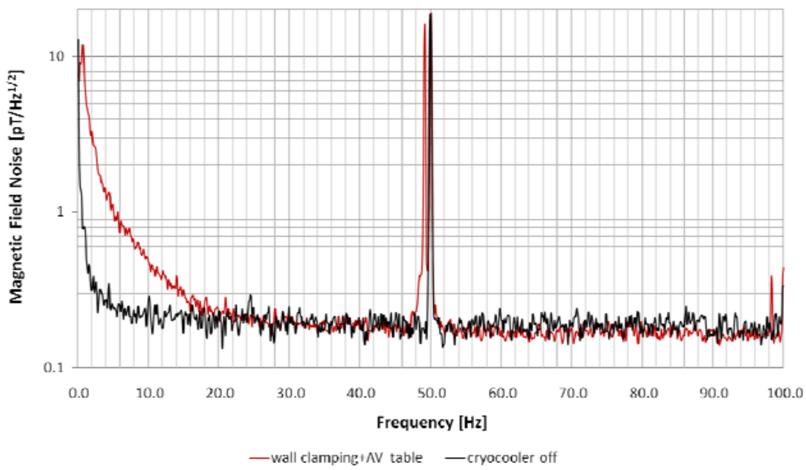

Fig. 7: Evaluation of effectiveness of the AV measures

4. Conclusion

The described cryocooled metal-in-food detector is a promising system for industrial applications. The EMI of the cryocooler compressor is eliminated completely. For each temperature, the noise of the cryocooled SQUID can be minimised by adjustment of the AC tuning parameters. Noise peaks caused by the compressor vibrations are either reduced or removed with the use of a wall clamp and an AV table.

Acknowledgments

We would like to acknowledge the contributions of Keith Leslie, John MacFarlane, Ed Preston and Sean Evenhuis.

References

[1] http://www.aip.org.au/wagga2007/2007_23.pdf, M. Santin and G.J.J.B. de Groot, 31st Annual Condensed Matter and Materials Meeting (2007), Wagga Wagga.
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