Vibration Characterisation of a Joule-Thomson Cryocooler for a SQUID-based Metal Detection System

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A commercial Joule-Thompson cryocooler – the Cryotiger® - is used to cool a SQUID-based metal detector. Compared to our previous liquid nitrogen cooled system the performance of the detector is reduced due to spurious magnetic signals introduced by mechanical vibration. In order to design vibration reducing measures, the vibration characteristics of several parts of the cryocooler cold head were determined. The characterisation was experimentally performed with a laser vibrometer and modelled with analytical and finite element methods. We observed good agreement between the measured and modelled natural resonant frequencies.

1. Introduction

Very sensitive high-temperature SQUID (Superconducting QUantum Interference Device) magnetometers are used for the detection of small metal contaminants in food and other products. When the SQUIDs are cooled with liquid nitrogen, good detection performance is obtained. However, when a commercial Joule-Thomson cryocooler – the Cryotiger® - was used, the performance was reduced due to spurious magnetic signals introduced by mechanical vibration, as can be seen in Figure 1[1]. Similar sensitivity issues were reported by Rijpma et al., [1].

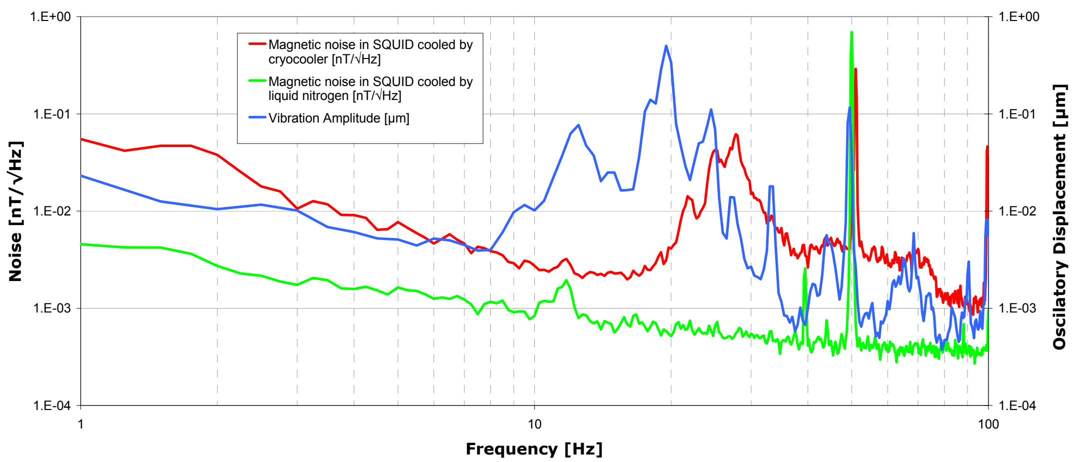

Figure 1. Comparison between vibration measured on the top of the titanium enclosure (blue trace), the noise of the SQUID magnetometer mounted on the cryocooled system (red trace) and mounted on the LN_2 cooled system (green trace).

It is assumed that that noise can be generated in two ways: the translation or rotation of the SQUIDs in a magnetic field and the movement of magnetised components of the cold head

[1] The vibration measurement corresponds to one translational orientation of the selected point on the component. The amplitude supplied by the vibrometer should be taken as approximate due to operation at, or below, the manufacturer's minimum specified amplitude range.

inside the shielding, [1]. Preliminary calculations indicate that the latter is the most likely source of noise. This aspect is still being investigated.

These movements may come from four sources of vibration: compressor; refrigerant movement in the cold head; excitations from the floor; and direct excitations to the cold head, i.e. shocks.

In order to design and implement measures to reduce the effect of vibrations, we aim to provide an improved understanding of the dynamic characteristics of the system components.

2. System description

The cold head is shown in Figure 2 and the experimental system components are shown in the Figure 3.

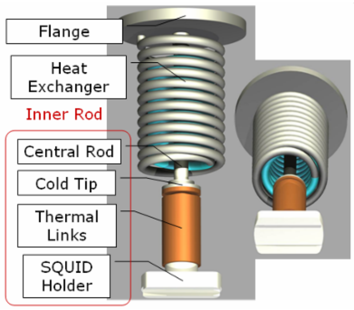

Figure 2. Simplified[2] model of the cold head. The inner part of the Heat Exchanger, also a helical tube, is shown in blue.

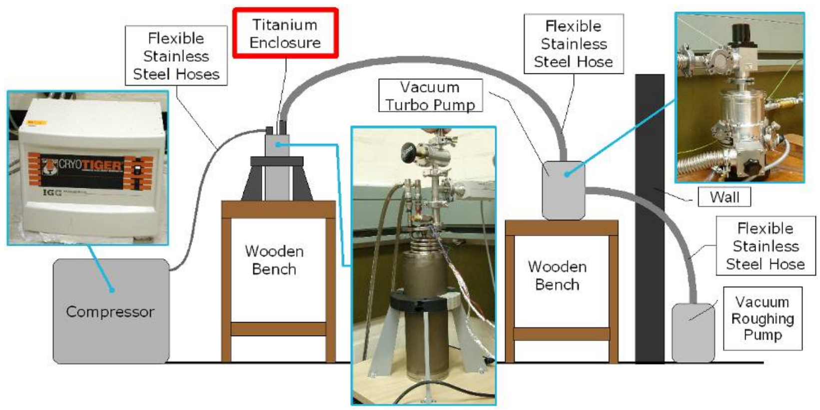

Figure 3. Previous experimental setup.

3. Vibration Characterization

The vibration characterisation was conducted by measurement and analysis of the response to excitation and by simulations of natural frequencies and resonant modes of the cold head.

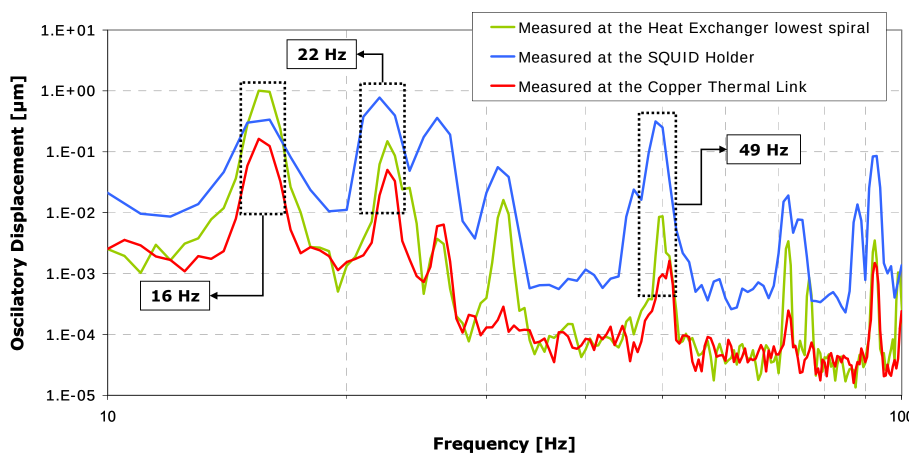

Figure 4. Impulse response of the cold head.

The vibration measurements were performed using a Polytec Laser Doppler Vibrometer. To determine the natural frequencies, the cold head was suspended by strings and excited with a rubber hammer. The impulse response is shown in Figure 4[3].

[2] In the modelling, it was decided not to include the boiler, throttle valve and the internal helical tube of the heat exchanger (which is inside the visible part and is part of the counter-flow assembly).

[3] See footnote 1.

The vibration frequency spectrum during system operation is shown in Figure 1 and the finite element (FE) and analytical models were used to determine which cold head components correspond to the measured resonant frequencies.

The main modes and frequencies found in the simulations are shown in Figure 5 and are in good agreement with the measured values, see Table 1.

Component / Method	Heat Exchanger – Outer Coil	Heat Exchanger – Inner Coil	Inner Rod
FEA	16.5 Hz(1)	21.4 Hz(2)	49 Hz(3)
Measurement	16 Hz(1)	22 Hz(2)	49 Hz(3)
1–See Figure 5(b); **2**–See Figure 2; **3** –See Figure 5(a).			

Table 1 - Natural frequencies obtained from FE analysis and measurements.

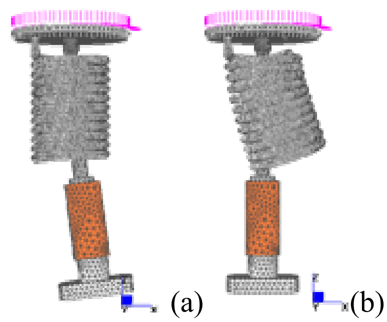

Figure 5. FE Simulations – (a) Inner rod resonance frequency, ≈ 50Hz. (b) Outer part of the Heat Exchanger resonance, ≈ 16,5Hz.

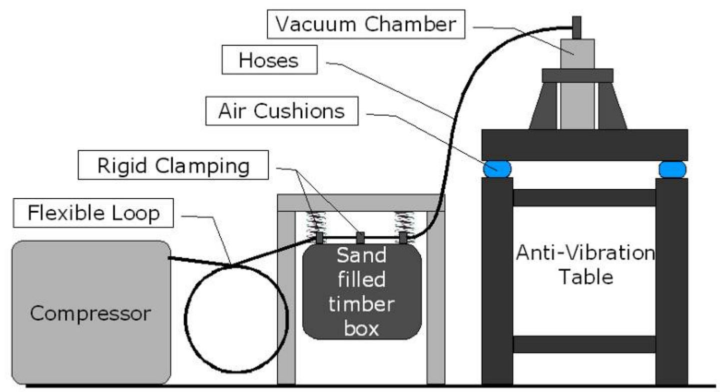

Figure 6. Diagram representing one of the proposed solutions.

4. Conclusions

We have measured and modelled resonance frequencies in the cold head which are in the same 'spurious' noise frequency range – 10 to 30 Hz - as measured with the SQUID when the cryocooler is operational. The measured and modelled 50 Hz resonance frequency of the cold head inner rod was also visible in the SQUID signal. This knowledge may be used to reduce signal deterioration due to the vibration. To reduce the effect of vibration, the external excitation should be reduced, the resonance frequencies should be altered and/or damping inside the cold head should be considered. A range of anti-vibration measures are proposed and are being implemented.

- Clamp the compressor hoses rigidly to a vibration absorber. For isolation from the ground a spring suspended timber box (filled with sand) was used, see Figure 6.
- Add damping elements, such as rubber disks, between the coils of the heat exchanger.
- Isolate the system from external (i.e. floor) excitations (anti-vibration table).
- Change the resonance frequency of the cold head components - aiming at higher frequencies - and hence avoiding resonance during excitation.

References

[1] A.P. Rijpma, H.J.M. ter Brake, E. de Vries, H.J. Holland and H. Rogalla. *Cryogenics* ***45,*** 317 (2005).