Operation of a Cryogenic Current Comparator in Presence of Mechanical Vibrations

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Abstract — **In measurements with cryogenic current comparators (CCCs), robustness against mechanical distortions is an issue. Sources of distortions are part of the experimental environment, efficient suppression is difficult. In a test setup, we intentionally applied mechanical vibrations to a CCC probe. In the 10 Hz to 3 kHz range, the frequency response of the SQUID detector's output signal was recorded for an integrative and an H_∞-controller. When applying vibrations at fixed frequency, the stability of the SQUID's locking depended on the chosen controller, but an influence on the result of a 12.9 kΩ vs. 100 Ω resistance comparison was not found.**

Index Terms — **Closed loop systems, control system analysis, frequency response, robustness, SQUIDs, system identification, vibration measurement.**

I. INTRODUCTION

The very high sensitivity of SQUID magnetometers used in CCC probes as null-detectors requires operation of such setups in a sufficiently quiet environment. Besides appropriate electromagnetic shielding, this includes the reduction of mechanical distortions to a tolerable level. Any relative movement between the SQUID's pick-up circuit, the CCC and the superconducting screen of the probe's cold head can produce an input to the control loop. Also movements of wires can do so (triboelectric effect). If so, a corresponding excursion of the feedback signal (output of the controller) will be observed. In case of insufficient cancellation of the distortion, traces are also found in the SQUID output. Finally, when the undesirable excitation exceeds certain strength, the SQUID cannot stably lock to its working point any longer – the occurring "flux jumps" make proper measurements just impossible. For a given excitation, it will depend on the performance of the chosen controller, which of these effects is observed.

Different possible sources of mechanical distortions have to be considered. The possibly simplest way to provoke vibrations is knocking on the liquid-helium dewar into which the probe is loaded. However, even much weaker impact can cause significant effects – examples include acoustically induced vibrations by clapping hands or speaking loudly. It is, on the one hand, common to all these examples, that the effective mechanical excitation cannot be easily quantified (magnitude and frequency). On the other hand, these kinds of excitation can and will be avoided in a regular measurement. In a typical laboratory environment, the more severe problems have to do with running pumps etc. An additional and unavoidable source of vibrations is specific for cryocooler-based CCC setups, but not investigated in this contribution.

Here we intentionally couple the CCC probe to a source of mechanical vibrations. The results presented below have been obtained within a comparative study of two different controllers: a conventional analog integrator (controller #1) and an H_∞-controller (#2) implemented by means of analog-to-digital and digital-to-analog converters with a complex programmable logical device (CPLD) in between [1].

II. EXPERIMENTAL APPROACH

In all experiments, the configuration of the measurement bridge was kept unchanged: we operated a 14-bit CCC [2] in a freely evaporating liquid-helium dewar choosing numbers of turns 4001, 31 and 1 in the main primary, the secondary or the auxiliary primary windings, respectively, for the comparison of a 12.9 kΩ and a 100 Ω normal resistor. Without exception, the controller was acting on the secondary current source.

As the vibration source, a commercial shaker was attached to the room-temperature end of the CCC probe by means of beeswax. The latter applies to a calibrated accelerometer as well. Fig. 1 shows all these modules as parts of the experimental setup. Amplitude and frequency of the shaker's vibrations depend on the settings of a voltage source and on the gain of a power amplifier between this source and the shaker. This gain was kept constant during the experiments.

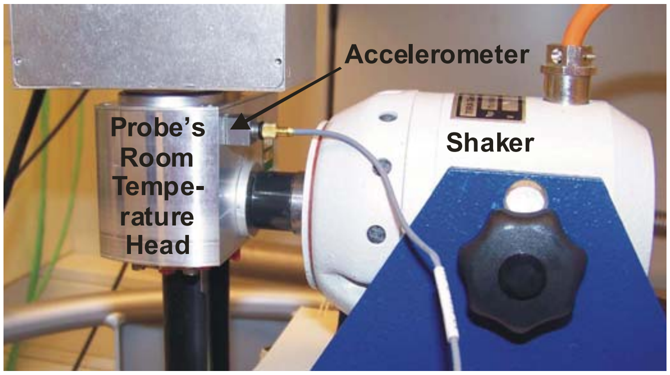

Fig. 1. Attaching the TIRA TV 50018 shaker and a Brüel & Kjær 4508-002 accelerometer to the probe. The orange and grey cables connect these items with a TIRA Power Amplifier BAA 60 or a Norsonic FRONT END type 336, respectively.

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III. MEASUREMENTS

For a series of acceleration measurements, we used a sinusoidal supply at different frequencies and recorded the time traces of both, the exciting voltage and the accelerometer output voltage, using a digital storage oscilloscope. Results are shown in Fig. 2.

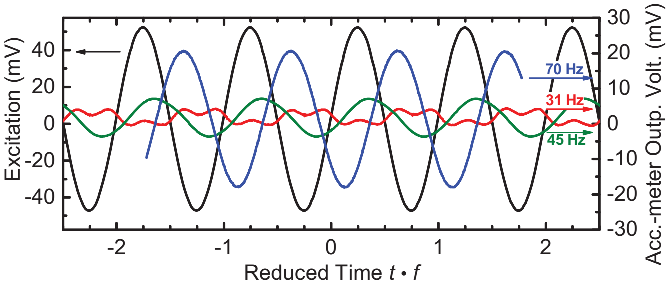

Fig. 2. Mechanical response to driven vibrations: time traces of function generator (excitation, black line) and accelerometer output (colored solid lines) voltages for selected fixed frequencies *f*. According to the accelerometer calibration performed prior to the measurements, a level of 2.88 V corresponds to 10 m·s^{-2}.

To characterize the response to vibrations over a wider frequency range (10 Hz to 3 kHz), we used an Agilent 35670 Dynamic Signal Analyzer in Swept Sine mode. Its source output was connected via the power amplifier with the shaker and with input channel 1, the accelerometer output with input channel 2. According to the measurement results shown in Fig. 3(a), the stability of the setup was acceptable. In Fig. 3(b), we then present data for the response of an electrical quantity, the SQUID output voltage, to the mechanical excitation. In this first measurement, the control loop was not closed yet.

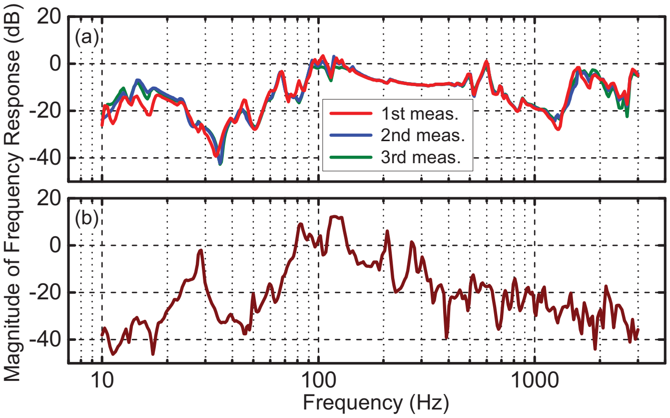

Fig. 3. Frequency response of (a) the accelerometer and (b) the SQUID output in open-loop operation when sweeping the frequency of vibrations supplied by the shaker. For the accelerometer, three measurements have been performed: before, during and after the experiments with the two controllers.

Later, the feedback loop for stabilizing the magnetic flux picked up by the SQUID was closed alternatively using the different controllers (cf. Fig. 4). The suppression of vibration-induced distortions is significantly more efficient running the digital H$_\infty$-controller: about an order of magnitude for frequencies up to 1 kHz. Therefore, the setup is expected to run in a more stable manner in case of being unavoidably exposed to vibrations in this frequency range. This tendency was confirmed in an experimental investigation of the robustness of SQUID operation in the presence of vibrations at 100 Hz. Here, we varied the output voltage amplitude of the function generator. Running controller #2, stable operation, i.e., the absence of flux jumps, was found up to a three times higher excitation level than for controller #1. However, when performing a series of resistance comparisons with or without shaker-induced vibrations, a clear influence of the latter was not observed. Working with the more delicate setup (controller #1) only, the results show some inconsistency within the ensembles of experiments with and without vibrations, whereas the average values of the ensembles agree well.

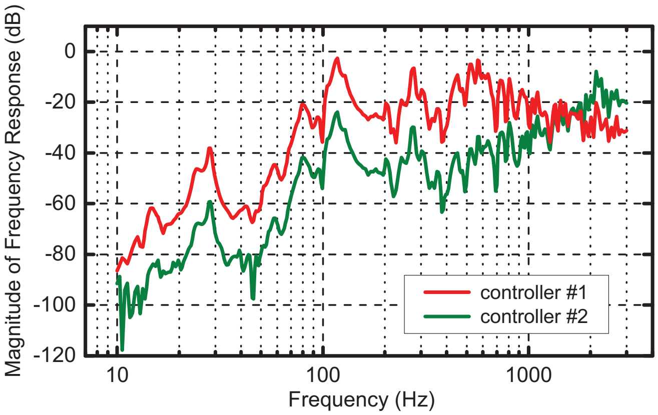

Fig. 4. Frequency response of the SQUID output when operated in closed feedback loop using the two different controllers. The lower the magnitude, the stronger the suppression of the applied distortion, i.e., as a tendency, a downward shift of the frequency response curves indicates a gain in stability within the respective frequency range.

IV. CONCLUDING REMARKS

The omnipresence of vibrations is potentially critical for the operation of CCC-based measurement bridges. Deliberately coupling a source of vibrations to the CCC probe, the robustness has been studied. Differences in the performance of two controllers are definitely found. The situation with respect to the possible effect of vibrations on the result of a resistance comparison is less clear so far and deserves closer attention.

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