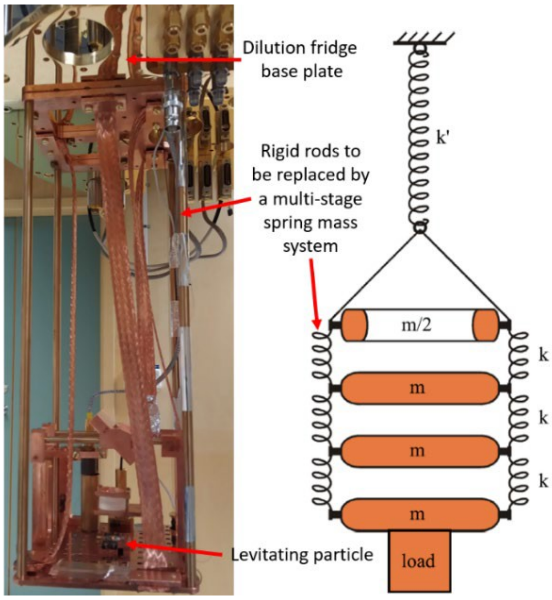
Vibration Damping Stage for Quantum Experiments at mK Temperatures



Background: A levitating micrometer-sized particle is a promising platform for quantum sensing application as it is maximally isolated from the environment. This makes it highly sensitive to forces on the order of Zeptonewton and thus can be used to detect, for example, weak gravitational signals. In our lab, we levitate superconducting microparticles using magnetic fields. Inside this magnetic field, the particle oscillates at a frequency of a few hundred Hz. For ultra-high force sensitivity, the particles need to be brought into the quantum regime (amplitude of a few femtometer). This is done by cooling the center-of-mass motion of the particle to its ground state. The entire experimental setup (see image) is placed inside a high vacuum cryostat that cools the system down to 20 Millikelvin. Ideally, the particle must remain isolated from the environment for cooling its motion. However, various external factors influence the particle and cause heating. A dominant noise source comes from external mechanical vibrations originating from the pulse tube compressor of the dilution refrigerator, as well as surrounding noise from the building.

The goal of this Master thesis project is *to develop a vibration isolation system* that should be designed to effectively dampen mechanical vibrations in the range of 1 Hz to 10 kHz to minimize the negative influence of vibrations on particle motion. This system can be a multi-stage spring-mass system [1,2] that replaces the existing vertical rigid rods of the setup. This design should be first studied analytically and then simulated on ANSYS or similar software. A prototype can then be fabricated in-house (if time permits during the thesis, done in a mechanical workshop by an engineer) and installed in the cryostat. A crucial design factor lies in combining maximum damping while keeping the *mass below 2kg, and dimensions within (120 x 120 x 300 mm)*.

Goals of the thesis:

- Analyze, design, and simulate a multi-stage vibration isolation system (mass below 2kg, dimensions within 120 x 120 x 300 mm) to be used at low temperatures (below 4 Kelvin).
- Noise damping from cryostat and surrounding must be at least 20 dB between 1 Hz to 10 KHz.
- If time permits, experimentally test the damping characteristics of the stage.

What will you learn?

- Vibration isolation for quantum sensing applications
- Measurements of micromechanical devices, cryogenic techniques
- Working in experimental physics with an interdisciplinary team

Required knowledge: Structure Dynamics, Control Systems, Dynamic Simulation software (e.g.,ANSYS Mechanical), Programming tool (Python, MATLAB)

References

[1] Leng, Y., et al. (2021). Mechanical dissipation below 1 µHz with a cryogenic diamagnetic-levitated micro-oscillator. *Physical Review Applied* 15, 024061 10.1103/PhysRevApplied.15.024061
[2] de Wit, M., et al. (2019). Vibration isolation with high thermal conductance for a cryogen-free dilution refrigerator. *Review of Scientific Instruments* 90, 015112 10.1063/1.5066618

Contacts

- Witlef Wieczorek, Associate Professor, witlef.wieczorek@chalmers.se
- Achintya Paradkar, PhD Student, achintya@chalmers.se