Heat dissipation induced by microvibrations in low temperature gas-gap heat switches

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Context

As satellite performance requirements for disruptive science missions have continuously increased over the years, **the impact of microvibrations on system design could become ever more critical.** The performance of low-temperature instruments using bolometers or calorimeters are very sensitive to the thermal stability of the coldest cooling stage. They will inevitably be affected by these microvibrations as at instrument level microvibrations could cause thermal disturbances due to their heat dissipation. This falls within the context of my **PhD thesis studying the effect of microvibrations on low-temperature instrument performances at CEA Grenoble (co-funded by CNES).**

Heat switch use and working principle

A heat switch is a device designed to control the flow of thermal energy between two components. As its tip can be thermally insulated while still permitting mechanical transmission, it is an ideal device for the study of the dissipation of microvibrations.

If no heating is applied to the mini gas pump (yellow), the gas remains trapped in the active charcoal. Low thermal conductivity ("OFF" mode) ensues. When heating the gas pump, gas is desorbed into the gas gap, causing high thermal conductivity ("ON" mode) between the copper base (red) and the copper tip (orange).

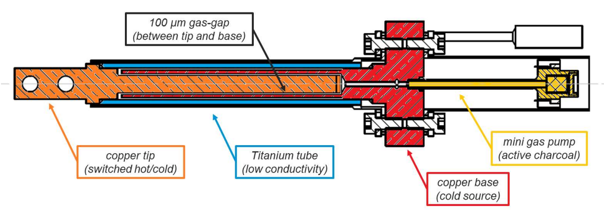

Fig 1. core components of a Planck gas-gap heat switch

Dissipation is induced by microvibrations injected at the copper base of the heat switch. If the copper tip is thermally insulated, its temperature is thus expected to increase at specific excitation frequencies. The highest dissipation is expected at the mechanical resonance of the heat switch (i.e. 1st mode of a cantilever beam).

Instrumentation & Testing

Sensitivity to measurement is maximised using:

- **helium baths** as the cooling method of choice (we avoid mechanical coolers)
- high sensitivity **cryogenic accelerometers,** low noise **signal conditioner** + **DAQ**
- **temperature sensors** and **laser displacement sensors**
- **mini shaker** for system excitation (hot and cold)

Fig 2. helium bath cryostat for the study of the dissipation induced by microvibrations

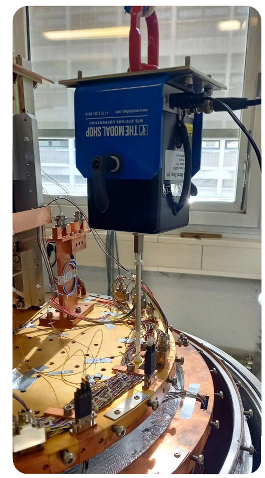

Fig 3. mini shaker attached to cryostat cold plate for hot vibration testing

Sensitivity to microvibrations is maximised by:

- **Increased thermal insulation** (whilst permitting mechanical transmission) through :
  - Lower operating temperatures (e.g. pumped bath, ADR, …)
  - Alternative setup geometries (e.g. suspension systems)
  - Alternative material choices (e.g. CFRP, Vespel, Kevlar, Nylon, …)

Results

Calibration of observed temperature increases

At specific excitation frequencies, temperature increases are observed at the copper tip. Temperature slopes (K/s) are calibrated to known injected heating powers (W).

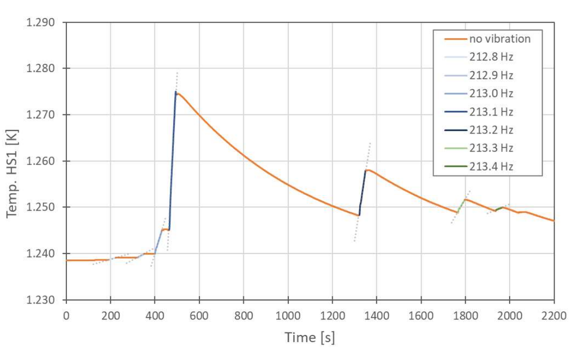

Fig 4. temperature of heat switch copper tip at fixed mechanical excitation frequencies (blue), separated by periods of no vibration (orange)

Dissipation as a function of excitation frequency

An image of the self-heating observed at the copper tip is obtained as a function of the mechanical excitation frequency, for several injected acceleration levels.

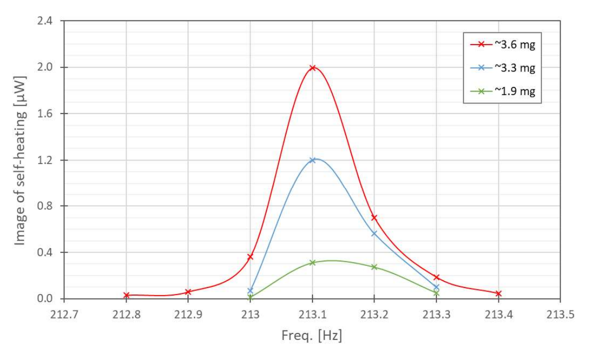

Fig 5. image of dissipations induced by microvibrations observed at heat switch copper tip, as a function of mechanical excitation frequency

Conclusion

- Self-heating induced by microvibrations has successfully been observed in simple cryogenics devices (heat switches)
- Basic thermomechanical modelling (not discussed here), has also helped predict the dissipation observed in them

Perspectives

- Additional thermal insulation and instrumentation will allow us to deduce the total heat load dissipated in the heat switch (ongoing)
- Further study of microvibration dissipation in other cryogenic devices (e.g. Kevlar suspension systems, thermal straps, …) is planned