High-Precision Heating Stage for the Bio Endstation of the Microprobe

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Introduction

For single-particle irradiation with sub-micron accuracy temperature control of the entire microprobe facility is essential. With relevant lengths of the most sensitive parts of the setup ranging around tens of cm and a thermal expansion coefficient of steel or aluminum around 15-25 µm per meter and Kelvin one can expect a temperature change of 100 mK to introduce a shift of a few hundred nanometers. With the current absolute targeting accuracy of our system being 700 nm such a shift is not negligible and we are thus continuously striving for improvements of this situation. For this reason, sources of heat have either been eliminated whenever possible (e.g. use of LED illumination as soon as commercially available [1]) or thoroughly separated from the most critical components. At the same time, these components have been kept at minimum lengths and are allowed to thermally stabilize before precision irradiations are conducted.

In conflict with this struggle, the vast majority of experiments depend on the introduction of various heat sources. Here, we report on a heat source with up to a whopping 25 Watts being flanged onto the thermally sensitive microscope stage of the bio endstation. This heat source allows for accurate irradiation of cell cultures at 37 °C instead of the constant but unregulated 30 °C with the unheated stage. The temperature is deemed to be a contributing parameter for absolute measurements of protein kinetics [2], where temperature is expected to strongly modify micro-'viscosity'.

Lazy Man's Approach – On/Off Thermostat

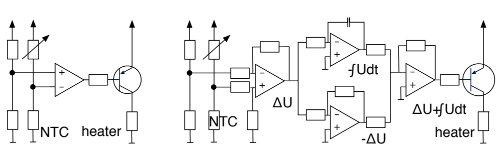

Figure 1: Schematic of a simple on/off-type thermostat (left) and a slightly more elaborate PI regulator (right).

A simple circuit that reads from a temperature sensor and drives current through heating resistors whenever the measured temperature is smaller than 37 °C is shown in fig. 1 (left). Here, a negative-temperature-coefficient resistor (NTC) mounted as close to the sample position as possible is part of a voltage devider. The thermo-voltage is compared to a reference voltage, with the full comparator sweep switching the current through the heating resistor on or off when the sensor reading is too low or too high, respectively. Using this regulator, we found a temperature hysteresis at the sample position of 0.4 K resulting in a thermal drift measured to be 1.2 µm. The hysteresis depends on the distance of heating and sensing elements as well as heat capacity and thermal conductivity of the stage and is as such difficult to improve while sticking with the thermostat approach.

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OK, That Didn't Work – PI Regulation

To cater for the thermal 'inertia' of the stage, the circuit in fig. 1 (right) introduces an integrating branch yielding a signal that represents the past difference between set-point and measured temperature. This slow integral (I) part is summed up with a voltage proportional (P) to the current temperature deviation from the set-point to speed up recovery from temperature excursions. The sum then adjusts the collector-emitter resistance of a power transistor, effectively regulating the current flowing through the heater.

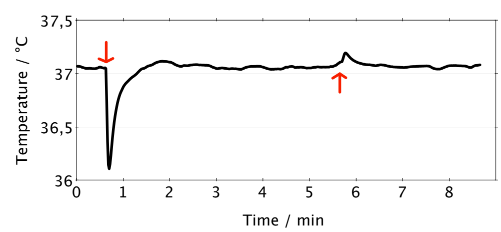

Figure 2: Recovery of the set-point temperature after a forced temperature excursion (arrow at 30 s). For this 1 K excursion, temperature returns to set point within roughly 100 s and remains stable to less than 1/20 K. Arrow at 5 minutes marks small forced excursion to higher temperatures. Temperature measured at sample site, fully integrated into microbeam setup.

Figure 2 shows the response of the well admixed proportional and integral branches to an excursion one might expect from a sample exchange (1 K) with a very small overshoot on the way back to 37 °C. When locked to 37 °C, no movement of the stage is detectable.

References

[1] B. Merk, B.E. Fischer, R. Neumann, K.-O. Voss, GSI Scientific Report 2008, 361

[2] B. Merk, K.-O. Voss, I. Müller, B.E. Fischer, B. Jakob, G. Taucher-Scholz, C. Trautmann, M. Durante, Biophysics section of this GSI Scientific Report