TESTING 1-K CONTINUOUS AT HIGHER LOADINGS

INTRODUCTION

The testing reported upon here has been carried out in order to examine the possibility of running a standalone 1-Kelvin continuous cooler to buffer the 350-mK stage of the MUSCAT instrument. The concept is to cool a copper ring to close to 1 K, this ring will be mounted from the 4-Kelvin stage via stainless-steel legs. The 350-mK stage will then be mounted from this ring via sapphire joints (as described by Bintley, Woodcraft, and Gannaway, **Cryogenics**, 47, 2007). The anticipated loading on this ring will be of the order of 0.5 mW.

The 1-Kelvin continuous cooler used for this testing is the 300-mK IPS continuous cooler modified by thermally shorting the helium-3 head of each sub system to its respective helium-4 head. The helium-4 pumps are then cycled while the helium-3 pumps are held at 4 K by keeping their heat switches closed. The thermal short between the helum-3 and helium-4 heads is made from stacked foils of high-purity copper, although this has produced non-ideal performance (see the Observations and notes subsection below). A photograph of the configuration is shown in Figure 1.

In a final system the helium-3 heads would be omitted and this simplification is also expected to offer a notable improvement. As such, the result presented herein represent something of a worst case scenario.

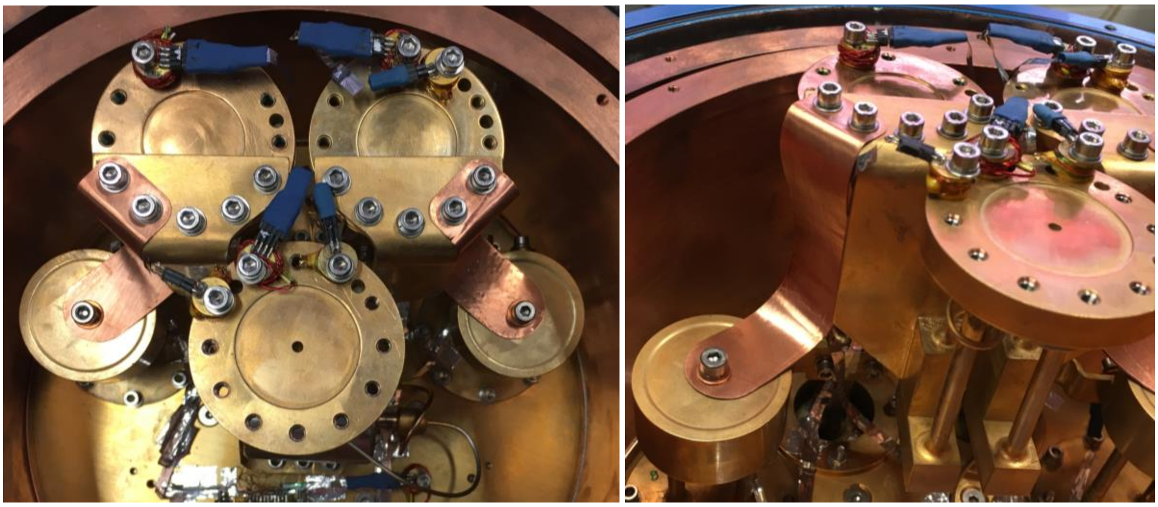

Figure 1: Photographs of continuous cooler adapted for 1-Kelvin operation.

TESTING

OBSERVATIONS AND NOTES

Upon commencing testing it became clear that the thermal links used to connect the helium-3 head to its helium-4 counterpart were performing notably better on the A subsystem than on the B subsystem. This is illustrated in Figure 2. The difference between the helium-4 and helium-3 heads is on the order of 300 mK for the A subsystem and 600 mK for the B subsystem. This is attributed to poorer clamping on the B subsystem. This is not entirely surprising as the overall system was not designed to have the two heads shorted and there is not an ideal interface present on the helium-4 pumps (the shorter pumps on the outside in Figure 1). These pumps only offer a single, untapped hole to clamp a link in place. Figure 2 shows that the overall performance of the two 1-K heads is comparable although the B system does get slightly hotter towards the end of its cycle. This is most likely due a weaker heat link to the final stage and not being able to lose energy through blast gas (helium 3) present in that stage.

All data presented from this point in this report have been taken for the A subsystem only in the belief that improved design or contact should present identical performance on both subsystems. This illustrates the need for a purpose built system, which would remove such imperfections. It is also suspect that this stopped or reduced the improvement in efficiency after multiple consecutive cycles that was observed when operating the system in the 300-mK configuration. This is further justification of the data presented here being a worst case.

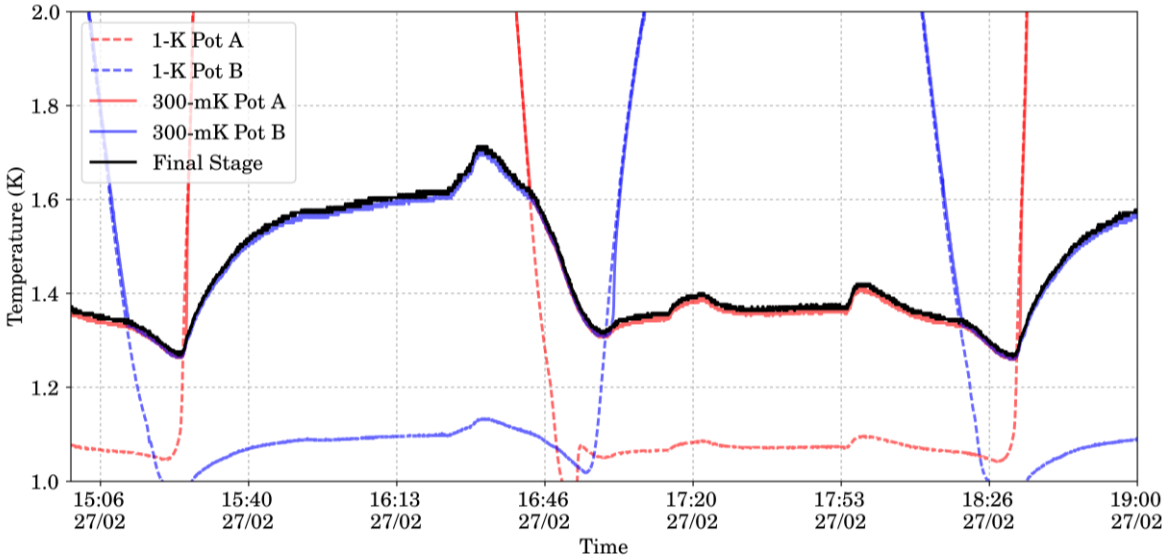

Figure 2: Cycle taken under 500 µW of leading. The difference in achieved final stage temperature (black line) for the A and B subsystems can be clearly seen.

LOAD CURVE MEASUREMENTS

A 10-kΩ heater was installed on the final-stage head of the system and the current through this controlled to produce a given heat load. Initially the heat load was set to the maximum value of interest, 500 µW. With the leading present the cycle parameters were tuned to optimise performance.[1] The final parameter settled upon are given in Table 1. It is interesting to note that, compared to when operating in 300-mK mode, the overall performance in 1-K mode is much less sensitive to variations in the cycle parameters.

[1] During this optimisation the issue of the discrepancy in performance between the A and B subsystems was investigated. It was found that altering the cycle parameters did little to mitigate this issue leading to the conclusion that the underlying causes was due to a poorer thermal link on the B subsystem.

Table 1: Default auto cycle parameters for unloaded system

Parameter	Value
Delay after switching off heat switches	480 s
Target baseplate temperature	4.8 K
Pump temperature	40 K
Condensing time	40 minutes
Time between subsystem cycles	90 minutes

These setting produced the performance illustrated in Figure 2 and were used for all power loadings. At each power level the maximum, minimum and approximate average temperature for the A subsystem cycle were recorded. These are shown in Figure 3. In deployment, it is likely that one may want to regulate the temperature through the use a PID controlled heater on the final stage. Irregardless, it is still the highest temperature, top of the shaded region in Figure 3, which is of interest. The data show that, for a 500-µW load on the final head, the achieved temperature is close to 1.4 K.

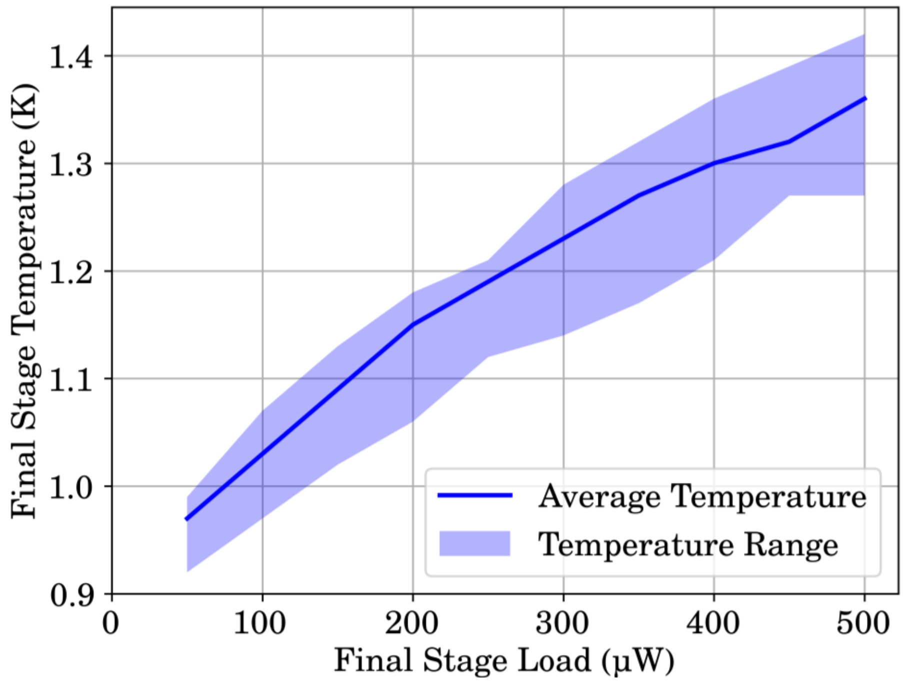

Figure 3: Load curve for continuous cooler operating in 1-K mode.

CONCLUSIONS

This brief study has shown that it should be possible to cooler an intermediate stage of MUSCAT instrument to at least 1.4 K continuously using a simplified version of the IPS continuous 300-mK cooler. It is believed that a specifically designed 1-K continuous cooler should offer improved performance to that shown here due to removing the poor thermal interface used here (copper foils). Furthermore, such a system is likely to be able to increase the efficiency of consecutive cycles in a way comparable to that seen when operating this module in 300-mK mode.