Development of Miniature Stirling Cryocooler for HOT Applications

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ABSTRACT

To support the needs of high-operating-temperature (HOT) applications, LE-TEHNIKA has started development of suitable cryocoolers. This has led to further miniaturization of our SRI (Stirling Rotary Integral) coolers. Two new coolers have been added to our lineup and are being tested at the moment: the SRI483, and a bit bigger SRI483GP. Their masses are around 115 g and 170 g, respectively (without a cold finger and electronics). They have both 12V internal motors and separate electronics and have an interface suitable for a SWAP cold finger (6 mm diameter). Their cooling powers range from 0.5 W to 1 W (110 K-150 K at room temperature), the GP version being the more powerful. Together with development of these new coolers, development of suitable dewar vessels for measurement of their performance has also taken place. As a result, several dewar vessels with thermal losses of around 160 mW at 77 K have been manufactured in-house.

INTRODUCTION

Considering integral Stirling rotary cryocoolers, LE-TEHNIKA has developed them in various sizes and cooling powers for temperatures around 80 K. The biggest is 1W SRI475 and the smallest is 0.25W SRI421. However, with rising demand to cool sensors to temperatures around 150 K, smaller cooling powers are needed which further generated demands for reduced mass and volume of coolers. This motivated further miniaturization of our SRI coolers at LE-TEHNIKA. As a primary goal, a cooling power of 0.5 W at 150 K was set. Next, we tried to fit the cooler into a volume of approx. 40 x 40 x 40 millimeters. For the dewar interface, a 30-millimeter long 1/4" SWAP cold finger with a inner diameter of 6.1mm was selected. Further-on, this produced a need for dewar vessels suitable for evaluation of the cooling performance of the newly developed coolers. As dewar vessels with solid insulation had too high thermal losses for evaluation of cooling performance in steady-state, vacuum dewar vessels were developed (Figure 1).

SRI483 AND SRI483GP CRYOCOOLERS: MASSES AND DIMENSIONS

Figure 3 shows the physical appearance of the SRI483GP cooler with integrated SWAP dewar vessel. Figure 2 shows a first prototype of its smaller sibling SRI483 with integrated SWAP cold finger. Both coolers were developed simultaneously, as final cooling power requirements were not known yet at the time of development. However, thermodynamic analysis showed that a relatively broad range of cooling powers can be achieved with a given thermal working cycle. The main

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Figure 1. SWAP vacuum dewar vessel after pinch-off.

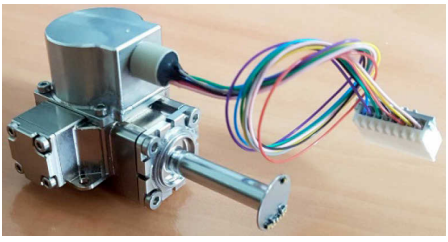

Figure 2. SRI483 cryocooler with SWAP cold finger.

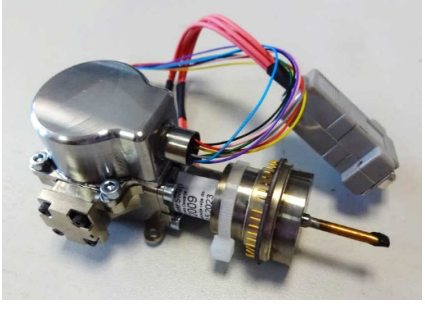

Figure 3. SRI483GP cryocooler with SWAP dewar vessel.

constraint in this case was input power, so two motors with different power characteristics were selected. The difference in motors accounts for the main weight increase of the SRI483GP compared to the SRI483, which is almost one third lighter than the GP-version (Table 1 and Figure 4). Initially, the mass of the SRI483 was below 100 g, but was later increased on account of a filling port sharing geometry with the SRI401 and SRI475 coolers.

Considering dimensions, the SRI483 cooler came quite close to the desired 40mm 'box', with only the height being 1 mm above (Figure 5). The SRI483GP is also near, having dimensions of 43.9 x 40 x 43.5mm (Figure 6). Figure 6 also shows a new design of motor cover which has integrated connector for electronics, contrary to previously used encapsulated cables (Figure 3). This design should further simplify assembly and make it more cost effective. Both coolers have the same attachment points.

Table 1. Masses of SWAP dewar and cryocoolers.

	SWaP dewar (with connector)	SRI483 with dewar	SRI483GP with dewar	SRI483 w/o dewar	SRI483GP w/o dewar
mass [g]	44.2	159.8	213	115.6	168.8

Figure 4. Masses of SWAP dewar vessel, SRI483 and SRI483GP cryocoolers.

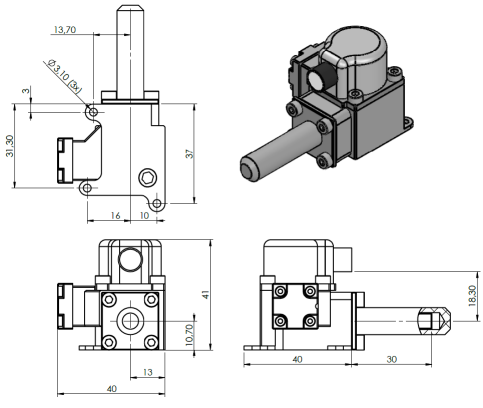

Figure 5. SRI483 cryocooler dimensions

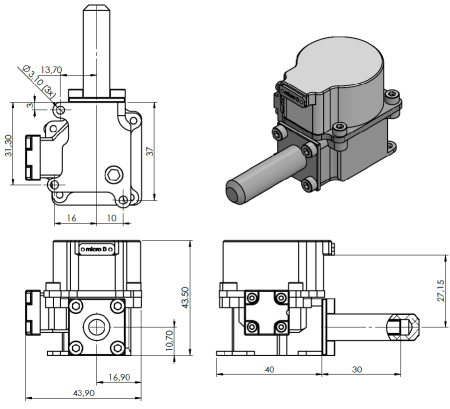

Figure 6. SRI483GP dimensions with new connector for electronics.

SRI483GP COOLING PERFORMANCE

At room temperature, SRI483GP has the possibility to produce more than 750 mW of total cooling power at 150 K (Figure 7), while at 110 K it still produces more than 550 mW. These levels of performance are obtained with a power consumption around 6 W. However, this figure only shows the top border of the achievable power envelope, as in a specific application, the actual efficiency at a given filling pressure has to be considered. As is shown in Figure 8, at a lower filling pressure, the efficiency curve has a peak at lower powers, while at a higher filling pressure, the peak moves towards higher powers. For a filling pressure selected somewhere in the middle of the range, the cooling performance of the SRI483GP cooler is shown in Figures 9 and 10.

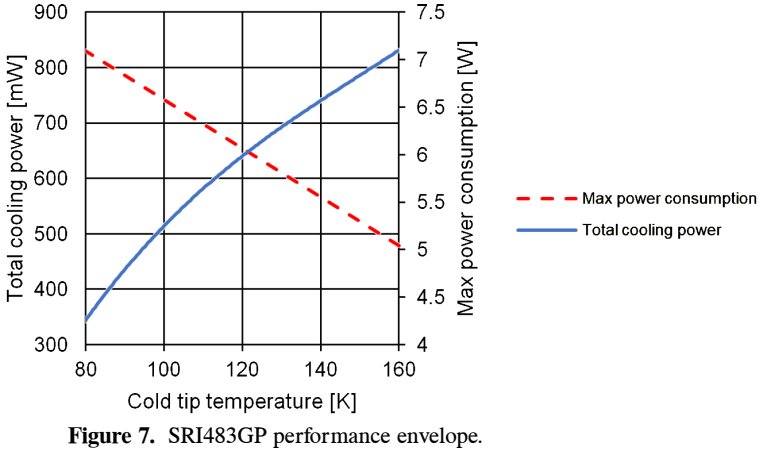

Figure 7. SRI483GP performance envelope.

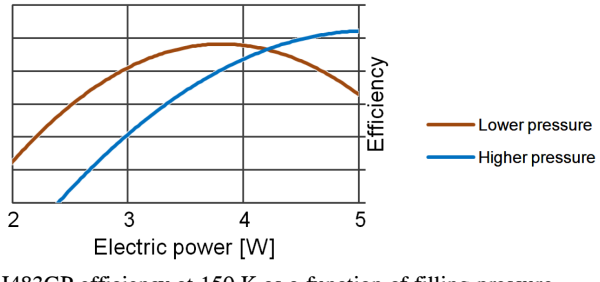

Figure 8. SRI483GP efficiency at 150 K as a function of filling pressure.

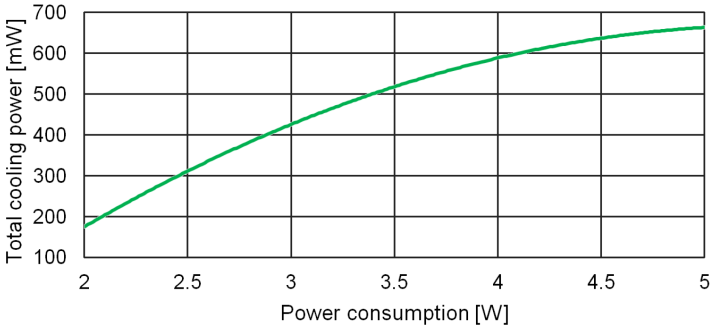

Figure 9. SRI483GP cooling power and power consumption at 150 K.

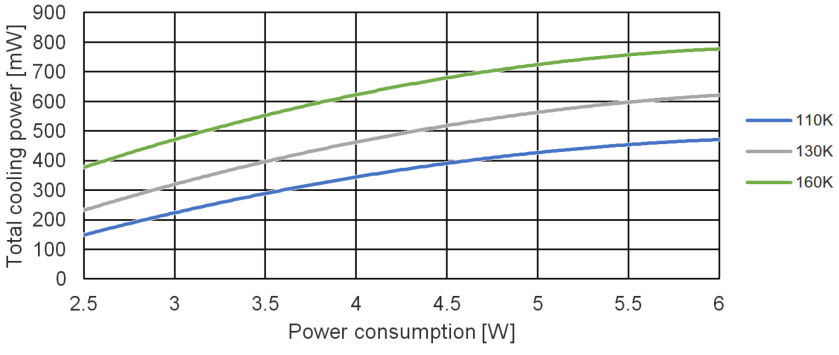

Figure 10. SRI483GP cooling power at various cold tip temperatures (ambient is at room temperature).

SRI483 COOLING PERFORMANCE

Figure 11 shows upper range of total cooling power for the SRI483 cooler at room temperature. It can be seen that it ranges from approx. 360 mW at 110 K to 580 mW at 160 K. Power consumption in that range is relatively low and does not exceed 4.5 W. In cases where higher power consumption is permitted, cooling power can be further increased.

For a given filling pressure, measurements of SRI483 thermal performance are presented in more details in Figure 12.

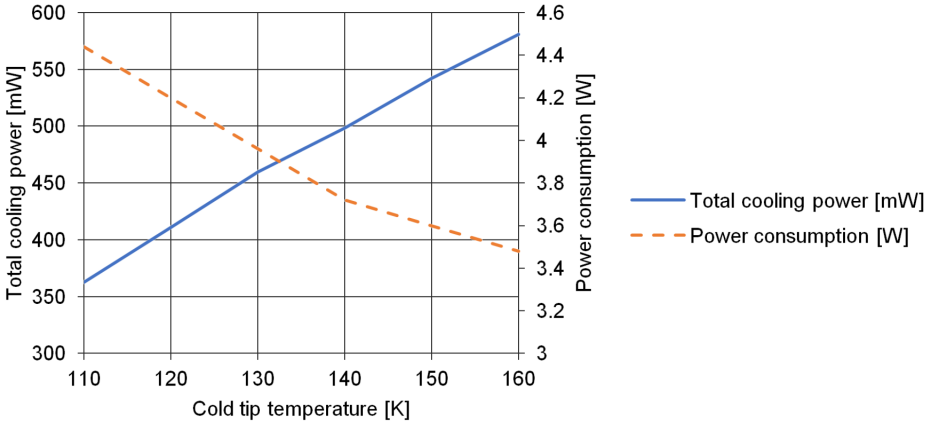

Figure 11. SRI483 performance envelope.

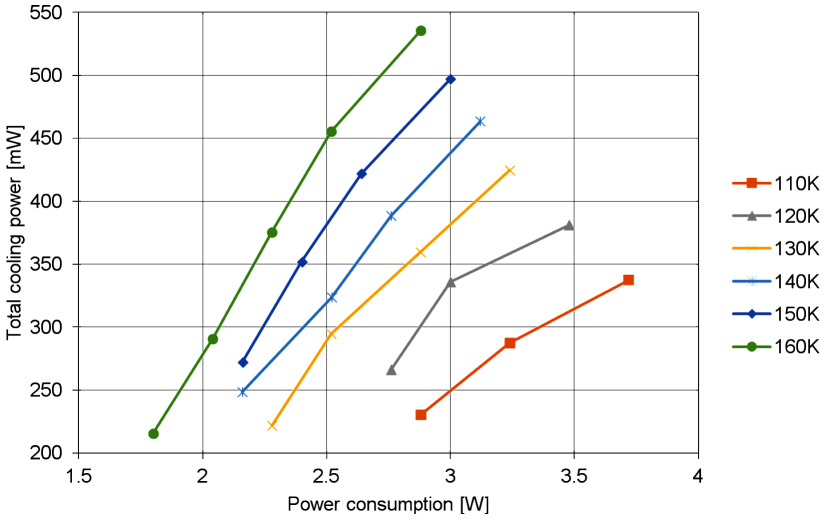

Figure 11. Measurements of thermal performance of SRI483 cooler at room temperature.

CONCLUSIONS

Two new miniature coolers in our SRI family have been developed by LE-TEHNIKA. They are both intended to cool to higher temperatures around 150 K and have approximately 0.5 W of cooling power. Their main difference is in mass and size. The smaller SRI483 weighs around 115 g, and the bigger SRI483GP weighs around 170 g, mainly on account of a more powerful motor; the larger motor also increases its cooling power at room temperature to around 800 mW.

However, extensive testing is still under way as well as development of electronics which will be in a separate package. Development of electronics was delayed because of shortage of electrical components but is expected to be finished in autumn 2022.