QUALIFICATION AND TEST RESULTS OF A 5 WATT COMMERCIAL STIRLING CRYOCOOLER

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ABSTRACT

We have successfully developed and qualified a 5-Watt Stirling cryocooler that is suitable for commercial applications in the high temperature superconductor (HTS) wireless communication systems. The cooldown time to 77 K is less than 5 minutes (with 4 Watts heat load and a thermal mass of 1465 Joules). The cooler can provide a refrigeration capacity of ~5 Watt at 70 K. The qualification and test results of this cooler are discussed.

INTRODUCTION

With the emerging industry of cryoelectronics, HTS suppliers need a low cost, high efficient and long life cryocooler. Much effort has been invested in the production of such a cooler [1-7], involving both space and tactical cooler manufacturers. Space coolers have the advantage of long life, but the lack of experience in mass production and cost cutting make the cooler quite unattractive in price. Tactical coolers on the other hand are low cost, but the cooler life suffers, as the mean time to failure (MTTF) of 4000 to 10,000 hours falls short of the 5 years expectation. A convergence in the field of cryocoolers is taking place, with space cooler manufacturers trying to cut cost drastically, and the tactical cooler manufacturers trying to extend cooler life.

FIGURE 1. A photograph of the B5000E Cooler.

FIGURE 1 shows a picture of the CMC B5000E Cryocooler. The cooler is common in design to the smaller models described elsewhere [8-12]. The physical dimensions and operating conditions of the cooler can be found in TABLES 1 and 2, respectively.

TABLE 1. Physical Characteristics

Weight	< 4.54 kg
Compressor Diameter	7.98 cm
Coldfinger Tip Diameter	1.3 cm
Coldfinger Length	4.318 cm
Expander Flange Diameter	5.537 cm
Expander Flange Thickness	0.429 cm

TABLE 2. Operating Condition

Charge Pressure	3.15-4.54 MPa
Frequency	45 Hz
Voltage	28 V
Maximum Input Power	240 W
Ambient Temperature	-54°C to 85 °C
Heat Load	0-5 W

Experimental Results

FIGURE 2 shows the cooldown characteristic of the B5000E cooler, with 1465 joules of thermal mass. The cooler takes around 2 minutes to reach 77 K with zero heat load applied during cooldown. With a heat load of 4 W, the cooldown time to 77 K is less than 5 minutes. Cooldown time as a function of thermal mass size can be found in FIGURE 3.

Refrigeration capacity (with 28 V input power) as a function of coldtip temperature is presented in FIGURE 4. The cooler reaches a temperature below 30 K with no load and can lift > 5 Watts at 70 K. Load curves of the B5000E cooler at three ambient temperatures are plotted in FIGURE 5. At an ambient temperature of 71 C, the cooler provides an impressive cooling capacity of >5 Watts at 77 K.

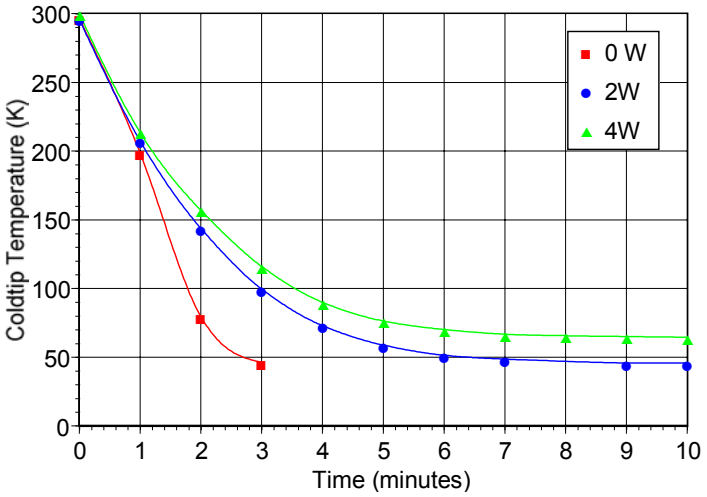

FIGURE 2. Cooldown characteristics of the B5000 cooler.

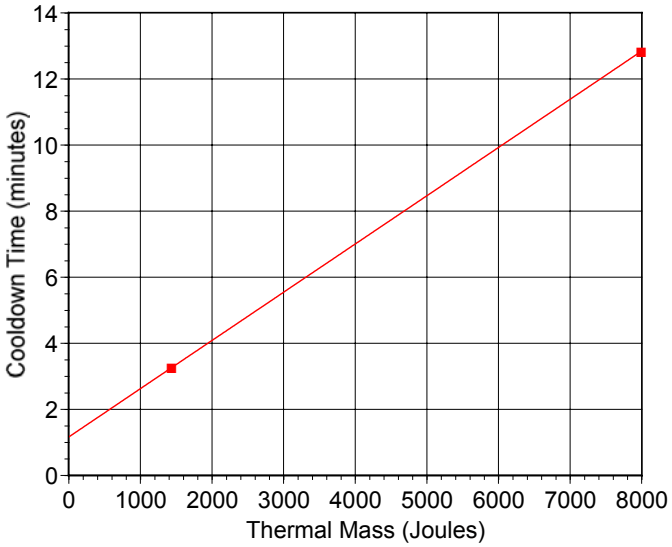

FIGURE 3. Cooldown versus thermal mass.

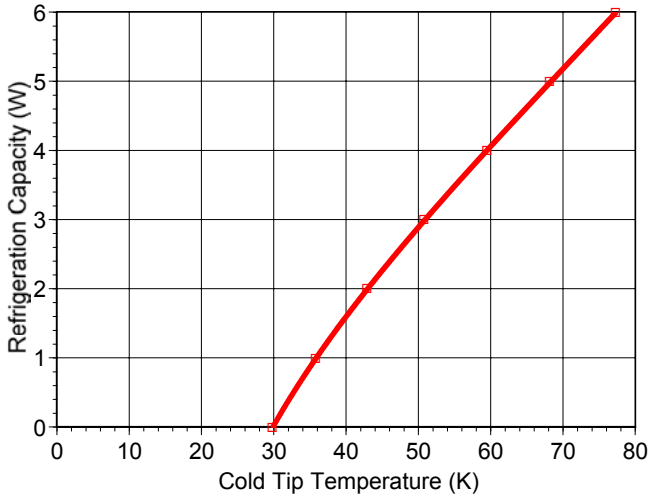

FIGURE 4. Refrigeration versus coldtip temperature.

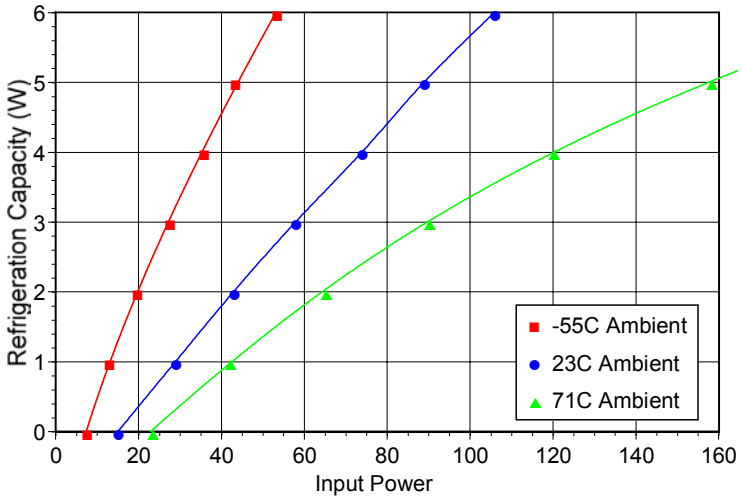

FIGURE 5. Refrigeration versus input power.

High Efficiency

The efficiency of the B5000E cooler is presented in FIGURES 6 and 7. In FIGURE 6, the specific power (W/W, input power / refrigeration) is plotted against the refrigeration capacity. The cooler achieves a specific power of ~18 W/W at 77 K (23°C ambient temperature), which is among the lowest in both space and commercial coolers. The specific power is only 30W/W at an ambient temperature of 71°C.

FIGURE 7 compares the efficiency of the coolers in the literature per weight of the cooler. With a specific refrigeration of 1.5 W/kg, the B5000E cooler is among the most efficient commercial coolers in the market.

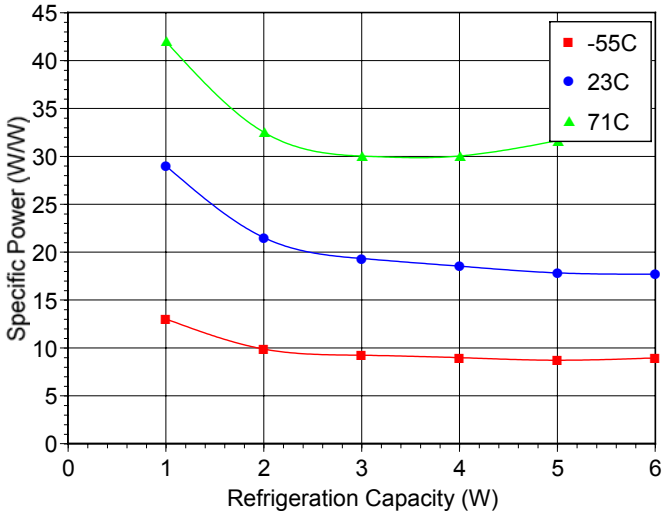

FIGURE 6. Specific power versus refrigeration.

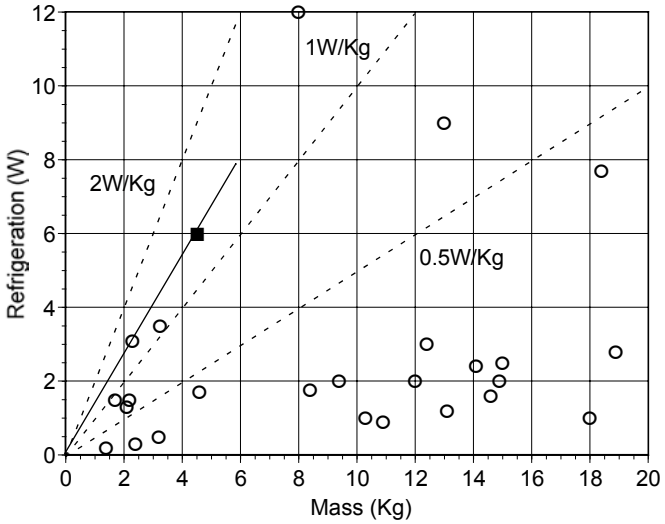

FIGURE 7. Refrigeration versus cooler weight, solid square-B5000E cooler, open circles-coolers in the literature.

Long Life

The B5000E cooler had gone through qualification tests as described in TABLE 3. The cooler has accrued more than 4,500 hours of run time to date. This cooler shares the same design as other CMC models that have demonstrated more than 10,000 hours of run time. It is fully anticipated that the life of the B5000 cooler will exceed 10,000 hours. TABLE 4 summarizes the life time of various CMC cooler models. It is noteworthy that the B512B life test is still in progress after demonstrated a run time of close to 13,000 hours. The life test started with four coolers. One of the units failed at around 10,000 hours. It was determined that the failure was due to mechanical interference of the moving displacer and the coldfinger. With a new displacer and coldfinger, the unit passed ATP showing that there is still a lot of life remaining in the compressor.

TABLE 3. Qualification of the B5000 Cooler*

Test Parameter	Description
Humidity	10 days at 100% relative humidity
Altitude	50,000 ft between –40°C and 71°C
Temperature Shock	From –54°C to 91°C
High Temperature Low Temperature	95°C Storage 7 days 95°C Operational 3 days -54°C Storage 4 hours -54°C Operational 4 hours
Imposed Vibration	Operational – 5–2000 Hz (16 G max) random vibration, MIL-STD-810D
Imposed Acceleration	Between –9.7 G and 9 G
Life/Reliability **	>4,500 MTTF

*The qualification tests were performed on a B5000D cooler which has a different expander.
**The life test is still in progress.

Life test results of the B5000 cooler to date can be found in FIGURES 8 to 10. The life test unit has a 1.83 meter long transfer line and a 18 grams Cu thermal mass.

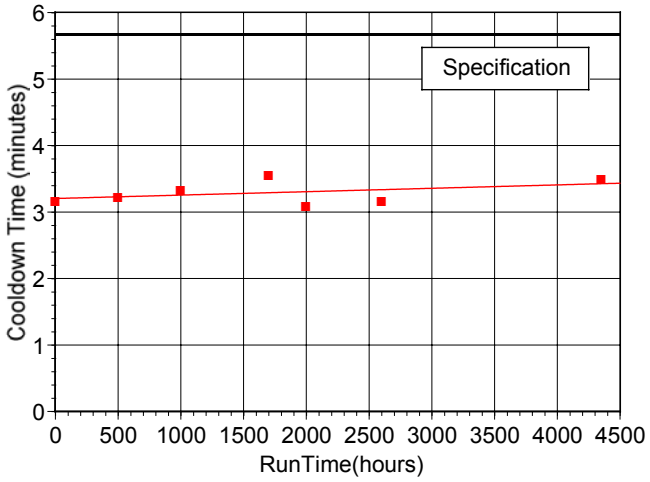

FIGURE 8. Cooldown time to 65 K as a function of run time, with 0.5 W heat load applied during cooldown.

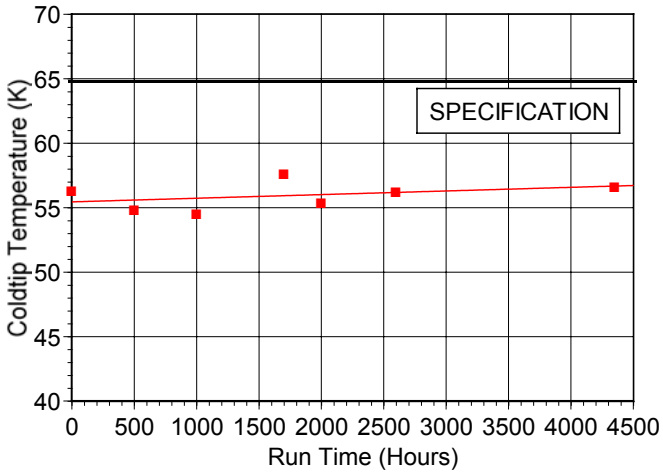

FIGURE 9. Coldtip temperature as a function of run time, with 28 V input power and 0.75 W heat load applied to the coldtip.

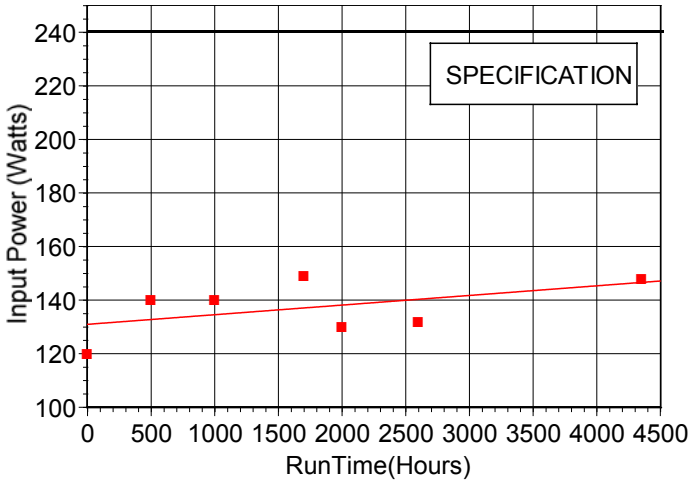

FIGURE 10. Input power as a function of run time, with coldtip temperature at 65 K and 0.75 W heat load.

TABLE 4. Life test results of other CMC Models of the same design

Model	Life (hrs)
B512B	> 12,900*
B602C	10,008
B1000E	11,750

* Life test in progress

Life test of the B5000 cooler is still in progress. Based on the life test of other models of the same design (Table 4), CMC fully anticipates that the life of the B5000 cooler will exceed 10,000 hours. CMC is actively pursuing to extend the life of our coolers through material selection, life predictions [13,14], contamination studies [15,16], and new designs (including pulse tube [17,18] and flexure bearings [17]).

CONCLUSIONS

A new 5 Watt cooler from CMC Electronics is introduced in this paper. This cooler is low cost (compared to space coolers), of high efficiency and reliable. It provides fast cooldown and high refrigeration capacity. With a thermal mass of 1440 joules, the cooldown time to 77 K is around two minutes. The cooler is very efficient, giving 5 W of cooling capacity at 77 K, even at an ambient temperature of 71°C.

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