

## **EXPERIMENTAL PERFORMANCE OF THE BEI ONE WATT LINEAR (OWL) STIRLING COOLER**

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### **ABSTRACT**

The experimental performance of the BEI One Watt Linear (OWL) Cooler is presented in this paper. In particular, the compliance with the Army specification will be discussed in detail. The cooldown time of the BEI OWL Cooler (to 77K) is less than 7 minutes with a thermal mass of 1465 Joules (at 23C ambient temperature). Its refrigeration capacity at 77K is 1.8W with 40W of input power, and 1W with 25.8W input power (at 23C ambient temperature).

### **INTRODUCTION**

The BEI OWL cooler is one of many in a family of linear Stirling-cycle cooler designs developed by the company.

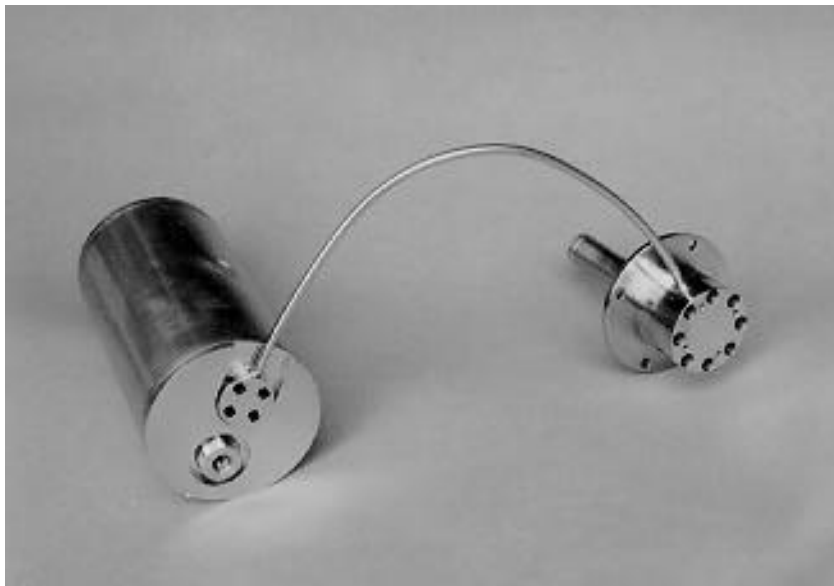
BEI's involvement in cryocoolers began with a corporate sponsored project in 1991 to develop a closed-cycle Joule-Thomson cooler for high-temperature-superconductivity application. After achieving limited success with a mixed gas refrigerant, the company leveraged its expertise in linear compressor technology to develop a miniature Stirling-cycle refrigerator for IR detector cooling.

The first miniature cooler designed for 150mW capacity at 78K has been well-received in the infrared user community<sup>1,2</sup>. BEI has recently enhanced the performance of this cooler by as much as 30% (Reference 1). A third design in BEI's family of coolers, in addition to the OWL Cooler, is the 350mW Linear Cooler. This design has recently undergone a flight test and

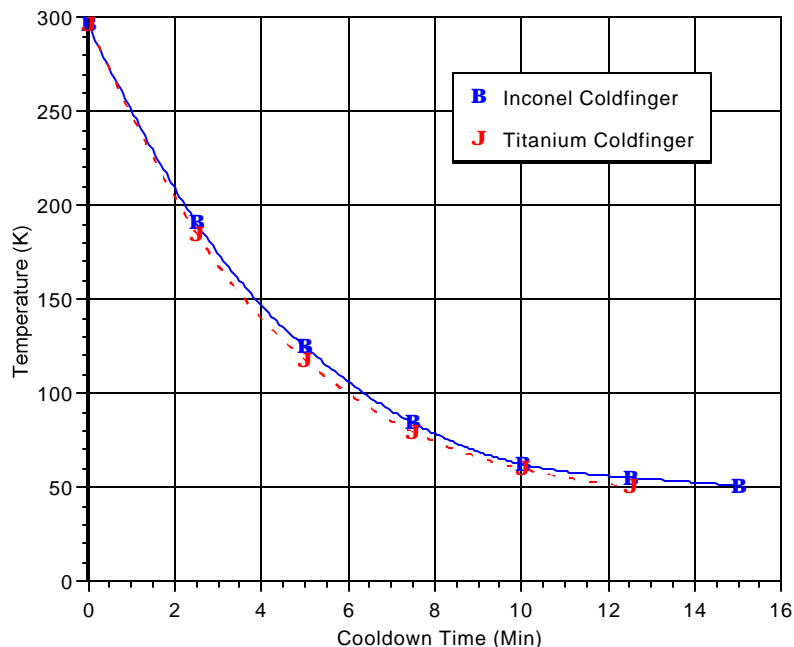
received high-marks on its performance. BEI has undertaken another development effort in the 1.75 Watt linear cooler. All these coolers are designed to satisfy their respective U.S. Army specifications. BEI is also in the process of developing a Dual Use Long-Life Low-Cost Pulse Tube Cooler<sup>3</sup>.

### **THE ONE WATT LINEAR (OWL) COOLER**

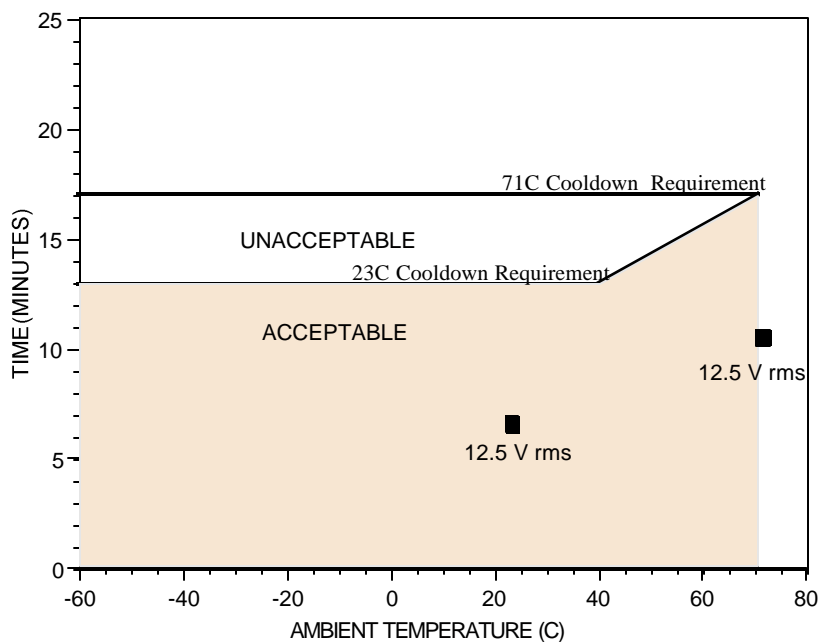
Figure 1 shows the external view of the OWL Cooler. The dimensions of this cooler are summarized in Table 1. The entire unit weighs only 3.8 lbs (meeting the Army requirement of 4.2 lbs).



**Figure 1.** The BEI OWL Cooler.



**Figure 2.** Cooldown characteristics of the BEI OWL Cooler.



**Figure 3.** Cooldown time versus ambient temperature.

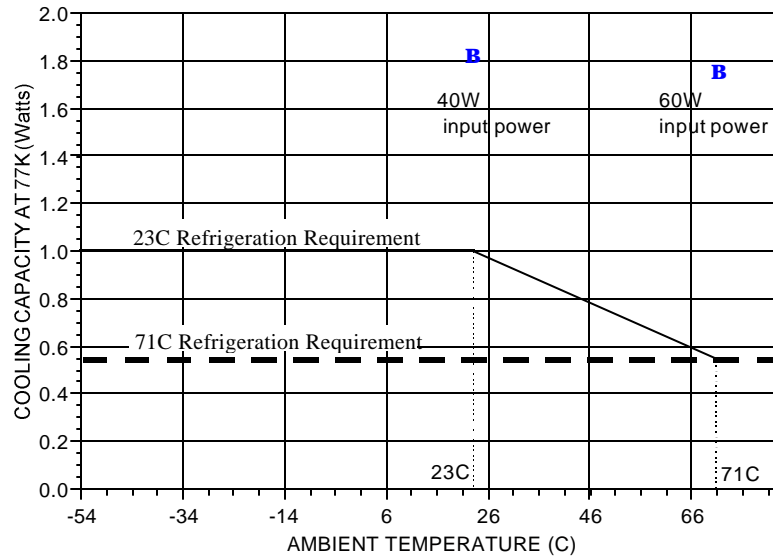
## COOLDOWN TIME

The cooldown time of a cooler is a function of the thermal mass and input power. Figure 2 shows a typical plot of coldtip temperature as a function of cooldown time (12.5 Volt rms, 23C ambient temperature) for the BEI OWL Cooler with an 8 inch transfer line and a thermal mass of 1465 Joules. The effect of using titanium as the coldfinger material as versus inconel is also shown, with a shorter cooldown time for the former, due to less static heat conduction.

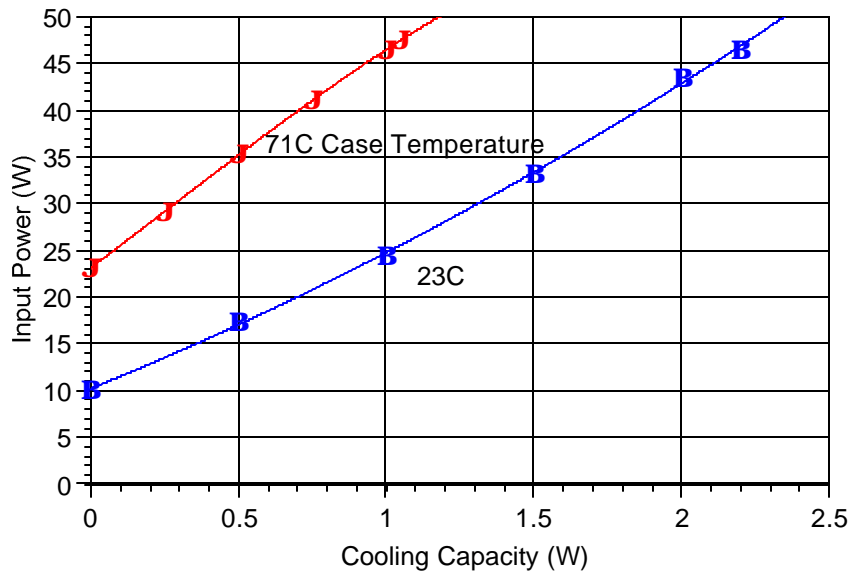
With a titanium coldfinger, the typical cooldown time to 77K is 6.8 minutes at 23C ambient temperature and 10.5 minutes at 71C ambient temperature, meeting the requirements of 13 minutes and 17 minutes respectively as depicted in Figure 3.

## COOLING CAPACITY

Figure 4 is a plot of cooling capacity as a function of ambient temperature. The data points in the figure represent that of a BEI OWL Cooler with a titanium coldfinger (with 40 Watts of input power). As one can see, the refrigeration capacity of the cooler (at 1.8 Watts) far exceeds that of the requirement (1 Watt) at 23C ambient. At a high ambient of 71C, the cooler provides 1.77 Watts of cooling at the maximum allowable input power of 60W.

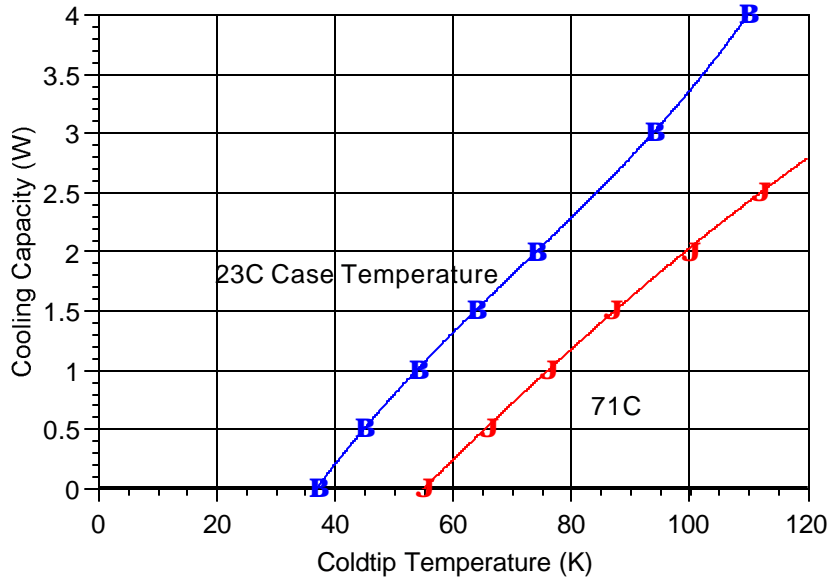


**Figure 4.** Cooling capacity as a function of ambient temperature.



**Figure 5.** Cooling capacity vs. input power.

Figure 5 is a plot of refrigeration capacity vs. input power. The BEI OWL Cooler can deliver as much as 2.25 Watt at 77K with an input power of 50 W, making this cooler a good candidate for the High T<sub>c</sub> Superconductor cooling. This cooler is also suitable for other commercial applications which require large cooling capacities. To increase the reliability of this cooler, flexure bearings or gas bearings can be incorporated into the compressor. The load curves of the BEI OWL cooler are plotted in Figure 6.

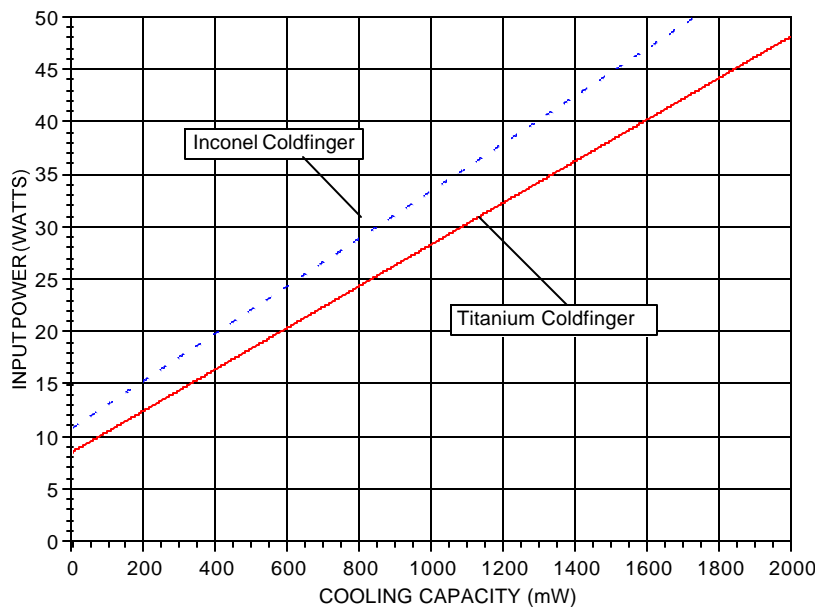


**Figure 6.** Cooling capacity vs. coldtip temperature.

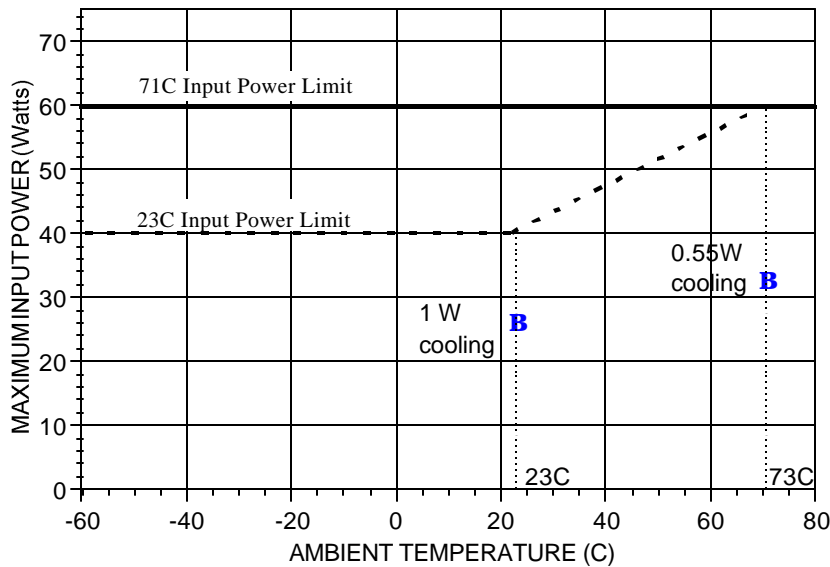
## INPUT POWER

Input power versus heat load of the BEI OWL Cooler (at 23C ambient temperature) is plotted in Figure 7 for both the inconel and titanium coldfingers. As expected, the latter outperformed the former due to less parasitic heat conduction along the coldfinger.

Maximum input power as a function of ambient temperature is shown in Figure 8. At 23C ambient temperature, the cooler provides 1 Watt of cooling with an input power of 25.8 W (more than 14W below the requirement), and at 71C ambient temperature, the cooler delivers 0.55 Watt of cooling with an input power of 32.4W (more than 27W below the requirement).



**Figure 7.** Input power as a function of cooling capacity.



**Figure 8.** Maximum power versus ambient temperature

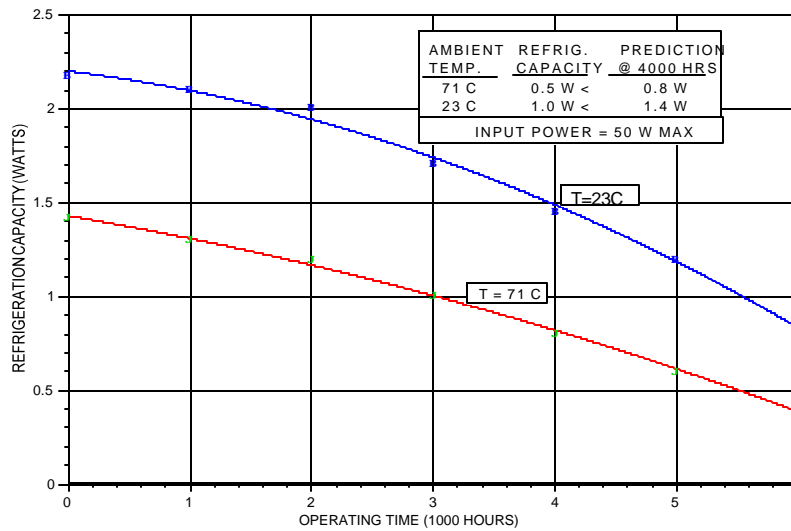
## RELIABILITY

According to the Army specification, a failure is characterized by failure in performance in one of the five areas, namely, minimum refrigeration, cooldown time, input power, leak rate, and vibration. BEI has ample experience in the life-test of a similar cooler from which the current proposed cooler was designed, based on scaling. Experimental results show that within 4000 hours of operation, the input power of the cooler did not exceed the specification. Figure 9 shows the life projection of the BEI OWL cooler based on analysis assuming that the life of the cooler is dictated by the wear within the compressor. After 4000 hours, the cooling capacity of

the proposed cooler is predicted to be 1.4W at 23C and 0.8W at 71C, exceeding the requirement of the U.S. Army.

## QUALIFICATION AND LIFE TESTS

Three BEI OWL Coolers have been fabricated and sent to the U.S. Army for environmental test to be followed by another three units for life tests. These units will be tested for vibration output, audible noise, and electromagnetic radiation. The results will be published in another paper.



**Figure 9.** Predicted life time of the BEI OWL Cooler.

## CONCLUSIONS

Experimental performance of the BEI One Watt Linear (OWL) Cooler is presented in this paper (as summarized in Table 1). The performance of this OWL Cooler far exceeds the U.S. Army's specification. Six units are scheduled to undergo environmental and life tests, and their results will be reported elsewhere. The BEI OWL Cooler is also suitable for other commercial applications which require large cooling capacities. To increase the reliability of this cooler, flexure bearings or gas bearings can be incorporated into the compressor.

**Table 1.** Specification Compliance

Ambient Temperature	-54C	23C	71C
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	Specificatio n	Performance	Specification	Performance	Specificatio n	Performance
<b>Cooldown Time to 77K</b>	13 min.	4.5 min (12.5 V)	13 min.	6.8 min. (12.5 V)	17 min.	10.5 min. (12.5 V)
<b>Cooling Capacity @77K</b>	1.0 W	1.61W @ 40W Input Power	1.0 W	1.8W @ 40W Input Power	0.55 W	1.75 W @ 60W Input Power
<b>Maximum Input Power @77K</b>	40 W	24 W (1W cooling)	40 W	25.8 W (1W cooling)	60 W	32.4 W (0.55W cooling)

## REFERENCES

1. D.T. Kuo, A.S. Loc, and S.W.K. Yuan, Enhanced Performance of the BEI 0.5 Watt Mini-Linear Stirling Cooler, parallel paper in Cryogenic Engineering Conference, Portland, Oregon, 1997.
2. D.T. Kuo, A.S. Loc, and S.W.K. Yuan, Experimental and Predicted Performance of the BEI Mini-linear Cooler, in the Proc. of the 9th International Cryocooler Conference (1997) p.119.
3. D.T. Kuo, A.S. Loc, and S.W.K. Yuan, Design of a 0.5 Watt Dual Use Long-Life Low-Cost Pulse Tube Cooler, parallel paper in Cryogenic Engineering Conference, Portland, Oregon, 1997.