Qualification of the BEI B512 Cooler, Part 1 - Environmental Tests

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ABSTRACT

BEI's involvement in cryocoolers began with a corporate sponsored project in 1991 to develop a closed-cycle Joule-Thomson cooler for a 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[1]. BEI has recently enhanced the performance of this cooler by as much as 30%[2]. In this paper, the qualification of this cooler to the Military Standard is discussed in detail.

INTRODUCTION

This is the first of two papers regarding the qualification of BEI's B512 cooler (Figure 1). The environmental tests performed are summarized here, while the results of the on-going life test are reported elsewhere.

Table 1 summarizes the performance specification at three different case temperatures. The following example illustrates the performance at 22 C. With an external heat load of 120 mW, the cooler cools down a 4.5 gram thermal mass from 22 C to 78K in less than 9 minutes. With an external heat load of 300 mW, the cooler maintains a cold tip temperature of 78K, with less than 14W of input power. With an input power of 20W, the cooler provides a minimum refrigeration of 400 mW.

Table 1- Performance Specification.

Case Temperature	Cooldown Time to 78K	Max. Input Power, Closed Loop	Min. Refrigeration
82 C	12 minutes / 150 mW	25 W / 300 mW	300 mW / 25 W
22 C	9 minutes / 120 mW	14 W / 300 mW	400 mW / 20 W

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-40C	6 minutes / 85 mW	8 W / 260 mW	400 mW / 16 W

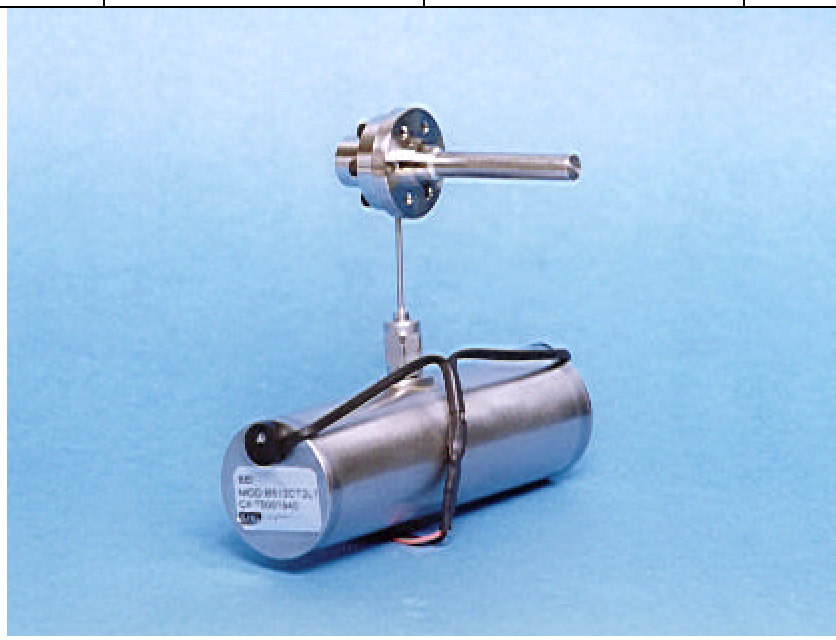

Figure 1. The BEI B512B Cooler

ENVIRONMENTAL TESTS

The Environmental Tests are comprised of the audible noise test, vibration output test, basic shock test, non-operational vibration test, and gun-firing shock test, and will be discussed in the following sections.

Audible Noise Test

The audible noise test was performed by the Night Vision and Electronic Sensors Directorate (NVESD) on a BEI B512C cooler (Serial number N0043). Sound pressure was measured along six axes of the cooler, one meter from the microphone. Table 2 summarizes the measured sound levels in dB as a function of center frequency, Hz.

To convert the above sound levels to a distance of 10 m (instead of 1 m), the following equation was employed.

$$dB(X_1) = dB(X_1)+20\log(X_1/X_2) \quad (1)$$

where X_1 is the 1 m distance, and X_2 is the 10 m distance.

Table 2. Sound Levels Measured at One Meter Away from the Cooler.

	Center Frequency (Hz)						
	125	250	500	1000	2000	4000	8000
Background	29.6	20.4	$\leq$10.0	$\leq$10.0	$\leq$10.0	$\leq$10.0	$\leq$10.0
Position 1	30.6	25.5	$\leq$10.0	24.6	31.7	30.0	37.2

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Position 2	29.5	23.6	≤10.0	29.5	38.6	30.1	36.9
Position 3	29.8	24.2	≤10.0	25.8	36.4	28.6	37.2
Position 4	33.2	23.6	≤10.0	30.6	36.2	28.0	35.9
Position 5	31.8	26.1	≤10.0	26.8	34.5	29.8	33.7
Position 6	31.4	29.5	≤10.0	27.5	35.3	26.5	35.4

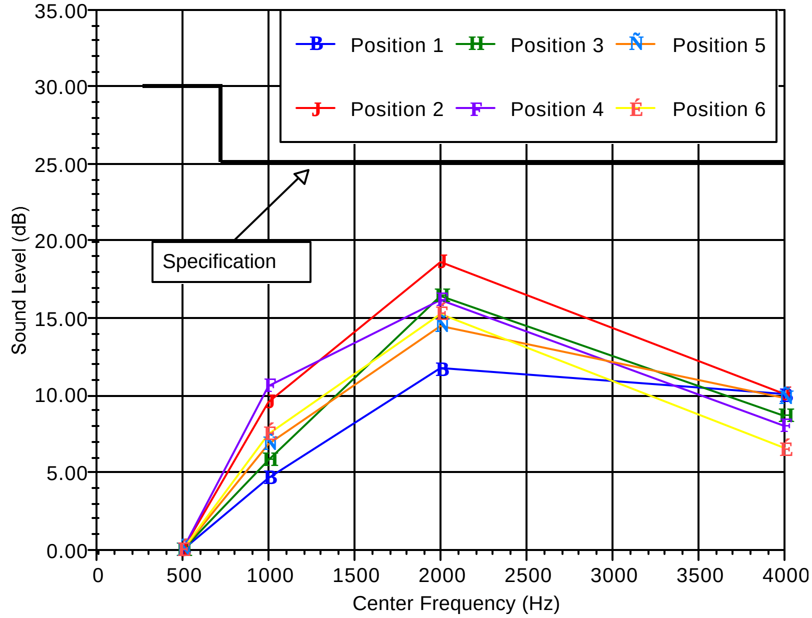

Figure 2. Measured sound level vs. center frequency.

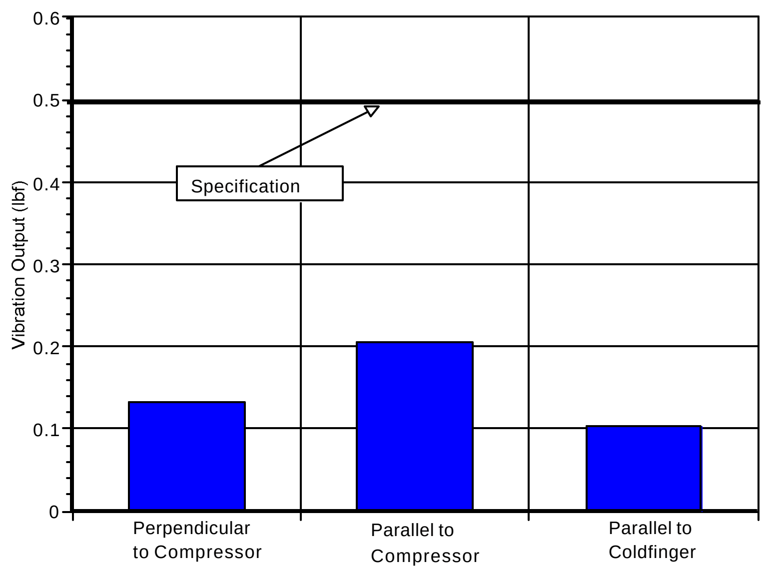

Figure 3. Vibration output forces.

Figure 2 shows the measured sound levels (at a distance of 10 m) as a function of the center frequency. The cooler met the specification for all frequencies.

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Vibration Output

The vibration output test was also performed by the Night Vision and Electronic Sensors Directorate (NVESD) on a BEI B512C cooler (Serial number N0043). Vibration output forces were measured in three directions. Figure 3 shows the vibration output forces along the three axes. The maximum vibration level was recorded on the axis parallel to the compressor. As noted, the forces are well below the specification of $0.5lb_f$.

Basic Shock

The basic shock test was performed at the facility of Environment Associates, Inc. Chatsworth, California. The cooler was subjected to shock impulses (half sine wave) of 30g for 18ms per MIL-STD-810C, Method 516.1, Procedure 1. Three shock impulses in each direction (+ and -) were imposed on all three axes for a total of 18 shocks. An ATP was performed immediately following the Basic Shock Test. When the cooler was first turned on, there was a large jerking motion and the unit then operated roughly. A clamped cable was discovered indicating that the cable was damaged by being clamped accidentally between the brackets of the shock/vibration fixture. It was verified that the cooler had been shorted. After careful inspection, it was noticed that the displacer spring bond was broken due to the shorted cable. The spring was reattached and bonded, and the cable repaired. The cooler then passed the performance ATP.

Non-Operational Vibration

The cooler was then subjected to the Non-Operational Vibration Test according to the spectral density profiles outlined in Tables 3, 4 and 5, of MIL-STD-810E, Method 514.4, Procedure I, Category 8. The test duration was 60 minutes per axis. An ATP was performed immediately following the Non-Operational Vibration Test. The cooler was found to operate in a rough manner for a couple of seconds and the abnormality subsided. The cooler then passed the ATP test.

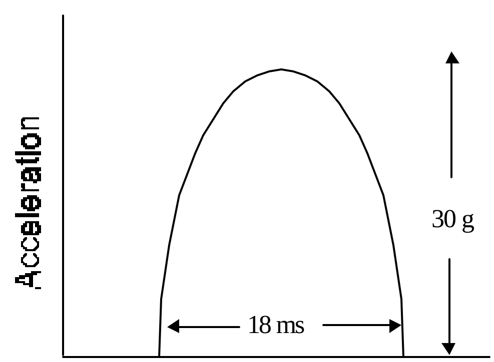

Figure 4. Basic shock profile.

Table 3- Vibration Spectrum Density Profile Along X-axis (Overall 18.05 grms)

Freq 1	Freq 2	PSD (g^2/Hz)	Slope	Mean SQ	Band GRMS

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5	15	1.0E-2	3.79	0.2432	0.4931
15	90	4.0E-2	0.00	3.000	1.7321
90	130	4.0E-2	11.31	3.6059	1.8989
130	140	1.6E-1	-56.12	0.8584	0.9265
140	340	4.0E-2	0.00	8.000	2.8284
340	485	4.0E-2	7.74	9.7496	3.1224
485	780	1.0E-1	0.00	29.500	5.4314
780	810	1.0E-1	238.13	19.1845	4.3800
810	915	2.0E+0	0.00	210.00	14.4914
915	1000	2.0E+0	-132.12	41.5903	6.4491
1000		4.0E-2			

Table 4- Vibration Spectrum Density Profile Along Y-axis (Overall 11.70 grms)

Freq 1	Freq 2	PSD (g^2/Hz)	Slope	Mean SQ	Band GRMS
5	15	1.0E-2	3.79	0.24	0.4931
15	340	4.0E-2	0.00	13.0	3.61
340	1000	4.0E-2	6.40	123.28	11.1
1000		4.0E-1			

Table 5- Vibration Spectrum Density Profile Along Z-axis (Overall 18.50 grms)

Freq 1	Freq 2	PSD (g^2/Hz)	Slope	Mean SQ	Band GRMS
	15	1.0E-2	3.79	0.2432	0.4931
15	30	4.0E-2	0.00	0.6000	0.7746
30	80	4.0E-2	2.12	3.0468	1.7455
80	120	8.0E-2	0.00	3.2000	1.7889
120	130	8.0E-2	60.32	2.0088	1.4173
130	160	4.0E-1	-33.27	4.5196	2.1259
160	200	4.0E-2	0.00	1.6000	1.2649
200	340	4.0E-2	13.02	23.9729	4.8962
340	520	4.0E-1	0.00	72.000	8.4853
520	610	4.0E-1	-30.25	17.5286	4.1867
610	845	8.0E-2	27.58	127.8548	11.3073
845	1000	1.6E+0	-46.14	85.6750	9.2561
1000		1.2E-1			

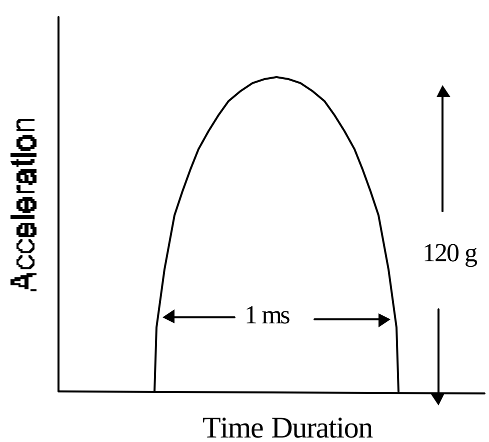

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Figure 5. Gun-Firing shock profile.

Gun-Firing Shock

The Gun-Firing Shock test was also performed at the facility of Environment Associates, Inc. Chatsworth, California. The cooler was subjected to shock impulses (half sine wave) of 120g for 1ms per MIL-STD-810C, Method 516.1, Procedure 1. Three shock impulses in each direction (+ and -) were imposed on all three axes for a total of 18 shocks. The profile of the gun-firing shock is presented in Figure 5. An ATP was performed immediately following the Basic Shock Test. The cooler was found to run rough. The operator tapped on the fill-port side of the compressor a few times and the roughness subsided. The cooler then passed the performance ATP.

POST-TEST ATP

The post-qualification ATP was performed a week after the other tests. The cooler passed the ATP with cooldown times of 7:57 minutes and 10:01 at 23 C and 82 C, respectively. Maximum refrigeration capacity was measured to be 500 mW at 23 C and 370 mW at 82 C. The input power was 12 W for 400 mW load at 23C and 19.6 W for 300 mW load at 82C.

CONCLUSION

The cooler passed all ATP tests following each environmental test described in this report. The life test of this cooler will be reported elsewhere.

REFERENCES

1 Kuo,D.T., A.S. Loc, and S.W.K.Yuan, Experimental and Predicted Performance of the BEI Mini-Linear Cooler, Cryocoolers 9, Plenum Press, New York (1997) p.119.

2 Yuan, S.W.K., D.T.Kuo, and A.S.Loc, Enhanced Performance of the BEI 0.5 Watt Mini-Linear Stirling Cooler, to be published in Proc. of Advances in Cryogenic Engineering, Vol. 43, 1997.

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