

## PERFORMANCE AND QUALIFICATION OF BEI'S 600 mW LINEAR MOTOR COOLER

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### ABSTRACT

BEI's B602 Linear Motor Cooler can deliver 600 mW of cooling at 78K with an input power of less than 30W. Cooldown time from room temperature to 78K is less than 3 minutes with a thermal mass of 250J. The cooler weighs less than 0.907 Kg and can operate at temperatures between 75°C and -54°C. In this paper, the performance of this cooler is discussed in detail. Environmental qualification of this cooler is also presented in this paper, in particular shock test, operational vibration, high and low temperature storage, interchangeability and vibration output, etc.

### INTRODUCTION

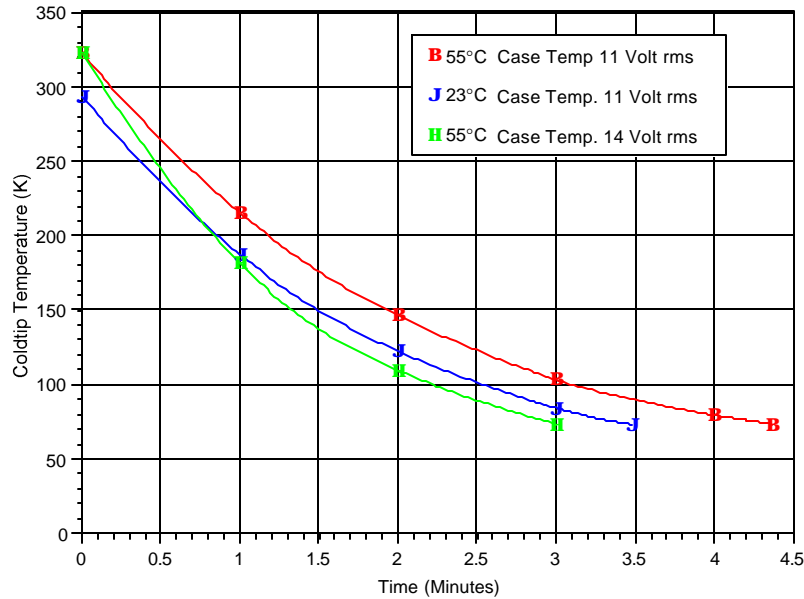
Among a vast variety of linear motor coolers manufactured by BEI<sup>1-8</sup>, the B602 model is widely used in Airborne GIMBAL and FSI SAFIRE systems. In this paper, performance and qualification of the B602 cooler are discussed. Weight and physical dimensions of the B602 cooler are listed in Table 1. Operating conditions of the cooler are listed in Table 2. The cooler has been tested extensively with charge pressure between 2.757 to 3.446 MPa. While the steady state performance of the cooler is more efficient at 2.757 MPa, the cool down time may be slightly worse.

**Table 1.** Physical Characteristics.

Weight	0.789 Kg
Compressor Diameter	4.445 cm
Cold finger tip Diameter	0.660 cm
Cold finger Length	5.080 cm
Expander flange Diameter	2.794 cm
Expander flange Thickness	0.435 cm

**Table 2.** Operating Conditions.

Charge Pressure	2.757-3.336 MPa
Frequency	60 Hertz
Voltage	11 Volts
Maximum Input Power	35 Watts
Ambient Temperature	-54°C to 75°C
Heat Load	600 mW



**Figure 1.** Cooldown time of the B602C cooler.

**Table 3-** Maximum voltage.

71°C	17.5 V
23°C	16 V
-40°C	11.5 V

## Performance

Figures 1 to 3 show the typical performance of the B602C cooler. The coolers discussed in this paper were charged to 3.336 MPa.

**Cooldown Time.** Figure 1 shows the typical cool down time of the B602 cooler at various case temperatures and input voltages. Typical cooldown time from room temperature to 78 K is about 3 minutes. At an elevated ambient temperature of 55°C, the cooldown time is approximately one minute longer. The maximum voltage for the B602C cooler is listed in Table 2. These are the maximum voltages that can be applied without having the compressor pistons hitting each other.

**Input Power.** Heat load curves of the B602C cooler at 73K are plotted in Figure 2. Average maximum refrigeration capacity was measure to be 550 mW at 71°C. The average input power was 35 W for 350 mW of heat load at 71°C. At room temperature, the B602C cooler can relieve 350 mW of heat load with an input power of less than 20 W.

**Refrigeration.** Figure 3 depicts the refrigeration as a function of cold tip temperature at 11 volt input power. Three ambient temperatures are included in the figure, namely -54°C, 23°C and 71°C. At 78K, the cooler can provide 0.9 W of cooling at 23°C ambient and 0.7 W of cooling at 71°C ambient. With no load, the cooler can reach a temperature of 33 K at 23°C ambient and 40 K at 71°C ambient.

## Environmental Qualification

Three coolers with serial numbers 525, 526, and 527 were tested for environmental qualification.

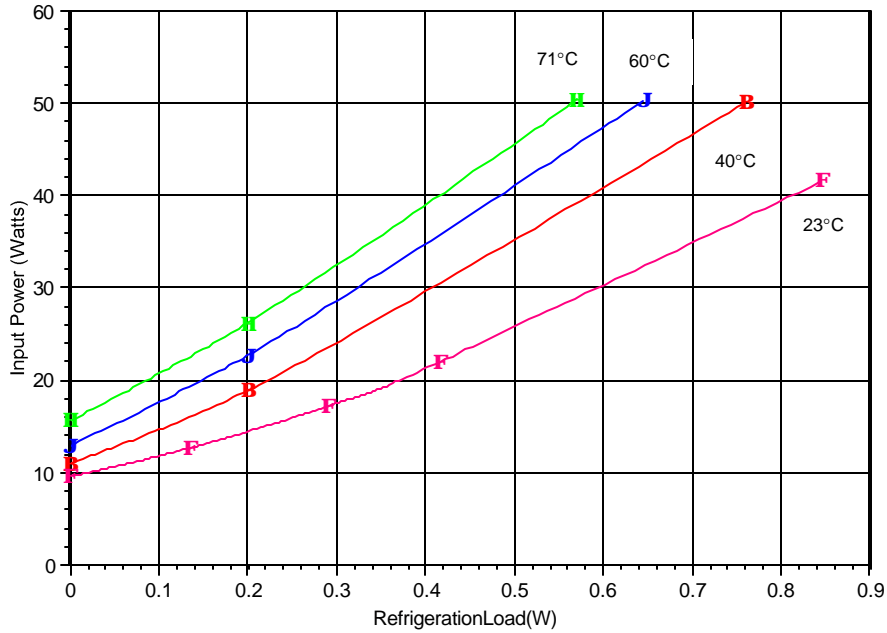


Figure 2. Input power versus refrigeration.

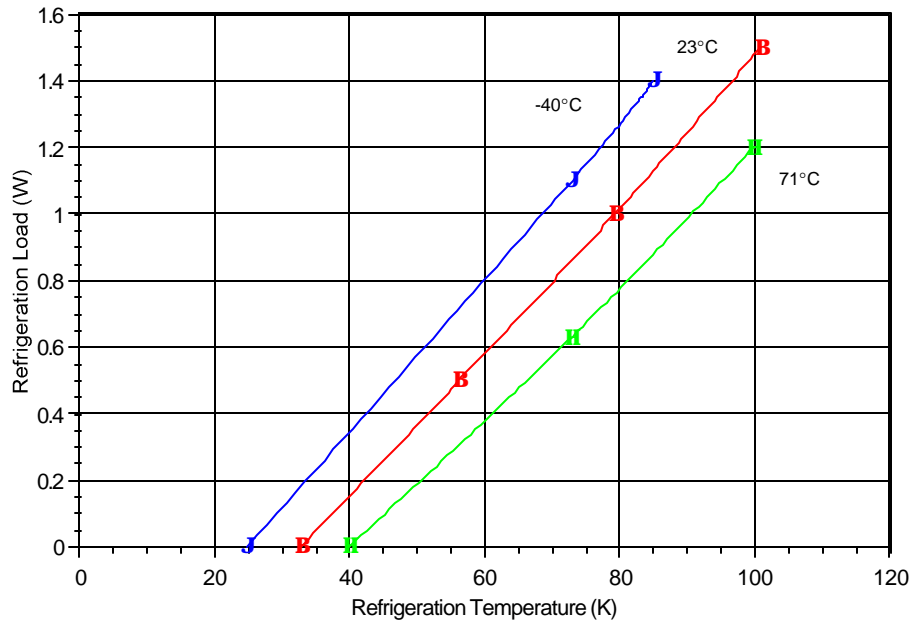


Figure 3. Refrigeration versus cold tip temperature.

Table 4. Specification for the B602C cooler.

	33°C	75°C
Cooldown Time* w/ 250J Thermal Mass	2:30 min	3:30 min
Min. Refrigeration @ 11.5V	750 mW	500 mW
Max. Input Power @ 350 mW	25 W	35 W

\*Cooldown starts at 23°C and 55°C respectively, instead of 33°C and 75°C.

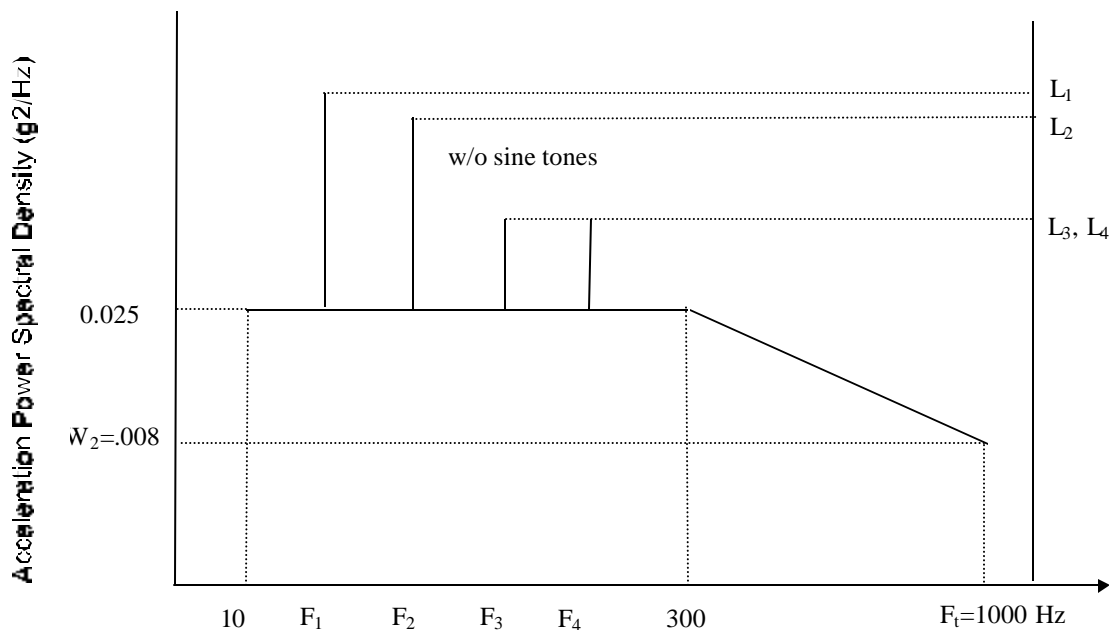
**High Temperature Soak.** The coolers were soaked in an elevated temperature of 71°C for 48 hours in a BEMCO environmental chamber per MIL-STD-810C, Method 501.1, Procedure 1, and found to meet the specification (in Table 4) afterwards.

**Low Temperature Soak.** The coolers were stored at -57°C for 24 hours in a BEMCO environmental chamber per MIL-STD-810C, Method 501.2, Procedure 1, and found to meet the specification (in Table 4) afterwards.

**Temperature Shock.** The Thermal Shock Tests were performed according to MIL-STD-810C, Method 503.1, Procedure. A BEMCO environmental chamber was set to 71°C and used as the high ambient soak. A Tenney Jr. III environmental chamber was set to -57°C and used as the low ambient soak. The coolers withstood changes in ambient temperature between -57°C and 71°C at a rate of 15°C per minute, and were found to meet the specification (in Table 4) afterwards.

**Operational Vibration Test.** The Operational Vibration Tests were performed at the facility of Environment Associates, Inc. Chatsworth. The coolers were subjected to a modified spectral density profiles (per MIL-STD-810D, Method 514.3, Category 6) as shown in Figure 4 for 60 minutes per axis. Acceptance tests were performed on the coolers at 71°C and they all passed the specification.

**Shock Test.** The Non-Operational Shock Tests were performed at the facility of Environment Associates, Inc. Chatsworth, California. The coolers were subjected to shock impulses (half sine wave) of 20g for 11ms in accordance with MIL-STD-810C, Method 516.2, Procedure 1 (Figure 5). Three shock impulses in each direction (+ and -) on each axis for a total of 18 shocks were applied. Acceptance tests were performed on the coolers at 71°C and they all passed the specification.



**Figure 4.** Spectral density profiles for operational vibration test.

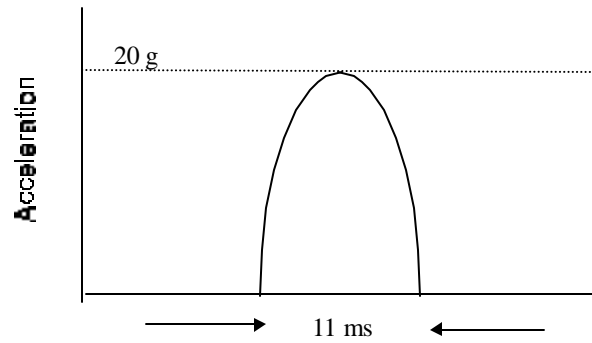


Figure 5. Shock Impulse.

**Interchangeability.** To satisfy the Interchangeability requirement, the expanders of the best performance cooler (Cooler Assembly S/N 525) and the worst performance cooler (Cooler assembly S/N 526) were swapped. Acceptance tests were performed on both coolers and both passed the specification.

**Vibration Output Test.** The Vibration Output Test was performed following the procedure supplied by Army's Night Vision Laboratory. In an open loop operation with an input voltage of 11.5 volts, vibrations were recorded along three axes for frequencies up to 20 KHz. All three coolers passed the vibration tests with less than 2.224 N in any of the three axes.

### Life Test

Two B602C coolers were used in the life test. The coolers were run at 45°C case temperature with a heat load of 350 mW at 73K. Instead of running the cold tip in a dewar, the cold fingers were inserted in a vacuum chamber. At 1700 hours, a power failure took place in a section of BEI's laboratory, which stopped the vacuum pump with the coolers still running.

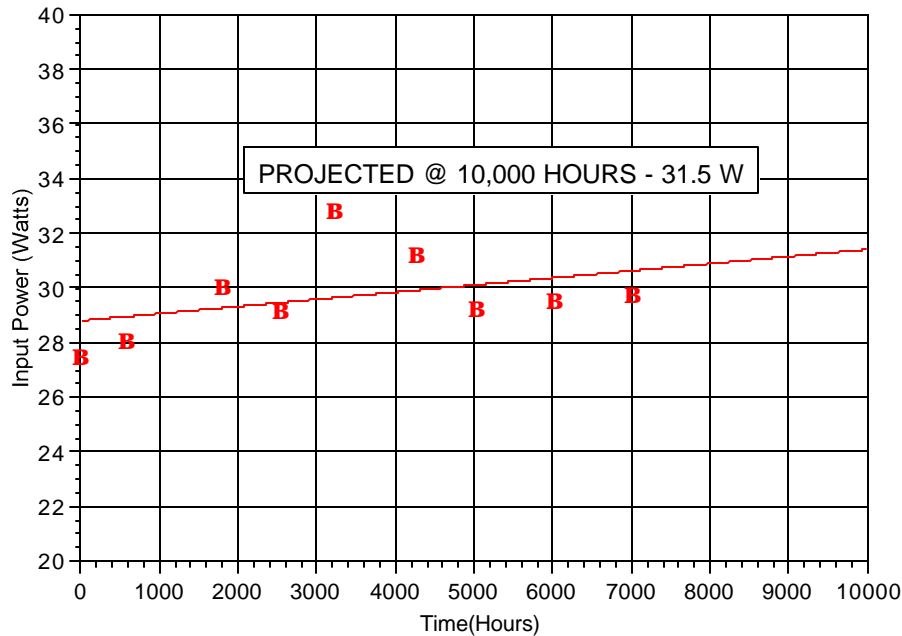


Figure 6. Input power vs. life for B602 cooler.

After losing vacuum, the coolers were overdriven by the drivers to meet the cold up temperature, leading to premature wear out of one of the coolers. The result presented here belongs to the cooler which survived the catastrophe. Figure 6 is a plot of input power vs. life. Figure 7 is a plot of cooldown time vs. life and Figure 8 is a plot of refrigeration vs. life. The B602 cooler has demonstrated a life of over 7000 hours to date. Qualification of BEI's B512 cooler can be found in Reference 6.

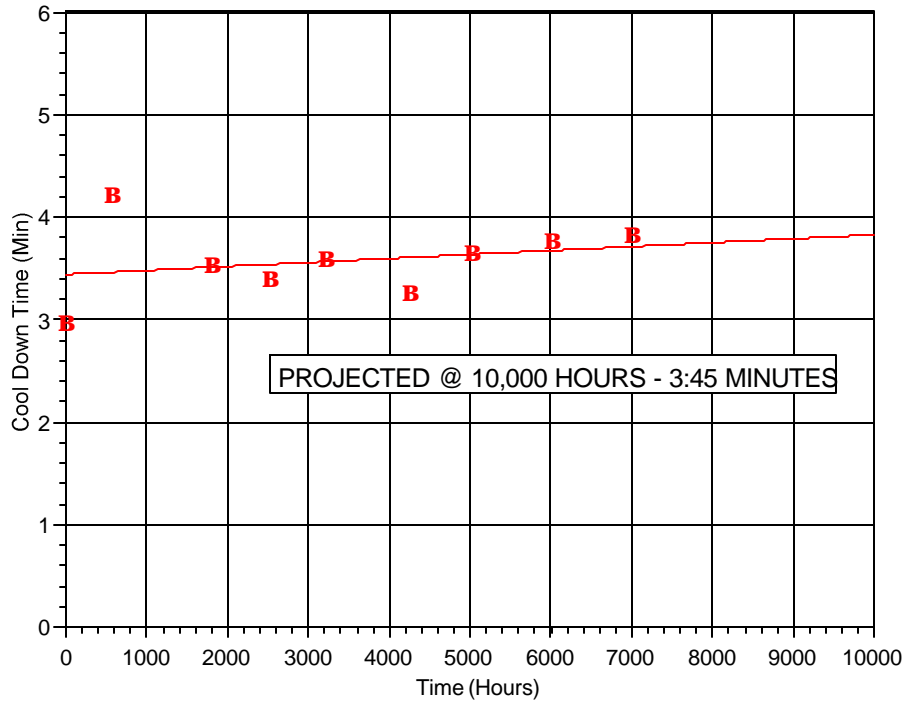


Figure 7. Cooldown time vs. life for B602 cooler.

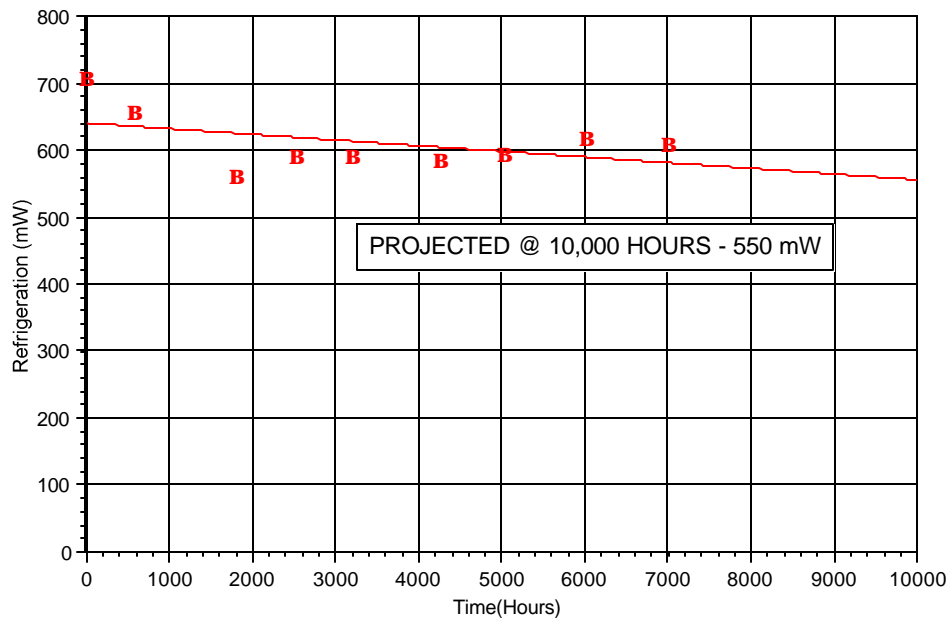


Figure 8. Refrigeration vs. life for B602 cooler.

## CONCLUSIONS

The performance and qualification of the BEI B602C cooler have been reported in this paper together with life test data. The cooler takes about 3 minutes to cool down to 78K. At steady state, the cooler delivers 350 mW of cooling at 78K, with an input power of less than 20 W. The maximum refrigeration of this cooler is 0.7W at 71°C ambient and 0.9 W at room ambient (with a cold tip temperature of 78K). The B602C cooler passed all the environmental qualification tests and has a life of exceeding 7000 hours to date. The coolers discussed in this paper have a charge pressure of 3.336 MPa. These coolers were found to be more efficient when operated at a charge pressure of 2.757 MPa, (data to be reported in a separate paper).

## REFERENCES

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