Reliability Growth of Stirling-Cycle Coolers at L-3 CE

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ABSTRACT

The objective of this paper is to present updated reliability data for the L-3 CE cryocoolers, 0.6-watt Cooler (Model B602C) and the 1.5-watt Cooler (Model B1500E). The reliability data are a composite of life testing under controlled laboratory conditions as well as field data. The information presented here extends the boundary of reliability data in a previous paper from the authors.

INTRODUCTION

Pruitt [1] describes the reliability characteristic of a cryogenic cooler with three distinct phases when failure rate is plotted as a function of operating time: 1) phase-1 is dominated by infant mortality, 2) phase-2 is dominated by random failures, and 3) phase-3 is dominated by wear-out. While infant mortality in phase-1 can be traced to material and workmanship issues, phase-2 failures are predominately random and characterized by the mean-time-between failure (MTBF). The mean-time-to-failure (MTTF) characterizes the phase-3 wear-out failure. Laboratory life testing is used to define the MTTF characteristic, while field units provide the sources of the MTBF estimate. Miskimins [2] shows a method of using the life test data for MTTF to derive a "watt-hour" characteristic for a cryocooler. This watt-hour value is used for estimating cryocooler life for conditions other than the life test. For example, variable conditions can include higher or lower cold-tip operating temperatures, different refrigeration loads, and ambient temperature conditions. These different conditions (duty-cycle) translate to an average input power that can be used to estimate life with a watt-hour value. Yuan [3] gives examples of the watt-hour method to calculate life for L-3 CE coolers.

This paper updates previously presented [4,5] life test data for the 0.6-W Cooler (Model B602) and 1.5-W Cooler (Model B1500.) Field data collected on the 1.0-W Cooler are used to estimate both MTBF and MTTF for L-3's 1000-Series cryocoolers.

TESTING

Life test coolers (three of each Models B602C and B1500E) are attached to a vacuum manifold with test dewar instrumentation for temperature and thermal load. During the life test, the coolers are monitored daily for any changes in their performance. Acceptance testing is performed on the coolers at approximately 500-hour intervals, and results are compared to customer-defined threshold requirements for any cooler failure. This life test is demonstrating that both the B602C and B1500E coolers exceed their respective life requirements of 4,000 hrs and 6,000 hrs MTTF.

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Table 1. Life test operating hours.

Model	Life Requirement Hrs MTTF	Test In-Progress, Hrs Operation	Projected Watt-hours
B602C	> 4,000 hrs	>13,000	> 221,000
B1500E	> 6,000 hrs	5,000, 6000, 13,000*	> 540,000

*Compressors accumulated hours of operation

Table 1 shows that Model B602C coolers have all progressed beyond 13,000 hours in the life test. Model B1500E coolers have operating times of 5,000 hours, 6,000 hours and 13,000 hours. The life test data are also used to formulate sets of empirical constants for life prediction for any operating condition using the watt-hour approach.

LIFE TEST DATA OF COOLER MODEL B602C

Cooler Model B602C was qualified [6] and has been in production since 1996. Life data for three B602C coolers are presented in Figures 1, 2 and 3 showing cooldown, refrigeration capacity, and input power, respectively. The coolers are driven at 22.5 W of input power (equivalent to 350 mW heat lift at 73 K cold-tip temperature, and 71°C ambient temperature environment) during steady-state condition. The slow rise in cooldown time and input power, and the decrease in refrigeration capacity with operating time is attributed to wear in the piston and regenerator seals as well as contamination due to outgassing and wear. All three figures show operating time from restart after the displacers were replaced.

This life test identified a design weakness in the cooler. One unit failed at 2,500 hours, with the other two units at 5,000 hours. The root cause was identified in the displacer wrist-pin linkage.

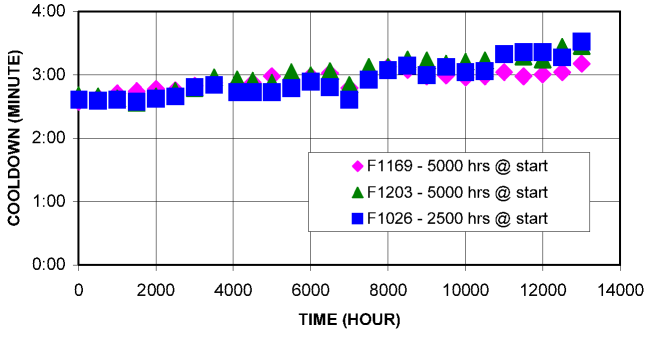

Figure 1. B602C cooldown time from 300 K to 73 K with 3.5 gm Cu mass and 33°C case temperature.

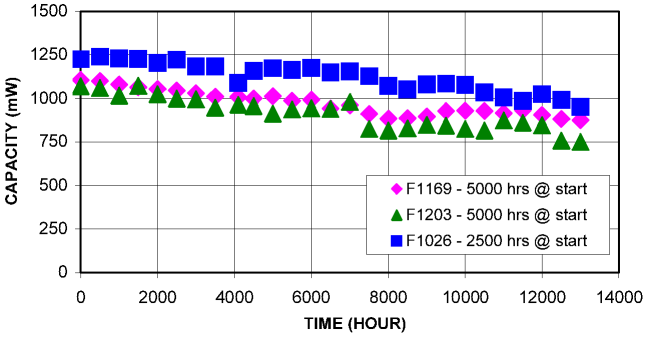

Figure 2. B602C refrigeration capacity at 73 K and 33°C case temperature.

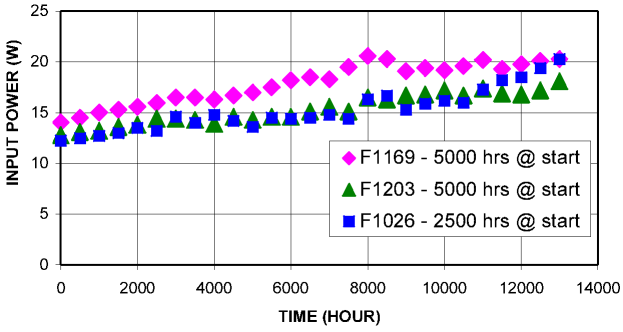

Figure 3. B602C input power for 350 mW load at 73 K and 33°C case temperature.

Improvements were implemented, and now the coolers are confirming the design improvement has fixed the problem. The displacer was replaced (with fix) after the cooler failure, and the life test resumed with its original compressor.

The life test will continue until wear out failure. A wear out failure is characterized by a sharp increase in input power. At the point of wear out, there will be a noticeable change in the slope of Figure 3. If the wear out point were to occur at the 13,000-hour mark, the watt-hour characteristic for this cooler would be approximately 221,000 watt-hours. This is the product of average power over the time to reach wear out. The actual number will be greater than this value, since the wear out point has not been reached.

LIFE TEST DATA OF COOLER MODEL B1500E

Lifetest data are shown in Figs. 4, 5 and 6 for the performance parameters of cooldown, refrigeration capacity, and input power, respectively. The cooler is driven at 45 watts of input power (equivalent to 700 mW heat lift at 67 K and 23°C ambient temperature) during steady state conditions.

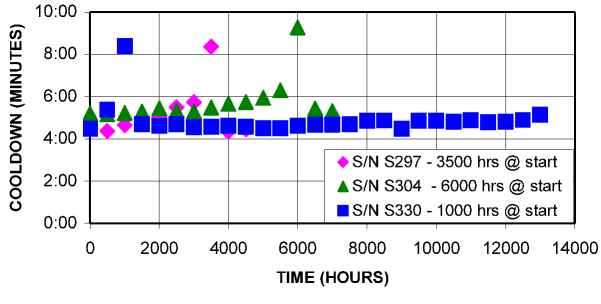

Figure 4. B1500E cooldown time from 296 K to 67 K with 21 gm Cu mass at 23°C ambient temperature.

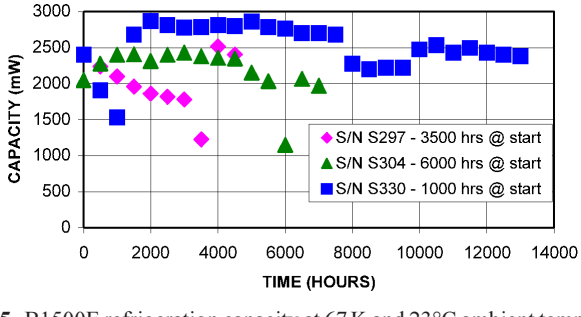

Figure 5. B1500E refrigeration capacity at 67 K and 23°C ambient temperature.

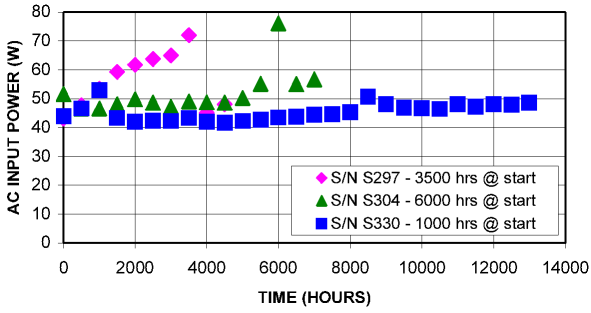

Figure 6. B1500E input power for 1500 mW load at 67 K and 23°C ambient temperature.

Table 2. Other B1000E Life Testing and Field Data [7].

1.0-W Cooler Life Data from other Sources					
Cooler S/N	Time (Hours)	Test Status	Data Type	MTBF (Hours)	MTTF (Hours)
1059	7,000	On-going	Lab	>143,915	> 14,392
1062	7,000	On-going	Lab		
1063	7,000	On-going	Lab		
CC1	18,000	On-going	Lab/Field		
AV1	9,555	Failed	Field		
AV2	20,970	On-going	Field		
AV3	20,970	On-going	Field		
AV4	20,970	On-going	Field		
AV5	20,970	On-going	Field		
AV6	11,480	On-going	Field		
Sub-Total	143,915				

This life test identified one weakness in the design. Failure occurred at 1,000 hours, 3,500 hours, and at 6,000 hours for S/N S330, S297 and S304, respectively. The root cause was identified in the displacer wrist-pin linkage, similar to the B602C cooler; improvements were implemented, and now the coolers are confirming that the design improvement has fixed the problem. The displacer was replaced (with fix) after the cooler failure and the life test resumed with its original compressor. Figures 4, 5, and 6 show that the performance returned to pre-failure levels after replacing the displacer. This is an indication the compressor was not affected by the displacer wrist-pin linkage failure.

Unlike the B602 Figures, these charts 4 through 6 show the life test from the beginning, including the failure points.

Table 2 shows a combination of actual field data and other laboratory life test data for the B1000E cooler. The model B1000E and B1500E are essentially the same cooler with the difference in the cooler control module (driver/control electronics) limited to 60W and 90W maximum input power, respectively. The MTBF for the B1000E cooler, based on this set of ten coolers, is greater than 143,915 hours (using point estimate number hrs/number failures), since the coolers are continuing to be operated. MTTF has yet to be determined and is currently greater than 14,392 hours. S/N 1059, 1062 and 1063 are life test units being tested in the lab. S/N CC1 is running in the lab in a continuous mode. The other six, S/N AV1-AV6, are from a lot of over 250 units where the user has provided confirmation of field use in a continuous mode. The balance of the units do not have a reporting mechanism. S/N AV1 was returned to the customer without failure analysis.

Further updates of both MTBF and MTTF will be provided in future papers.

SUMMARY

L-3 CE continues to support the user of cryocoolers with information in life testing and updates to the reliability database as field data become available. Life testing performed to date show L-3 CE coolers meet the current user requirements for product life. Further updates in the future will lead to both extension of expected life with a higher level of confidence.

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