Life test result of Ricor K529N 1Watt linear Cryocooler

Ilan Nachman, Alexander Veprik and Nachman Pundak
Ricor Cryogenic and Vacuum Systems, En Harod Ihud, 18960, Israel

ABSTRACT

The authors summarize the results of the accelerated life testing of the Ricor type K529N 1 Watt linear split Stirling cooler. The test was conducted between 2003-2006. During this period, the cooler accumulated in excess of 27,500 working hours at an elevated ambient temperature, which is equivalent to 45,000 hours at normal ambient conditions, and performed about 7,500 operational cycles including cooldown and steady-state phases. The cryocooler performances were assessed through the cooldown time and power consumption; no visible degradation in performances was observed.
After the cooler failure and the compressor disassembling, an electrical short was discovered in the driving coil. The analysis has shown that the wire insulating varnish was not suitable for such elevated temperatures. It is important to note that the cooler under test was taken from the earliest engineering series; in the later manufacturing line military grade wire with high temperature insulation was used, no customer complaints have been recorded in this instance
Special attention was paid to the thorough examination of the technical condition of the critical components of the cooler interior. In particular, dynamic piston-cylinder seal, flying leads, internal O-rings and driving coil were examined in the compressor. As to the cold head, we focused on studying the conditions of the dynamic bushing-plunger seal, O-rings and displacer-regenerator. In addition, a leak test was performed to assess the condition of the metallic crushed seals.
From the analysis, the authors draw the conclusion that the cooler design is adequate for long life performance (in excess of 20,000 working hours) applications.

Key words: Cryocooler, reliability, linear cooler, life test.

1. INTRODUCTION

The split Stirling linear Ricor Type K529N 1W cryocooler comprises a single-piston compressor and a pneumatically driven expander connected using the short and flexible transfer line. The cooler is driven by a modern digital controller specially built for the stringent military environment.
Starting from 1995, in excess of 1,200 Integrated Detector Dewar Cooler Assemblies (IDDCA) relying on the above K529N cooler were delivered to numerous customers, primarily for military use.
In this particular cooler, for the sake of performance, compactness, price, reliability, ease of assembling and maintenance, we abandoned the fashionably popular idea of using the so-called “contactless” approaches relying on the flexural bearings. In particular, both piston and cylinder sleeves are tightly matched to 4μm radial clearance and made of steel hardened to HRC 65 and machined to N3; no exotic surface treatment and plating were applied. In this approach the piston-cylinder sleeves may be matched more tightly as compared to the contactless design; this yields essential decrease of the blowby losses and makes the cooler more reliable under the harsh conditions of the modern battlefield.
Since this design relies on sensitive components such as flying leads, crushed metal sealing and feedthrough, rubbing metal-to-metal contacts and elastomeric O-rings for internal sealing and preloading, it became critical to prove the high cryocooler reliability and to establish the attainable life time.
The test was conducted between 2003-2006. During this time, the cooler accumulated in excess of 27,500 working hours at an elevated ambient temperature, which is equivalent to 45,000 hours at normal ambient conditions, and performed about 7,500 operational cycles including cooldown and steady-state phases. The cryocooler performances were assessed through the cooldown time and power consumption; no visible degradation in performances was observed.
After the cooler failure and the compressor disassembling, an electrical short was discovered in the driving coil. The analysis has shown that the wire insulating varnish was not suitable for such elevated temperatures. It is important to note that the cooler under test was taken from the earliest engineering series; in the later manufacturing line, military grade wire with high temperature insulation was used, no customer complaints have been recorded so far.
Special attention was paid to the thorough examination of the technical condition of the critical components of the cooler interior. In particular, dynamic piston-cylinder seal, flying leads, internal O-rings, feedthrough and driving coil were examined in the compressor. As to the cold head, we focused on studying the conditions of the dynamic bushing-plunger seal, O-rings and displacer-regenerator. In addition, a leak test was performed to assess the condition of the metallic crushed seals.
The authors are releasing here the main results of the test along with a number of important findings.

2. THE CRYOCOOLER OVERVIEW

2.1. **K529N Cryocooler**

In Figure 1, the Ricor Type K529N Cryocooler consists of the single-piston linear compressor, pneumatically driven expander and transfer line.

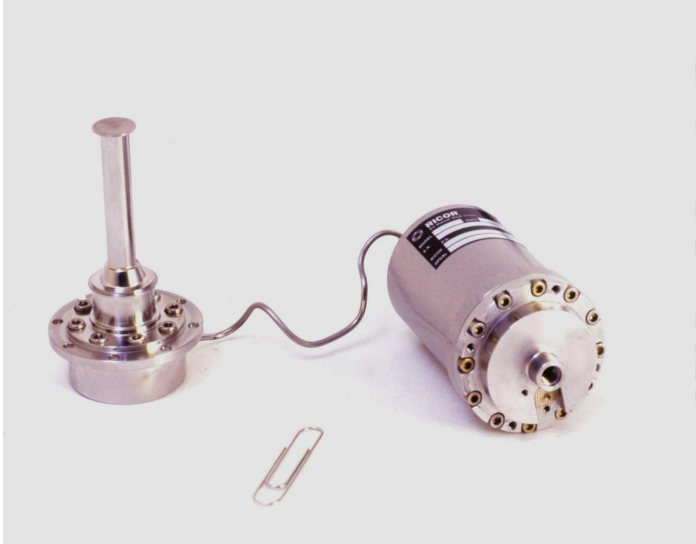

Figure 1: Ricor Type K529N Cryocooler.

2.2 K529N Controller

The K529 controller is digital with all the benefits of digital PID control, 242/386 type communication, programmable chip and special features in accordance with customer request. Figure 2 shows the controller PCB.

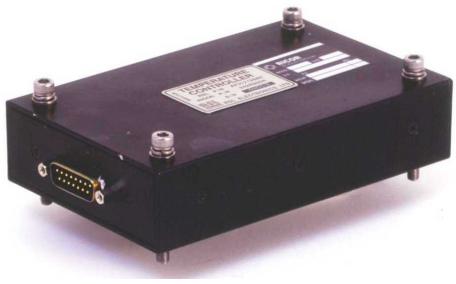

Figure 2: Controller

3. TERMS OF THE ACCELERATED LIFE TEST

3.1 General

The cooler under test was running with dynamically evacuated simulation Dewar. A 2N2222 transistor was placed on the cold tip of the cold finger and its B-E junction was used as a temperature sensor. A resistor mimicking additional heat loading was added. After each 2,000 working hours, the cooler was tested in accordance with the Ricor's internal Acceptance Test Procedure to ensure the compliance with all requirements.

3.2 Thermal terms.

The Unit was thermally isolated from the environment in order to reach cooler skin temperature in excess of 70^0C. The constant power supplied to the cooler controller was 26 Watts out of 32 Watts available. This level of power consumption mimics the closed loop operation in a 72^0C environment.

3.2 Running Profile.

For the first 2,000 hours the cooler ran continuously at an elevated skin temperature in excess of 70^0C. During the following 15,000 hours the cooler ran according to a special profile and performed 7,500 cycles according to the following schedule: 90 minutes of continuous operation and 25 minutes of shutdown. Figure 3 shows the typical cycle. During the last 10,500 hours the cooler ran continuously.

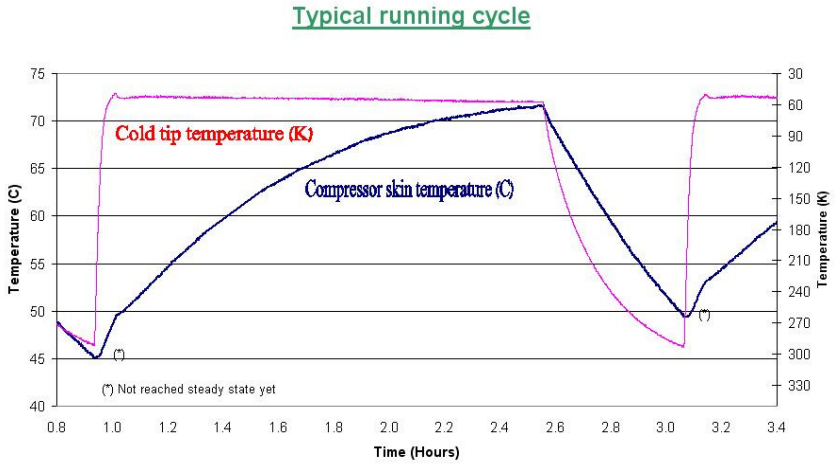

Figure 3: Test cycle

4 Results

4.1 General

The cooler under test accumulated 27,500 net working hours. The cooler finally failed as a result of the cooler motor failure.

4.2 Motor failure

The motor failed due to a current short in the coil .wire. The examination showed that the wire insulation experienced degradation in its properties as a result of the long term exposure to elevated temperatures. It is important to note that the cooler under test was taken from the earliest engineering series where the wire insulation class 150^0C was used. Since then the manufacturing line uses military grade wire with high temperature insulation (180^0C) and no customer complaints have been received so far.

4.3 Piston – cylinder sleeves

The moving piston sub-assembly accurate reciprocation and compression ratio developed by the compressor depends entirely on the technical condition of these two rubbing parts. Examination has shown that after 27, 500 working hours the above parts were in excellent condition: the sliding was free, the piston and cylinder geometry remained unchanged. The flow rate testing of the new and old assemblies showed practically the same results. Some minor scratches were noticed on the surface of the piston and the cylinder. This is shown in Figure 4.

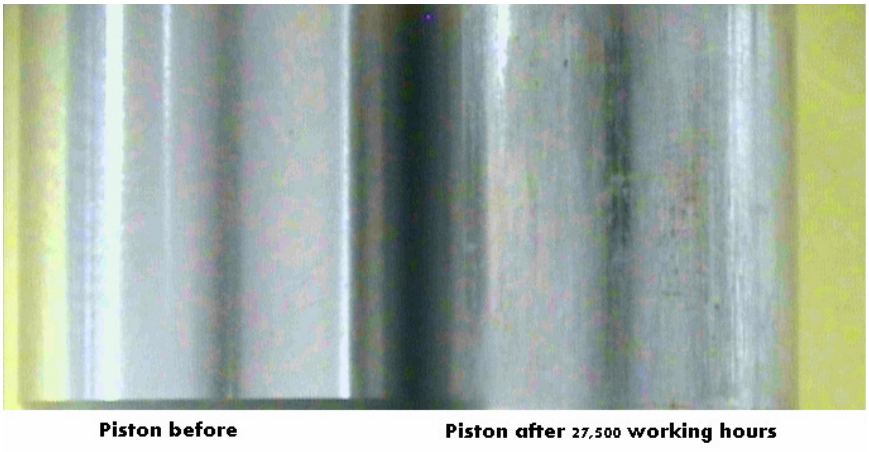

Figure 4: Compressor piston: “before and after".

4.4 Metallic seals and feedthrough

All the metallic crushed seals and the feedthrough passed the leak test successfully. The Helium leak rate in all the tests was better than 6E-08 SCCS (Standard Cubic Centimeters per Second).

4.5 Cold head

The pneumatically driven cold head was in perfect working condition. The "bushing-plunger" dynamic seal didn’t show any degradation in geometry and surface rubbing was minor. The pressure drop test performed with the new and old assemblies has shown the same number. Figure 5 portrays the plunger before and after the test.

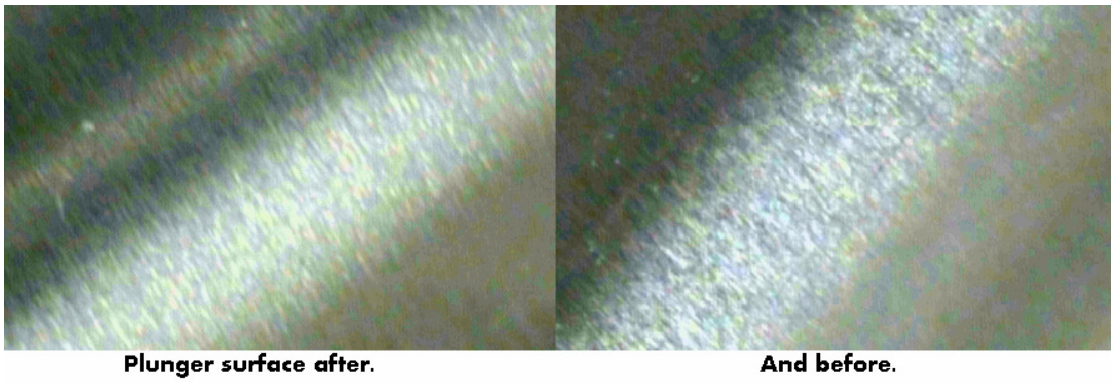

Figure 5: Plunger surface after and before 27,500 running hours.

Figure 6 shows the technical condition of the displacer. Some minor surface contamination and scratches are seen. This however had no visible impact on the cold head performance – the same cold head was reassembled with the repaired compressor without cleaning and practically the same cooling performance was observed.

Figure 6: Cold head "after 27,500 working hours"

4.6 Performances

Figure 7 shows the dependence of the closed loop power consumption on the accumulated time. We observed a 15% degradation in the cooler performance. This may be explained by the gas loss, gradual development of the electrical short in the motor coil and degradation of the controller performance.

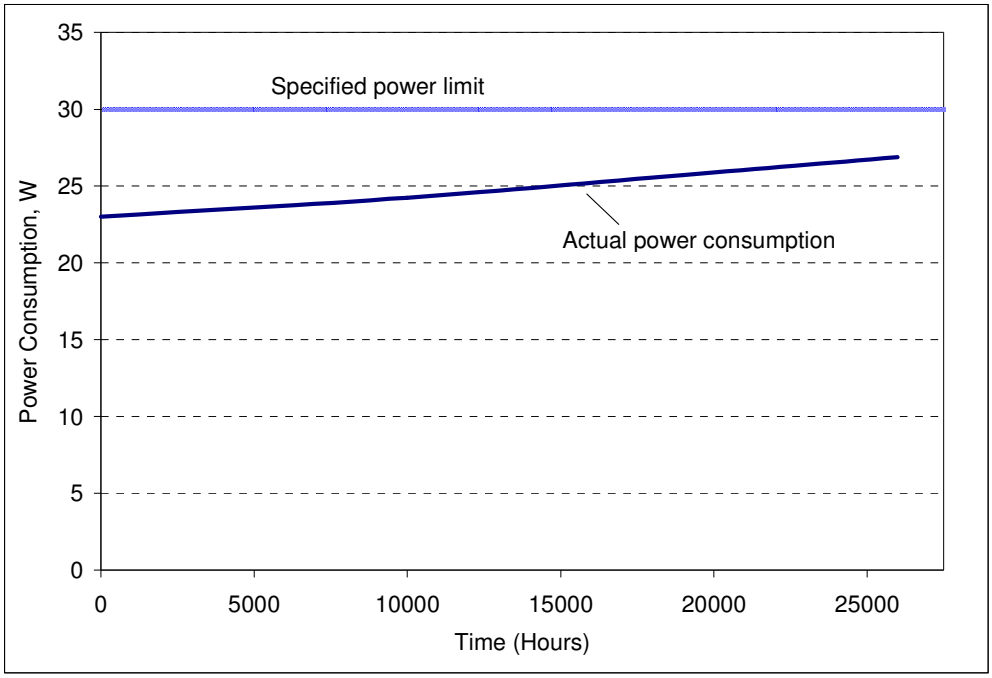

Figure 7: Stabilized power consumption vs. Time.

5 SUMMARY

Ricor has proved that the K529N linear cryocooler has passed 27,500 working hours at a high elevated skin temperature which is equivalent to 45,000 hours under normal ambient conditions. The mode of failure was the degradation of the coil wire. For the past two years Ricor has used the improved 180^0C class wire. All other components of the cooler are likely to continue working for twenty thousand hours and more. Clearly this design meets the requirements for a long life cryocooling application.

REFERENCES

1. Kim S-Y., etal, "*Reliability Test Results of LGE Pulse Tube Cryocoolers",* Proceedings of the Cryogenic Engineering Conference -CEC, Vol. 47A, 2001.
2. Kuo D. T., etal, "*BAE's Life Results on Various Linear Coolers and Their Correlation with a First Order Life Estimation Method"*, Cryocoolers 11, ed. Ross R. G., 2001.
3. Yuan S. W. K., Kuo D. T., "*Cryocooler Contamination Study: Temperature Dependence of Outgasing"*, Cryocoolers 11, ed. Ross R. G., 2001.