RICOR's Advanced Rotary & Linear miniature Cryocoolers for HOT IR detectors

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ABSTRACT

In recent years, the trend of moving IR detectors to operate from standard 77K to the High Operating Temperature (HOT) of 150K, drives RICOR's onward development focusing on SWaP-C, a new family of miniature cryocoolers, alongside continuing to make improvements to existing cryocooler models.

The main objective for the development of a new family of cryocoolers is to focus on SWap-C by creating cryocoolers that maintain a small size, low weight, low power consumption and an attractive cost. This effort has yielded advanced Linear & Rotary miniature Cryocoolers named K580, K588 and K590.

This paper will review the progress made with qualification and the move to production of the K590 Linear Dual Opposed model using customized cold finger & engineering efforts to optimize the K588 model that based on the same compact dual opposed compressor integrated with a common cold finger.

In addition, the paper will present the improvements made for K580I Integral Rotary Model with lower induced force level and will review the accumulated experience of 3 mature models under production named K527, K562S and K562SI.

Keywords: Cryocooler, RICOR, Stirling, IR detector, Infrared, SWaP-C, HOT, Dual opposed

1. INTRODUCTION

In previous paper publications [1], [2], [3], [5], progress reported in development of several cryocoolers that are specified for HOT SWaP-C applications and based on rotary and linear drive.

RICOR's HOT SWaP-C Roadmap includes six different Cryocoolers as shown in Figure 1, starting from K562S rotary integral cryocooler and K527 single piston split linear cryocooler that was developed for 95-110K FPA temperatures and later adapted to operate at 150K. The second step included the K562SI rotary integral cryocooler, which is a compact derivative of the K562S who's cold finger length is half size and has a new motor assembly.

The third step included development of two SWaP-C cryocoolers from scratch named K580 and K590 that are dedicated for operation at HOT temperatures typically at 150K. The K580 is a compact rotary integral cryocooler and the K590 is a compact dual opposed linear cryocooler. Both models are qualified and under production at RICOR.

The fourth step includes continuous improvement to the K580I cryocooler with reduced induced forces level and ongoing improvements for the K590 cryocooler to optimize production yield & cost. In addition, a new model named K588 is under engineering phase. This model is based on the K590 dual opposed compressor with common cold finger as used by the K580 cryocooler. (The K590 includes a specific cold finger)

Figure 1: HOT SWaP-C Roadmap at RICOR

2. K527 & K562 MODELS OVERVIEW

2.1 K562S Cryocooler

The K562S is a qualified rotary integral cryocooler that was developed for detectors operating at >95K and under production for more than a decade. The cryocooler is a downscale of larger RICOR's integral Cryocoolers with a light weight of 185gr, low typical input power of 3Wdc at 200mW&110K@23°C and compact size. The cryocooler is driven by a DC brushless motor with two options of temperature controllers: analog version and digital sensor less version both by external boards.

A derivative of K562S with half cold finger length named K562 Short is available for a temperature range of 150-180K once there is a tight volume constraint.

An optional acoustic pad could be considered as an interface between the cryocooler and the optical bench in a case of a strict requirement for acoustic noise level.

2.2 K527 Cryocooler

The K527 is a qualified split linear cryocooler that was developed for detectors operating at >95K and has been under production for a decade. The K527 cryocooler is based on a compact single piston compressor with options for a dynamic balancer to minimize induced forces while the compressor drives pneumatic cold head that fit with few types of cold fingers, including the standard K508 cold finger. The K527 cryocooler includes a ruggedized digital temperature controller that enables operation at a wide range of FPA temperatures from 95K up to 150K.

A life demonstration test has been running at RICOR's laboratory for almost 7 years while the current test results at 20°C and at 80K is more than 55,000 operating hours. The test will keep running until all cooler's end of life failure.

More than 1,600 cryocoolers have been delivered so far, most being used for Airborne applications with harsh mechanical & thermal environmental conditions.

2.3 K562SI Cryocooler

The K562SI is a derivative of the K562S model with half size cold finger length and new motor assembly that was developed for FPA temperatures in the range of 130-180K. The cryocooler is qualified with a light weight of 185gr, low typical input power of 2.5Wdc at 200mW&150K@23°C and compact size to meet tight volume constraint. A life demonstration test was performed on 3 cryocoolers at accelerated conditions and yielded MTTF of >17,000 hours at basic profile. More than 5,000 cryocoolers have been delivered so far from K562S and K562SI models while there is a plan for continuous high volume in the next few years.

3. K580 & K590 MODELS OVERVIEW

3.1 K580 Cryocooler

The K580 is a qualified integral rotary cryocooler that was developed from scratch to operate at HOT temperatures in the range of 130-180K and followed the SWaP-C objectives. The development included new technology to shorten the cold finger length and to achieve improved efficiency.

The K580 excels in low regulated input power of 1.5Wdc typ. at 150mW&150K@23°C while keeping compact volume, low weight of 190gr and highly compact length in the cold finger axis of 57.5mm.

Following main parameters of the K580 model and outline dimensions:

Parameter	Typical Value
Cooling capacity	600mW@150K@71°C
MTTF	>16,000hr @basic profile
Regulated Input Power	1.5Wdc typ. (150mW@150K@23°C)
Max. Input Power	10Wdc typ.
Cool down time	3min typ. (150J@150K@23°C)
Weight	Cooler - 190gr, Controller - 30gr
Input Voltage	4-16 VDC (6V or 12V nominal operation)
Ambient Temperatures	-40˚C to +71˚C
Acoustic noise	non-detectability from 20m
Temperature stability	±0.1K

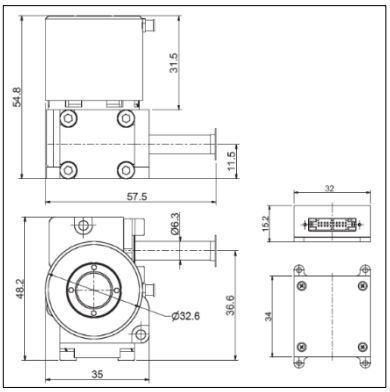

Figure 2: K580 main characteristics and outline dimensions

The K580 cryocooler is driven by an external digital temperature controller with an accurate long-term stability of ±0.1K and fits with the common cold finger. The K580 is qualified and has completed life demonstration tests while more than 1,000 cryocoolers have been delivered so far.

Following production DC power consumption performances at 185mW&150K@23°C and at 270mW&150K@71°C both at regulation mode:

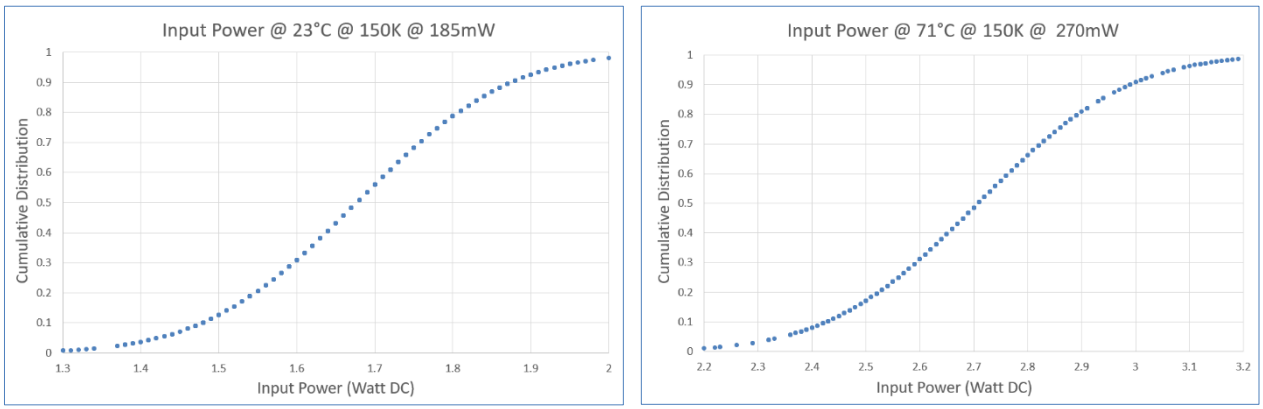

Figure 3: K580 DC regulated power consumption performances

3.2 K590 Cryocooler

The K590 is a qualified split rotary cryocooler that was developed from scratch to operate at HOT temperatures in the range of 120-180K and followed the SWaP-C objectives. The development included new technology of dual opposed compressor, all welded seal technology and moving magnet linear motors.

The K590 excels in low regulated input power of 2.15Wdc typ. at 180mW&150K@23°C while keeping compact volume, low weight of 190gr, highly compact compressor D26mm x L52mm and compact cold head in length of 40mm.

Following main parameters of the K590 model and outline dimensions:

Parameter	Typical Value
Cooling capacity	500mW@150K@71°C 370mW@120K@71°C
MTTF	>30,000hr @basic profile (D. goal)
Regulated Input Power	2.15Wdc typ. (180mW@150K@23°C)
Max. Input Power	12Wdc typ.
Cool down time	2min typ. (180J@150K@23°C)
Weight	Cooler - 180gr, Controller - 10gr
Input Voltage	5.5-16 VDC
Ambient Temperatures	-40˚C to +71˚C
Acoustic noise	non-detectability from 10m
Temperature stability	±0.1K

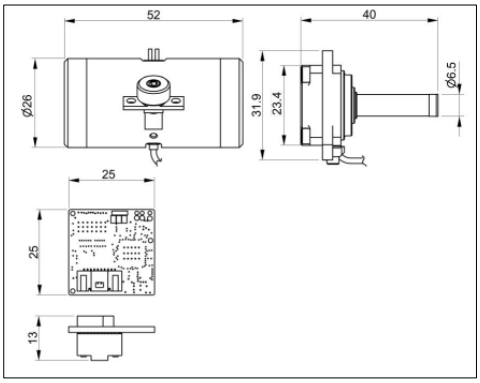

Figure 4: K590 main characteristics and outline dimensions

The K590 cryocooler is driven by an external digital temperature controller with an accurate long-term stability of ±0.1K and fit with a specific compact cold finger. The K590 is qualified and under testing of life accumulated operating hours, more than 550 cryocoolers have been delivered so far.
The K590 operates in high and fixed frequency of 110Hz while the typical induced forces measured once operating with side-by-side configuration (compressor parallel to the cold head) is about 20grf or about 200mN in the driving axis.
In the field of reliability, a batch of K590 Cryocoolers under a life demonstration test while all of them kept running and one out of the batch already passed 20,000 hours and continued to the target of 30,000 hours.

Following production DC power consumption performances at 180mW&150K@23°C and at 250mW&150K@71°C both at regulation mode:

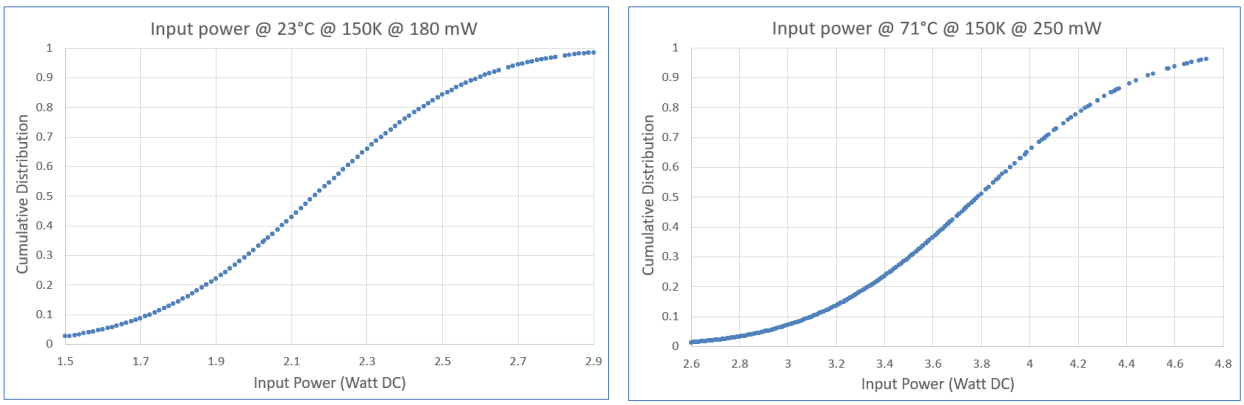

Figure 5: K590 DC regulated power consumption performances

4. K580I, K590 GEN. II & K588 MODELS ENGINEERING OVERVIEW

4.1 K588 Cryocooler

As part of engineering effort to adapt coolers with standard cold fingers, a new model named K588 is under engineering work by adapting the K590 compressor to drive a new cold head that fits with the common cold finger as used by K580 and K580I models. The K588 is a split rotary Cryocooler that relies on the K590 technology of compact dual opposed compressor with outer dimensions of D26mm x L52mm, all welded seal technology and moving magnet linear motors. The K588 excels in low regulated input power of 2.1Wdc typ. at 180mW&150K@23°C, compact volume, low weight of 190gr, highly compact cold head length of 46mm and with a high reliability goal of 30,000 operating hours.
Following main parameters of the K588 model and outline dimensions:

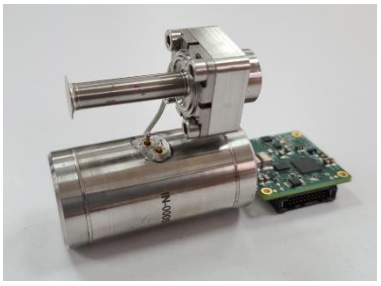

Figure 6: K588 dual opposed compressor with common cold finger

Parameter	Typical Value
Cooling capacity	550mW@150K@71°C 420mW@120K@71°C
MTTF	>30,000hr @basic profile (D. goal)
Regulated Input Power	2.1Wdc typ. (180mW@150K@23°C)
Max. Input Power	12Wdc typ.
Cool down time	2min typ. (180J@150K@23°C)
Weight	Cooler - 190gr, Controller - 10gr
Input Voltage	5.5-16 VDC
Ambient Temperatures	-40˚C to +71˚C
Acoustic noise	non-detectability from 10m
Temperature stability	±0.1K

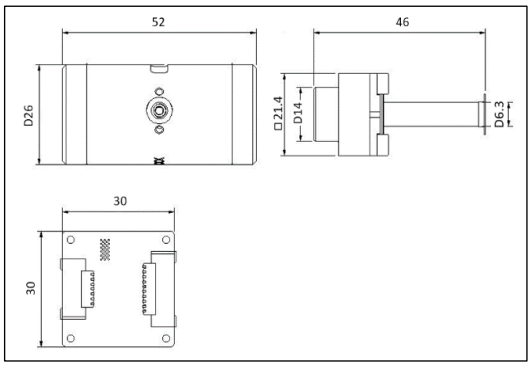

Figure 7: K588 main characteristics and outline dimensions

Following DC regulated power versus heat loads for K588 prototype at 120K and 150K and at 23°C and 71°C ambient:

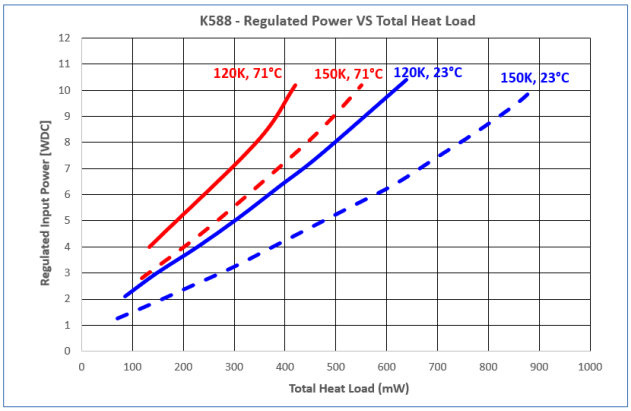

Figure 8: K588 regulated DC power Vs. heat load

Following mapping of K588 cooling power at 120K and 150K and at ambient from -40°C up to 71°C:

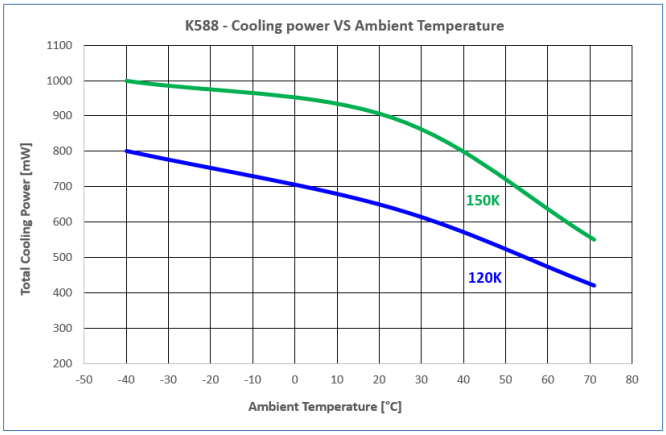

Figure 9: K588 Cooling power Vs Ambient temperatures at 120K&150K

The linear technology of compact dual opposed compressor excels in low induced forces levels and low acoustic noise. Following acoustic noise measurement performed in an anechoic room and induced forces measurement in the axis of moving parts direction while the compressor and the cold head clamped in side-by-side configuration by common mechanical jig to dynamometer test equipment.

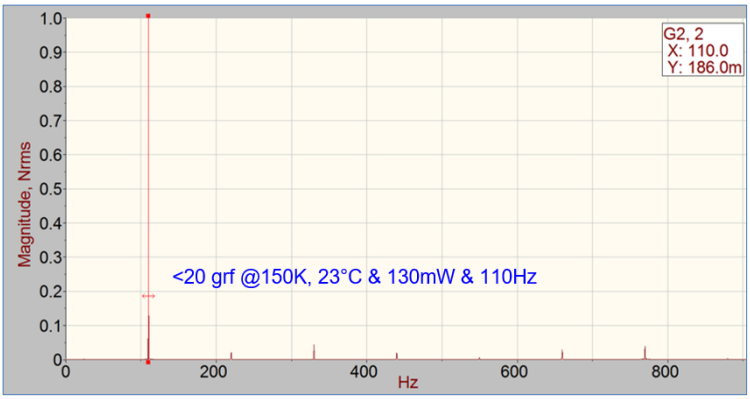

Figure 10: K588 Induced forces measurement at 150K

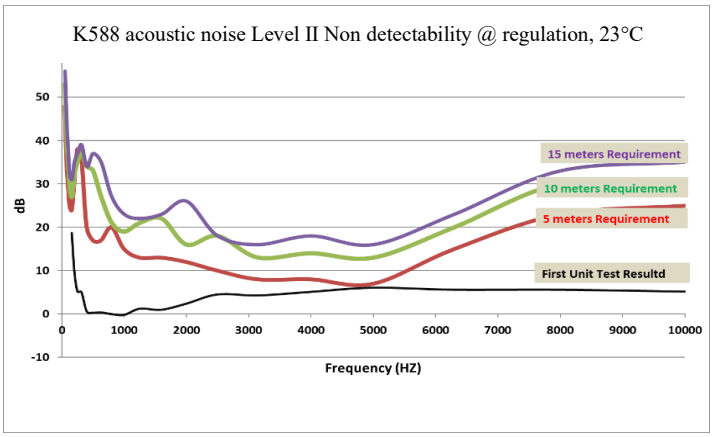

Figure 11: K588 Acoustic noise measurement at 150K

4.2 K590 Gen. II Cryocooler

As part of continuous improvement, an engineering effort is under way to introduce K590 Gen. II that will include a set of improvements. From a configuration aspect, the Helium fill valve port shifted from external part to be integral as part of the compressor housing for better functionality, handling and clamping.
Additional ongoing improvements in the field of Cryocooler dynamics to reduce performance distribution, optimize cost, yield enhancement, extend high ambient temperature for operation and new optional motors for low input voltage.
There is a potential to perform one more step by increasing Cryocooler's cooling power while this will be considered as part of a separate activity.
The K590 Gen. II drives by the temperature controller that used by K588 model as presented in Figure 7.

Figure 12: K590 Gen. II Cryocooler

4.3 K580I Cryocooler

As part of continuous improvement activity, engineering work was performed in order to improve the induced forces level created by the mechanical moving parts of the cryocooler.
The Induced Forces are defined as a key parameter and highly important for applications with lightweight construction and for stabilized applications.
The engineering work focused on advance balancing methods for the mechanical rotating parts and yielded reduction in induced forces level that became more significant if the operating frequency increased.
For example, a reduction of more than 80% achieved at frequency of 80Hz which represents operation at high ambient temperature with relatively high heat load. In addition, the induced forces at an operating frequency of 45Hz are reduced to a low level of 2grf or 20mN, which represents typical operation at room ambient temperature.

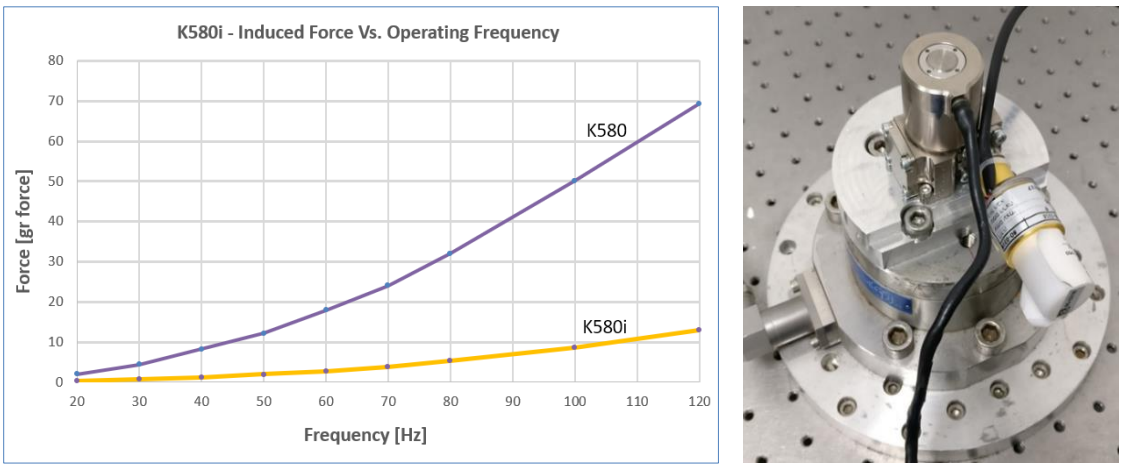

Figure 13: K580I induced forces measurement

5. SUMMARY

RICOR is continuing to follow the trend of cooled IR detectors that are moving to operate at HOT temperatures by developing a road map that started in 2006 with Cryocoolers for 95-110K and continued in the recent years with cryocoolers for typically 150K.

The development of cryocoolers for HOT at RICOR followed by coping with challenging SWaP-C objectives of small size, low weight, low power consumption and an attractive cost. The engineering effort yielded a family of six cryocoolers with different technologies: split linear single piston, split linear dual opposed compressor and rotary integral. All alternatives are driven by external digital temperature controllers to keep stable operation.

The variety of RICOR's SWaP-C cryocoolers for HOT detectors provides the possibility to choose the optimal configuration for each specific need by analyzing key parameters such as regulated power consumption, MTTF, induced forces, acoustic noise, weight, volume, size and others.

RICOR is looking forward to future trends and needs in the field of HOT detectors to adjust the cryocooler road map plan to meet new challenging requirements.

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