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PRODUCTION OVERVIEW AND R&D IMPROVEMENT PROGRAMS STATUS FOR RICOR'S SWAP-C CRYOCOOLERS FOR HOT DETECTORS

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ABSTRACT:

In line with growing trend of moving to HOT detectors, more than 8,250 Ricor's SWaP-C Cryocoolers were successfully delivered to our customers for various projects in recent years. During this period, we launched R&D improvement programs to bring more capabilities from the current models. These improvements will enable us to provide systems with much better performances.
This paper will report on production performances of the K590 and K580. The steady state power, acoustic noise, CDT, induced forces and more parameters will be presented in statistical measures.
In addition, the paper will review the development status of improvements for the K580I & K590 and the status of the K588 linear Cryocoolers.
Ricor's innovative linear and rotary SWaP-C Cryocoolers for HOT detectors are progressing according to schedule from production and R&D improvement programs aspects. These Cryocoolers enable better IR system performances and capabilities.

1. INTRUDUCTION

RICOR's HOT SWaP-C Roadmap includes six different Cryocoolers as shown in Fig. 1, starting from the 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 whose 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 a common cold finger as used by the K580 cryocooler. (The K590 includes a specific cold finger).

This paper will be focused on the third and fourth steps.

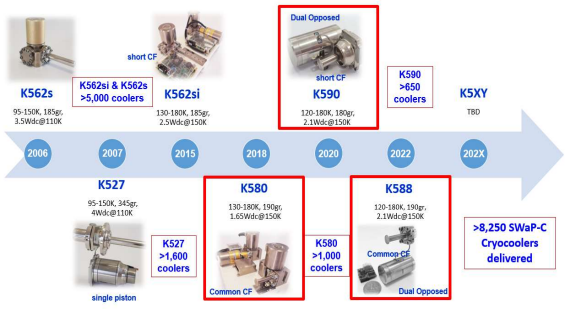

Figure 1. HOT SWaP-C Roadmap

2. K580 & K590 OVERVIEW

2.1 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

1.65Wdc typ. at 180mW&150K@23°C while keeping compact volume, low weight of 190gr and highly compact length in the cold finger axis of 57.5mm.

Fig. 2 shows the parameters of the K580 model and outline dimensions:

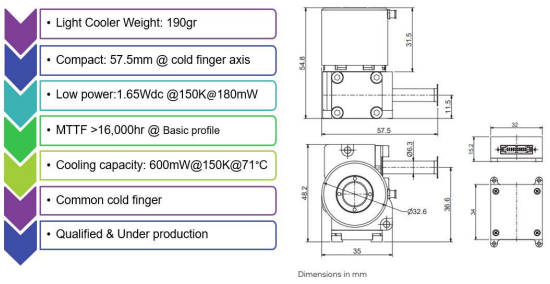

Figure 2. K580 Main characteristics

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.

Fig. 3 and Fig. 4 summarize the production DC power consumption performances distribution at 180mW&150K@23°C and at 250mW&150K@71°C both at regulation mode of 196 different units:

Figure 3. K580 regulated power@23°C

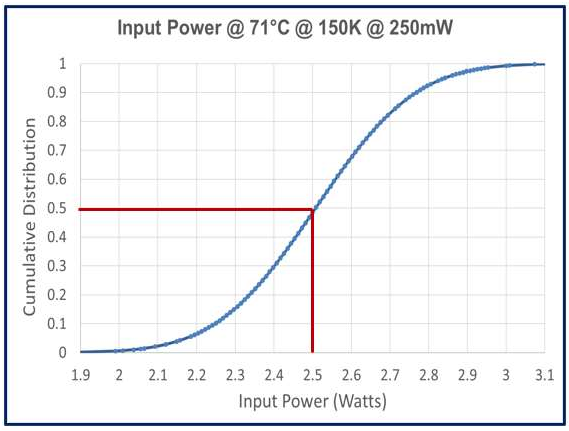

Figure 4. K580 regulated power@71°C

Fig. 5 and Fig. 6 show the production cooldown time distribution at 180 Jouls&150K@23°C and at 250 Jouls&150K@71°C of 196 different units:

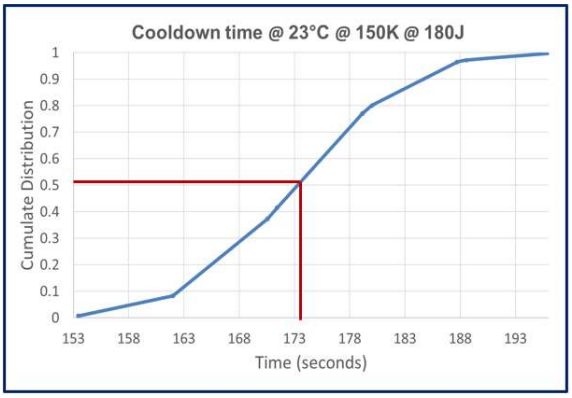

Figure 5. K580 cooldown time @23°C

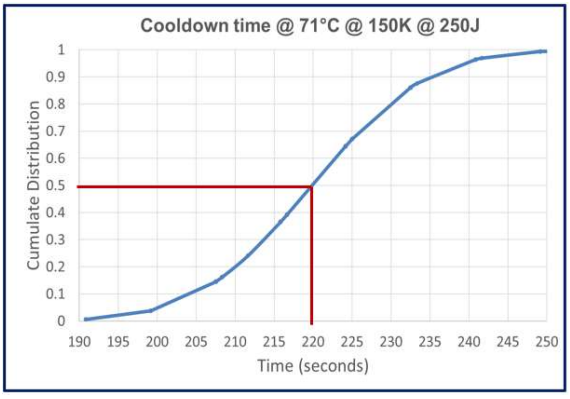

Figure 6. K580 cooldown time @71°C

Fig. 7 shows the production noise distribution at 45Hz of 700 different units:

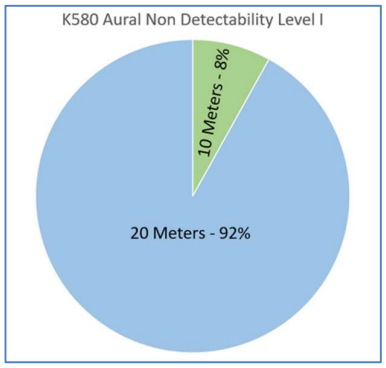

Figure 7. K580 Noise

2.2 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 a dual opposed compressor, all welded seal technology and moving magnet linear motors.

The K590 excels in low regulated input power of 2.1Wdc typ. at 180mW&150K@23°C while keeping compact volume, low weight of 190gr, highly compact compressor D26mm x L52mm and a compact cold head with a length of 40mm.

Fig. 8 and Fig. 9 show the parameters of the K590 model and external dimensions:

Parameter	Typical Value
Cooling capacity	500mW@150K@71°C 370mW@120K@71°C
MTTF	>30,000hr @basic profile (D. goal)
Regulated Input Power	2.1Wdc 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 8. K590 parameters

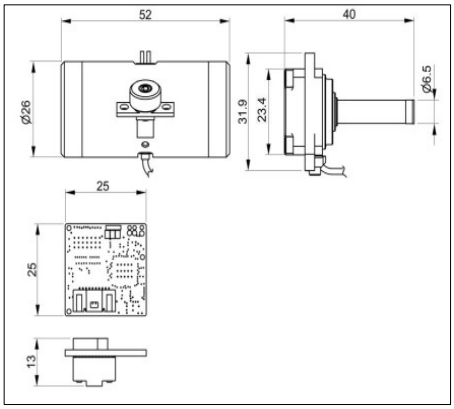

Figure 9. K590 external dimensions

The K590 cryocooler is driven by an external digital temperature controller with an accurate long-term stability of ±0.1K and is fitted with a specific compact cold finger. The K590 is qualified and is undergoing an accumulated operating hours life test. More than 650 cryocoolers have been delivered so far.

The K590 operates in a 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 240mNrms in the driving axis at 150K@23°C@180mW.

In the field of reliability, a batch of K590 Cryocoolers are undergoing a life demonstration test. All of them are still running and one out of the batch has already passed 21,000 hours and is continuing to the target of 30,000 hours. All the units are running without degradation See Tab.1 for K590 life test status.

Table 1. K590 life test

Unit Number	Unit Type	Life Accumulated hours	AC Input Power @ 23°C @ 150K @ 180 mW
1-0030	Prototype Gen 1	21,117	2.0W
1-0293	Qualified unit Gen 1	9,934	1.8W
1-0280	Qualified unit Gen 1	9,780	1.7W
IN-0003	Prototype Gen 2	9,890	1.4W
IN-0009	Prototype Gen 2	9,483	1.4W
IN-0010	Prototype Gen 2	9,611	1.3W

Fig. 10 and Fig. 11 shows the production distribution of DC power consumption in regulation mode:

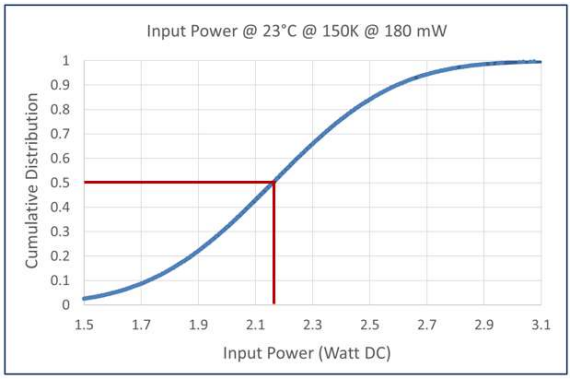

Figure 10. K590 regulated power@23°C

Figure 11. K590 regulated power@71°C

Fig. 12 and Fig. 13 show the production cooldown time distribution at 180 Jouls&150K@23°C and at 250 Jouls&150K@71°C of 650 different units:

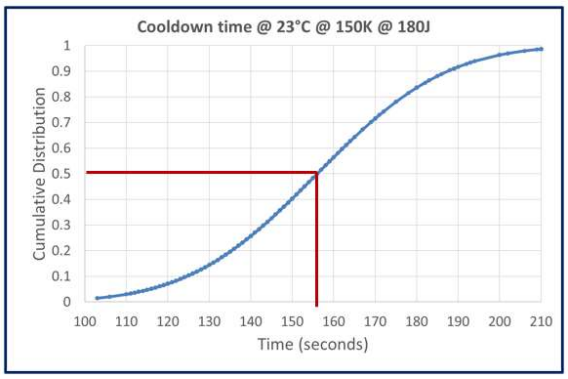

Figure 12. K588 cooldown time @23°C

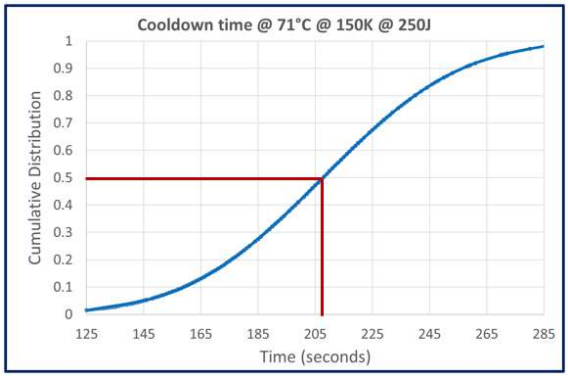

Figure 13. K588 cooldown time @71°C

Fig. 14 shows the production distribution of acoustic noise according to MIL-STD-1474 level II.

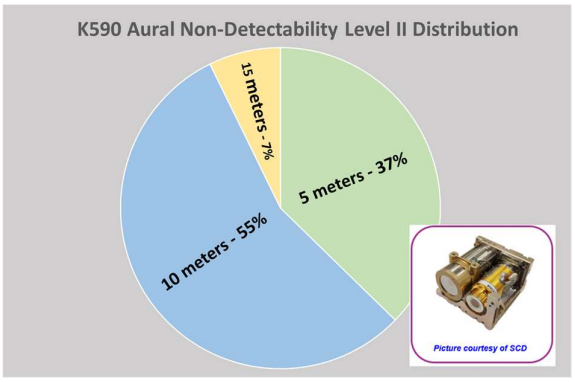

Figure 14. K590 acoustic noise

Fig. 15 and Fig. 16 show the production distribution of induced forces from the compressor and the cold head at 23°C at 150K at 180mW total load in simulation dewar of 650 different units.

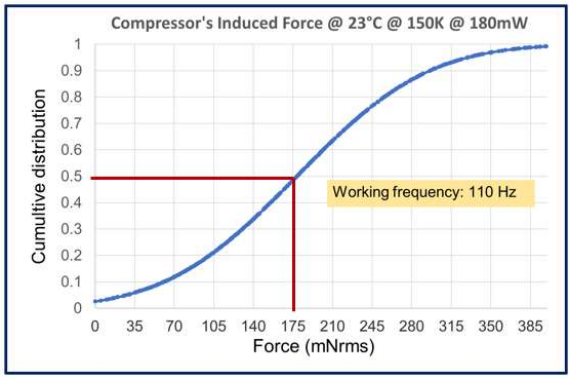

Figure 15: Compressor's induced force

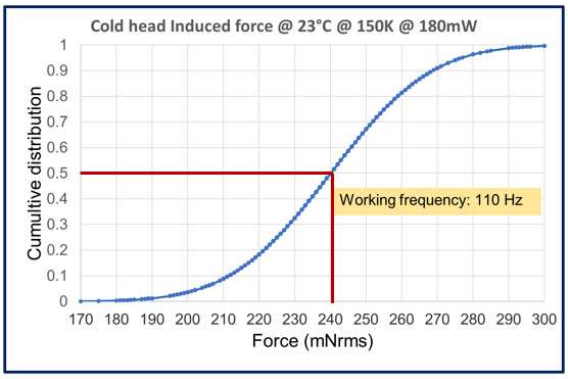

Figure 16: Cold head induced force

Fig. 17 shows production distribution of induced forces at 23°C @150K @180mW total in a side-by-side configuration (CDD level). It interesting to see that the average value of induced force of the CDD is like the value of the induced force from the cold head at cooler level.

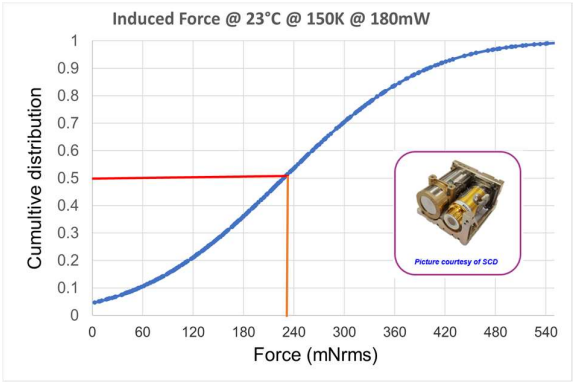

Figure 17: induced force at CDD level

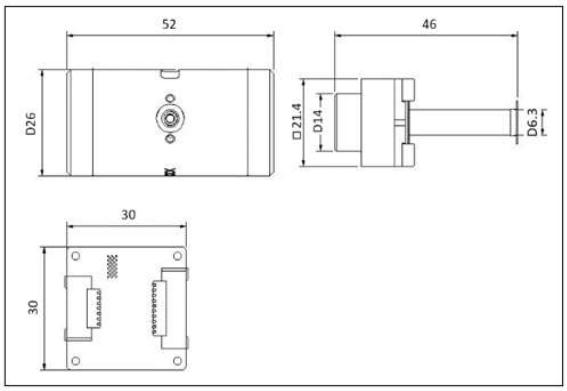

Figure 13: K588 external dimensions

3. R&D programs K580I &K590 GEN. II &K588

3.1 K588 Cryocooler

As part of engineering effort to adapt coolers with standard cold fingers, a new model named K588 is undergoing engineering work by adapting the K590 compressor to drive a new cold head fitted with the common cold finger as used by the K580 and K580I models. The K588 is a split rotary Cryocooler that is based on the K590 technology of a compact dual opposed compressor with external 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 has a high reliability goal of 30,000 operating hours.
Fig. 12 & Fig.13 show the main parameters of the K588 model and external dimensions:

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 12: K588 main parameters

Fig. 14 demonstrates the DC regulated power versus heat loads for the K588 prototype at 120K and 150K and at 23°C and 71°C ambient.

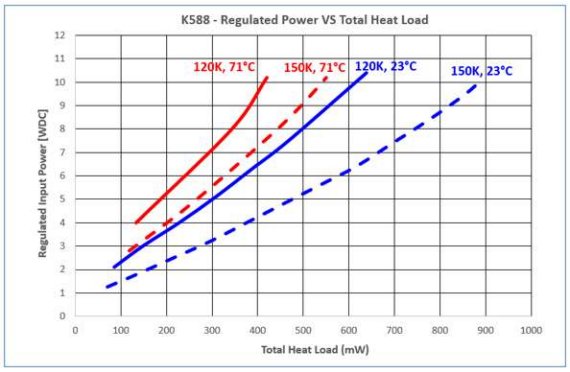

Figure 14: K588 regulated DC power Vs. heat load

Fig. 15 demonstrates the mapping of K588 cooling power at 120K and 150K and at ambient from -40°C up to 71°C:

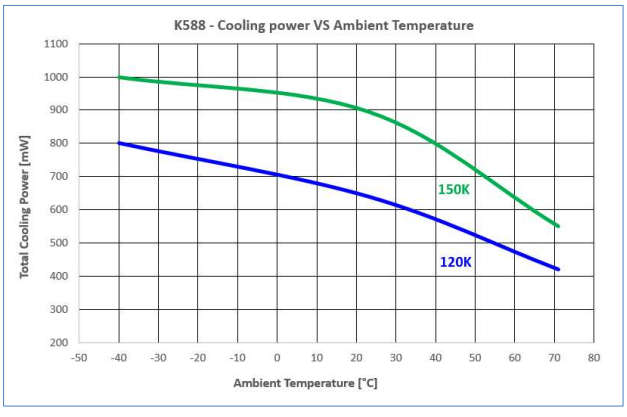

Figure 15: K588 Cooling power Vs. Ambient temperatures at 120K&150K

The linear technology of a compact dual opposed compressor excels in low induced forces levels and

low acoustic noise. Fig. 16 and Fig. 17 demonstrate 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 a common mechanical jig to the dynamometer test equipment.

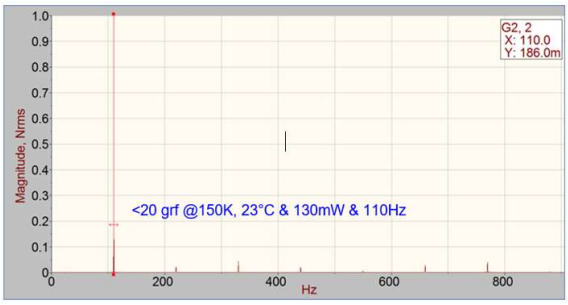

Figure 16: K588 induced force measurement

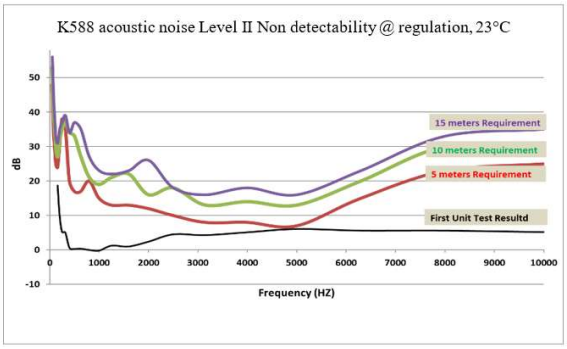

Figure 17: K588 acoustic noise measurement

3.2 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 is shifted from the external side and became an integral part of the compressor housing for the purpose of better functionality, handling, and clamping.
There are 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 motors for low input voltage.
There is a potential to perform one more step by increasing the Cryocooler's cooling power. However, this will be considered as part of a separate activity.
Tab. 2 lists the added value from these improvements.

Table 2: K590 Gen II improvements and added values at system level.

	K590	K590 Gen II	Added Value
Configuration	External fill port	Internal fill port	Enables simpler system design
Motor Voltage@ Maximum Power	High (8.5Vac)	Low (4.5Vac)	Enables to have highly efficient controller at low DC input voltage
Operating at high temperature	Ambient 71°C	Ambient 78°C	Enables to design smaller systems with high format detectors
SST Power Diversity (Deviation over average)	16%	10% (Goal)	Enables to commit to lower power requirements
Compressor's Induced Force Diversity (Deviation over average)	50%	25% (Goal)	Enables to commit to lower induced force requirements

3.2 K580I Cryocooler

As part of a continuous improvement activity, engineering work was carried out 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 are highly important for applications with lightweight construction and for stabilized applications.
The engineering work focused on advanced balancing methods for the mechanical rotating parts and yielded reduction in induced forces level that became more significant when the operating frequency is increased.
For example, a reduction of more than 80% achieved at a frequency of 80Hz which represents operation at a 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. See Fig. 18 for induced force comparative values.

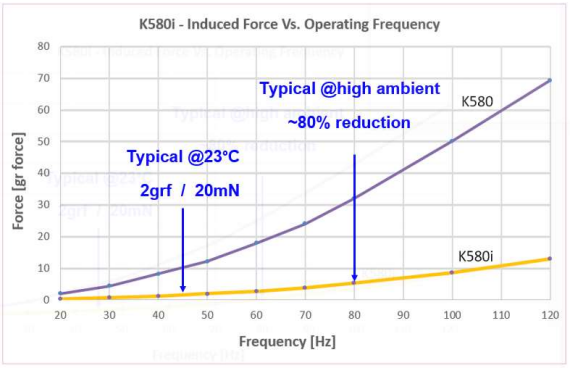

Figure 18: K580I induced forces measurements

4. SUMMARY

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.

Ricor monitors each cryocooler's performances and analyzes the distributions of each parameter in order to provide the best solution for customer needs.

The R&D improvement programs extend the capability of the models and enables us to design systems with the best performances in the market.

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.

5. REFERENCES

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