Current Rotary Coolers Improvements Usable for Next Generation of Rotary Coolers

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ABSTRACT

Today, many new systems using cryocoolers have a prime requirement to be compact, lightweight, and have a low power consumption. These system requirements have a direct impact on the cryocooler technology to be used within these applications. Furthermore, the cooling technology and product definition should be compliant with the required product reliability and the system operational requirements (Robustness, Induced Vibrations, EMI-levels, ROHS, etc.).

Improvements and technology developments of cooled IR sensors have had significant impact on the required cryogenic cooling power and temperature to be produced by the cryocooler. Originally, the detectors used to be cooled to a cryogenic temperature of 77K. More recently, depending on detector technology, bandwidth and required performance, the detector operating temperature may vary in a broader range, between 60K to 170K. Furthermore, greater cooler efficiency and power density are required to ease the definition of compact and flexible IR-cores.

This paper focuses on the next generation cooler characteristics linked to the above-mentioned system requirements. The latest cooler developed by Thales, the RMs1 is used as a case study to illustrate these characteristics leading to a compact and efficient cooler, low induced vibration and noise combined with a high reliability.

In the first part of the paper, the definition and the basic cryogenic performance of the RMs1 cooler is presented. In the second part of the paper, the latest improvement are presented such as the impact on overall performance of the newly developed and qualified electronic driver. Based on the results achieved with the RMs1, an approach for future generation compact cryocoolers is presented. The RMs1 cooler and its future spin-offs may be used in different market segments and is surely not restricted to the cooling of IR sensors.

INTRODUCTION

Today, IR detectors are rapidly improving with respect to a smaller pixel pitch, higher resolutions and larger total sensor area. However, achieving high EO performance at a high operating temperature (> 150K) of these new detectors is still a big challenge. It is very important that the cryogenic performance of the cooler can be correctly tuned to the actual need of the detector and the application in which the cooler is used.

Added to that, there are strong requirements at the system level to reduce the system size. This is linked to an improvement in the use of the equipment but also to a reduction of environmental impacts. This requirement also has to be applied on the cooler.

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Thales developed a new cooler to provide SWaP cooling solutions dedicated to HOT detectors. This cooler is now qualified and in serial production. The conclusion of this qualification effort is that the RMs1, due to its high efficiency and power density, is able to cool a wide range of application from 110K to 170K. The RMs1 product has been designed to deliver a high cryogenic power at a high overall efficiency with half the volume and half the weight of a RM2 cooler. Moreover, the RMs1 implemented the generic cold-finger interface designed to reduce the variation in dewars at our customers.

Even if the product is very good and answers he customer requirements, it is important to continue to improve it. In the second part of the paper, a new improvement made to the electronic driver is presented. This improvement reduces the size, the weight and the consumption of the electronic driver.

Finally, the last part of the paper describes how to use all the solutions developed for the RMs1 to other coolers to answer the new detectors and system levels trends.

RMS1 STATE OF THE ART FOR HOT COOLER

Dewar characteristics

The RMs1 rotary cooler has been designed for HOT detectors. It is not obvious to define a reference point for the cooler. According to data issued from FPA manufacturers, most of the HOT applications will operate at 150K. Nevertheless, in literature we can find some application with higher cold temperature such as 160-170K [1]. Moreover detectors at 150K are not easy to produce and it is still a challenge [2]. To conclude we define a reference at 150K as define in the Table 1 for a baseline. But the cooler shall operate between 110K and 170K or more. All the performance characteristics described in this paper are issued from tests with this dewar.

RMs1 presentation

The latest cooler developed at Thales, the so-called RMs1, is qualified [3]. This section briefly summaries the characteristics and the performances of the RMs1. This cooler is a very small cooler designed for HOT applications (such as 150K). Figure 1 presents the overall dimension of this cooler. The RMs1 cryocooler weight is 142 gm.

The performances are by default given for an input voltage of 12 Vdc to the cooler control and a cold operating temperature of 150K.

Cryogenic performances

Cool down time: Figure 2 represents the typical cool down time (CDT) measured as a function of the nominal ambient temperature. For a nominal operating temperature of 150K, the cool down

Table 1. SWAP initial requirements

Parameter	Value
Operating temperature	150 K
Total heat load [mW] between 20°C and 77K which includes: - Cold finger wall parasitics - Dewar load (radiative) 110 mW - Wire load (conductive) - Active load – power dissipated by the detector 50 mW	160 mW
Thermal mass [J] between 20°C and 77K	120 J

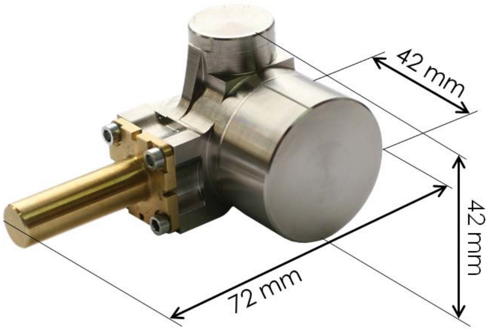


Figure 1. Picture of the RMs1 with its main dimensions

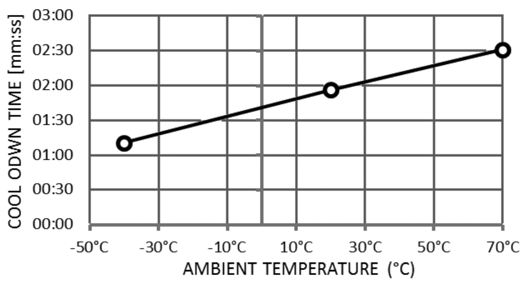


Figure 2. Cool down time as a function of ambient temperature

time at room temperature is about 2 min. At +70 °C ambient temperature, the cool down time is about 2 min 30 sec.

Input power in regulation: Figure 3 represents the typical AC input power measured at the cooler input in steady state operation as a function of the cold temperature set-point and for different ambient temperatures.

Total cryogenic capacity: Figure 4 presents the measurement of the total cryogenic capacity of the cooler, including the thermal losses of the dewar itself. The total cooling power is close to 1W whatever the ambient temperature. This shows that the cooler is optimized to cool significant heat loads at 150K but is also able to reach quickly stable operating conditions at lower temperatures i.e. 110K.

Because this cooler is still able to provide 1W @ 150 K @ 71 °C, the RMs1 is the ideal SWaP cooler for larger FPA's e.g., FPA's requiring cooling to 110K or ROIC with a higher dissipation.

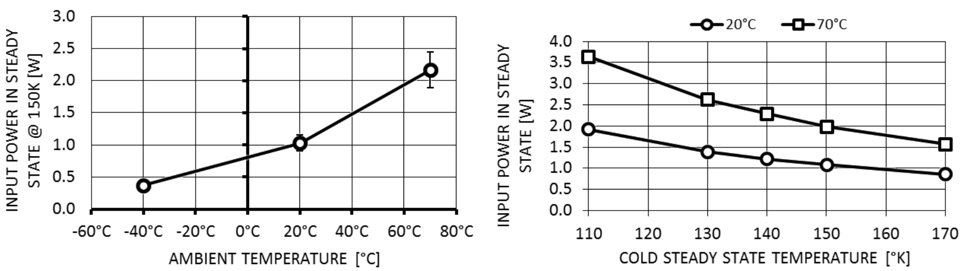


Figure 3. Steady state ac input power as a function of cold temperature and ambient temperature

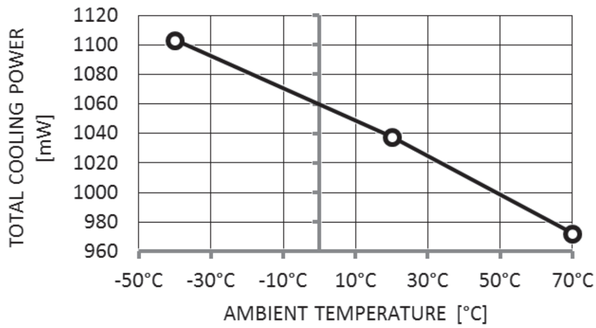


Figure 4. RMs1 total cooling power at 150K in function of ambient temperature

The efficiency of the RMs1 can be appreciated when looking at the relative efficiency compare to the Carnot efficiency. This relative efficiency has been evaluated at 3 different ambient temperatures and at the approximate minimum, average, and maximum rotational speed of the RMs1 cooler. The results are depicted in Figure 5.

With a dual set point mode, provided by the control electronics, it will also be able to run the sensor at a higher temperature setting to obtain a correct image while preserving battery power, and to quickly cool it down to a lower temperature setting when a better detector performance is required.

RMs1, a very quiet cooler

With regard to the integration of the cooler in the host system, two of the important aspects are the level of induced vibrations, and audible noise generated by the cooler operation. These parameters have to be as low as possible in order to avoid two effects at system level: movement of the sensor to be cooled (source of lower Line of Sight stability and blur of the image produced by the thermal imager) and the generation of acoustic noise by the system. The RMs1 has been specifically designed to minimize the generated induced vibrations, and the acoustic noises.

Induced vibrations: Figure 6 shows the mean and standard deviation for the induced vibrations measured for 15 coolers. The measurement is made on the three cooler axes (defined as compressor axis, cold finger axis and motor axis). For these measurements, all coolers are running at the same rotational speed in order to be able to compare intrinsic cooler performances. Moreover, the RM2 global level is added to the comparison. The current level of the RM2 is known and experienced to be compatible with demanding applications like optronic gimbal for airborne applications.

From this comparison, it can be concluded that the RMs1 generates less induced vibrations than RM2 cooler on the compressor axis, which was the most critical one. Furthermore, the global levels are similar between all RMs1 coolers indicating that the design and the associated manufacturing processes are fully mastered.

Coupled with its compactness and its power capacity, RMs1 may be a very relevant cooler for devices which have to operate in stabilized mini gimbal applications.

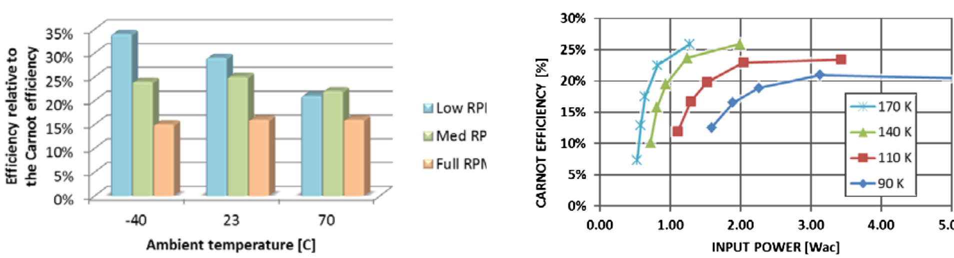


Figure 5. Efficiency relative to the Carnot efficiency of the RMs1 (left) as function of T_{amb} (right) as function of P_{ac}/T_e

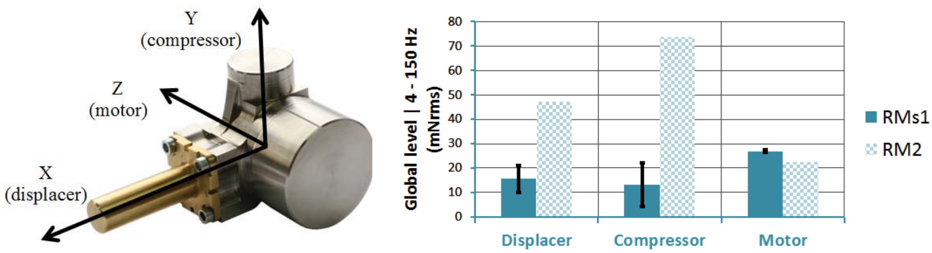


Figure 6. Induced vibration axis and measurement results

Acoustic noise: Figure 7 represents the results of the measurement performed according to MIL-STD-1474, non-detectability test. The RMs1 unit which has been tested is silent at 10 m in a steady-state mode at 150K. The impact of the acoustic noise at higher frequencies can be damped with adequate system integration. The global sound power level according to ISO 3744 is 43 dBA.

All the performances described previously are the mean value of measures on several coolers. Today more than 30 coolers were built and tested. All these coolers have similar performances. The repeatability of the results is very good.

The conclusion of this chapter is that the RMs1 is a very stable product coupling, compactness, high efficiency with low induced vibrations and acoustic noise levels. Due to its high achievable cooling power, the RMs1 is also a good platform for many other applications with larger detectors and detectors operating at lower temperature. Thus allowing to use a single type of cooler in a large variety of application and to optimize the storage, logistics and manufacturing costs.

PERFORMANCE IMPROVEMENTS – NEW ELECTRONIC DRIVER

RMs1 cooler is already a good cooler and it is recognized as the best cooling solution for HOT applications. However, we can still improve the complete solution by reducing the global input power. A consumption repartition analysis shows that for SWAP HOT application, electronic driver consumption becomes an important part of the global consumption (about 45%). To this end a new electronic driver was developed to have a complete SWAP solution (cooler and electronic driver).

At the beginning of the development, the main target for this new electronic was to divide the size and the driver consumption by two compared to existing solutions. Moreover, new technologies for electronic components are available that allow us to integrate more memory or function with less size.

The Table 2 shows a comparison between the new electronic driver and the older one used with the RMs1.

Qualifying a new electronic driver is still a challenge at system level. That's why the NEO electronic driver can replace DE0009 with only few modification. All DE0009 functions are pres-

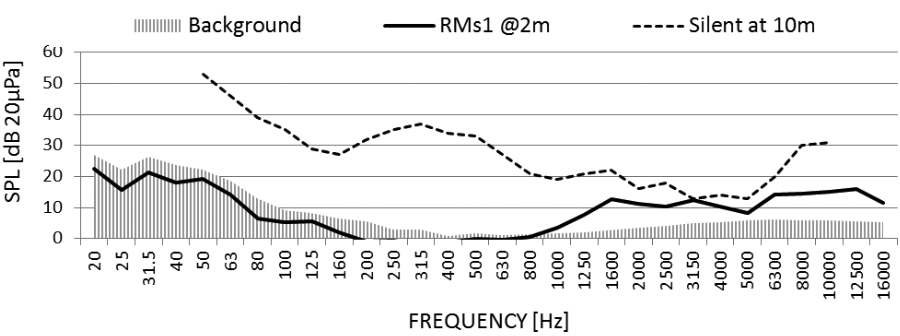
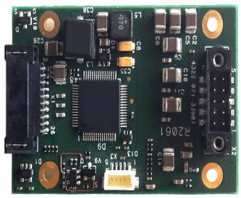
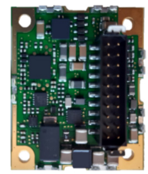


Figure 7. Non-detectability measure in steady state

Table 2. Comparison between old and new cooler drive electronic

	Older electronic driver (DE0009)	**New electronic driver (NEO)**
Picture		
Size and weight	53 x 35 x 11 < 15 gr	30 x 35 x 11 < 10 gr
Efficiency @ 20°C / 150K	> 60 %	> 70 %
Typical consumption with RMs1 @ 20°C / 150K	1.8 Wdc	1.4 Wdc
Integrated functions	Motor driving	
	Cold temperature regulation (with diode polarization)	
	Serial communication RS422	
	Hours counter	Hours counter and power ON counter
		life parameters saving (maximum values)
	Safety functions	
		Error saving
		Improved EMC / EMI filters
Compatibility with other coolers	No	Yes (RM2, RM4)

ent in the NEO electronic driver. We can have a specific PCB with the same mechanical interfaces. The only challenge is to change the electrical interface.

Moreover, it can be noticed that this improved new electronic driver can also drive some other coolers such as the RM2 and RM4. For these cooler, the benefit is a driver size reduction by 60% and a consumption improvement by 10%.

To conclude this part, NEO electronic driver is the smallest and most efficient electronic driver available for rotary cooler driving. This solution is very efficient for application where size and consumption are key drivers.

APPROACH FOR FUTURE GENERATION COMPACT CRYOCOOLERS

Complete RMs1 solution (including electronic driver) is the best solution for HOT SWAP applications. Why can't this status be conclude for other application?

For 30 years, Thales has developed very efficient and compact rotary coolers for a wide range of applications [4]. A thermal simulation model shows that the current Thales legacy coolers cover a wide range of applications (cold temperature, ambient temperature and cooling capacity). Nevertheless, efficiency and compactness become key criteria for many applications and not only for HOT or handled applications. We can think, for example, about airborne or civil applications.

The simulation model can also be used to define the cooling power needs for future applications. Today, Thales is working on a new application where the key requirements cannot be reached

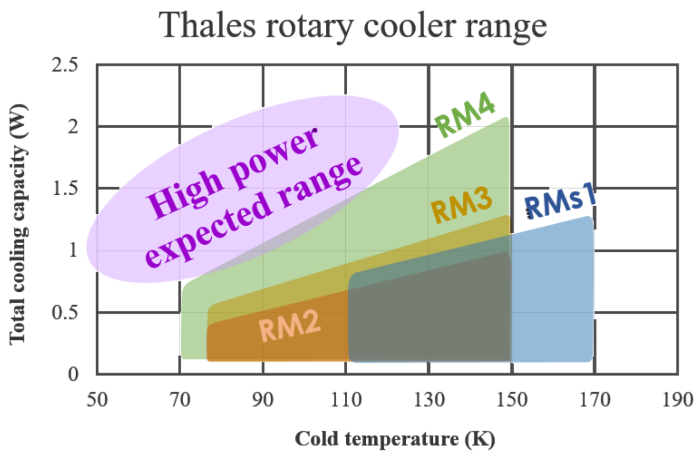


Figure 8. Thales existing rotary cooler range and new expected cooler

within the validated performance envelope of today's RMx coolers. The complete set of simulation tools available at Thales Cryogenics (including thermodynamic analysis) has been used to define the required cooling performance characteristics for this new "High Power" cooler.

All the feedback issued from RMs1 development will be used to develop this new cooler. The goal will be to save 50% of efficiency and size compared to existing cooler for high power application (above 1W of cooling power at 70K). Studies made during the RMs1 cooler development showed that it is possible to increase power density for high power applications. As an example, most of existing cryocooler have a power density below 2 (maximum cryogenic capacity divided by the cooler weight). For the RMs1, the power density is about 3. We hope to reach a power density above 2.5 for a high power cooler.

These required cooling performance characteristics have been defined and are intended to be verified in a specific cryocooler mock-up. The expected development lead time for this new cooler is 4 years to TRL 6 and 5 years for initial production.

The expected cooling power range for this new definition of the high power cooler has been depicted in Figure 8.

CONCLUSION

In this paper, the latest improvements made on RMs1 cooler have been presented. The RMs1 was already a very good solution for compact applications where size, weight and power are key criteria. With the new electronic driver, this state is even more true. It allows to save 22% of the cooler consumption, which is significant at system level.

We saw that SWAP concepts can be also used for other applications than handled applications with HOT detectors. All the work made in the frame of RMs1 can be used also for some other coolers. Now the goal is to apply all the bricks and technologies developed for the RMs1 to other coolers. For instance, the next step will be to develop a high power cooler with the RMs1 concepts.

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