

Raytheon Productized High Frequency Cryocooler

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ABSTRACT

The Raytheon Dual-Use Cryocooler (DUC) has been packaged into a flight configuration incorporating a surge volume and inertance tube integrated with its cold head. The operating frequency of the DUC has been also been increased from 60 Hz to 100 Hz in order to facilitate a reduction in its size and mass and to take full advantage of the performance characteristics of the Raytheon advanced regenerator. The operating frequency increase and re-optimization of the cold head for the advanced regenerator have resulted in an approximately 20% reduction in size and mass along with a significant increase in predicted performance in comparison with the brassboard DUC. Design information such as mass, package dimensions, and predicted thermodynamic performance for the flight packaged DUC are presented.

INTRODUCTION

Raytheon's Dual-Use Cryocooler (DUC) was originally developed to bridge a gap between the traditional space and tactical cryocooler domains, offering the high reliability and thermodynamic efficiency typical of a space cryocooler with a lower cost and lead time than such systems traditionally require [1]. More recently, it has been updated to incorporate the Raytheon advanced regenerator [2]. Although the substitution of the advanced regenerator as a drop-in replacement for the previous screen regenerator yielded a significant performance improvement, the DUC was not optimized to take full advantage of the new regenerator. For this reason, the DUC has undergone an additional design evolution, resulting in the Raytheon Advanced Miniature (RAM) cryocooler.

One of the foremost advantages of the advanced regenerator is its suitability for relatively high frequency operation. Operating a cryocooler at higher frequencies yields significant benefits, both by helping to reduce unwanted exported disturbance and allowing the system size and mass to be decreased. The RAM-100 cryocooler capitalizes on these advantages by operating at 100 Hz as opposed to the 60 Hz operating frequency of the DUC. The -100 designation in the RAM-100 refers to this operating frequency.

In addition to being optimized to take full advantage of the capabilities of the advanced regenerator, the RAM-100 design has been refined into a production-ready package. As shown in Figure 1, the design now features an integrated surge volume and inertance tube as well as thermal and structural interfaces that will greatly simplify integration. In a parallel effort, drive electronics are being developed for the RAM-100 which include a path to high reliability, radiation hardened components. Integrated testing of the RAM-100 Thermo-Mechanical Unit (TMU) with a brassboard version of its drive electronics is anticipated near the end of 2014.

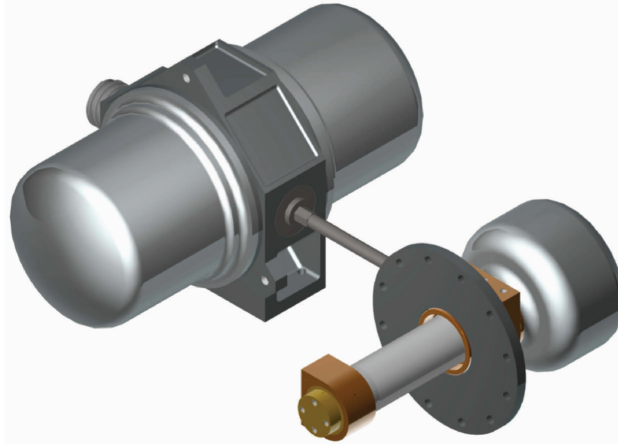


Figure 1. 3D Rendering of RAM-100 Cryocooler.

DESIGN UPDATE

Following the encouraging results of a feasibility study for a high frequency miniaturized DUC in 2013, internal funding was awarded in 2014 for the purpose of designing, fabricating and testing a fully-optimized production-ready RAM-100 cryocooler system. The compressor architecture of the RAM-100 draws heavily on several recent design efforts, including the Raytheon Medium Capacity-RSP2 (MC-RSP2), High Capacity-RSP2 (HC-RSP2), and the Low Temperature (sub-12K) RSP2 production compressor (LT-RSP2). Numerous innovative production and cost-saving improvements from these designs have been implemented in the RAM-100, reducing part count and assembly time. Integrated heat-rejection flanges have been incorporated into the compressor housing, allowing for simple heatpipe or hard-mounted temperature regulation. Industry standard connectors have been added for straightforward power and telemetry wiring. The RAM-100 compressor is capable of being installed utilizing load washers or chassis-mounted accelerometers, allowing flexibility depending on the integration environment. Compared to previous DUC IRAD designs, package size and weight have decreased while thermodynamic efficiency has increased; re-designed linear motors and flexure bearings provide improved compressor capability, while increasing the operating frequency to 100 Hz. Multiple linear flexure bearings were designed for the compressor, including a longer travel, high-performance flexure and a non-rotating flexure for even lower exported disturbance, which is currently undergoing life-testing.

The RAM-100 expander architecture also incorporates a number of manufacturing and thermodynamic improvements, including several years of DUC IRAD design advances. The cold-end now incorporates two flat mounting interfaces, creating predictable, consistent thermal-strap and instrumentation conduction paths. The surge volume and inertance tube of the pulse tube expander have been incorporated into the single body design of the RAM-100 design, with no external tubing or joints. The expander is designed to be mounted using a built-in thermally isolating, sealing surface, ensuring easy integration with temperature sensitive dewar structures.

Table 1 summarizes the mass attributes of the RAM-100 cryocooler as compared to the earlier Raytheon DUC unit.

ADVANCED REGENERATOR TESTING

The Raytheon advanced regenerator was incorporated into the DUC in 2012 and tested for performance across a wide range of cold tip temperatures and input powers [2]. The results of this testing are summarized here along with the results of a correlated Sage model of the DUC. This correlated model was adapted for the RAM-100 and was used for its design optimization and for the prediction of its performance prior to initial testing.

Table 1. Compressor and Expander Size and Mass Comparison.

DUC TMU			RAM-100 TMU		
	Compressor	Expander		Compressor	Expander
Mass:	3.9kg	1.4kg	Mass:	2.8kg	0.9kg
Package Size:			Package Size:		
Length	8.2in	5.4in	Length	7.9in	6.3in
Width	4.5in	4in	Width	3.75in	3.4in
Height	4.5in	4in	Height	3.75in	3.4in

In the DUC, the advanced regenerator was used as a drop-in replacement for a screen regenerator. A new cold head was constructed having identical dimensions to the previous DUC cold head, allowing a direct comparison between the screen and advanced regenerators. Although the advanced regenerator significantly outperformed the previous screen regenerator, this methodology potentially prevented the advanced regenerator from achieving its maximum performance as the geometry of the cold head and DUC operating parameters were originally optimized for the screens.

Typical load lines for the DUC with the advanced regenerator and screen regenerator at a nominal input power of 160 W are displayed in Figure 2. This roughly corresponds to the maximum input power to the brassboard compressor or approximately 95% of its full stroke. Fig. 2 shows an increase of approximately 1-3 W of heat lift for the advanced regenerator relative to the screens for cold tip temperatures from 50 K to 120 K. A decrease in no-load temperature from 45.6 K to 41.3 K was also observed.

Following the testing of the advanced regenerator in the DUC, correlation of the DUC Sage model was performed to reconcile the model predictions with the experimental data. This correlation included the full range of tested operating conditions, including variations in frequency, input power, cold tip temperature, and heat rejection temperature. Partial results of this correlated model are compared with the experimentally measured DUC performance data in Figure 3, which shows that the model predictions closely match the measured data. Because this correlated model was used as the basis for the RAM-100 Sage model, the accuracy of the correlation provides additional confidence in the performance predictions for the RAM-100.

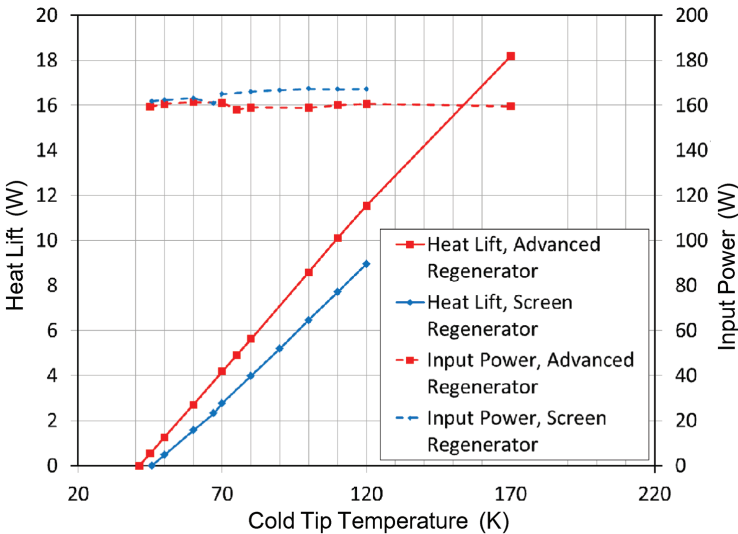


Figure 2. Raytheon DUC load lines for advanced and screen regenerators.

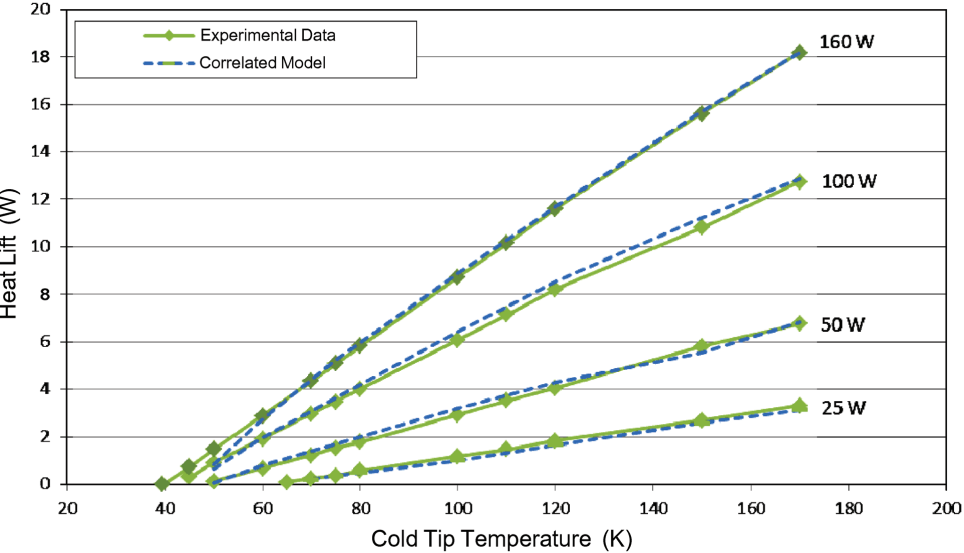


Figure 3. Sage model correlation for DUC with advanced regenerator.

RAM-100 PREDICTED PERFORMANCE

Thermodynamic performance for the RAM-100 cryocooler has been predicted using a Sage model that was based upon the correlated model of the DUC and advanced regenerator. Predictions were generated incorporating both of the available flexure bearings. The first, a non-rotating flexure, is anticipated to provide additional reductions in exported disturbance, while the second, a more traditional rotating flexure, provides a slightly greater stroke at its infinite life deflection limit. Aside from the substitution of the flexure bearings, the two resulting versions of the RAM-100 are identical and are predicted to operate at the same frequency of 100 Hz. Predicted performance for the RAM-100 is shown in the Ross plots of Figure 4 and Figure 5, which respectively incorporate the non-rotating and rotating flexures.

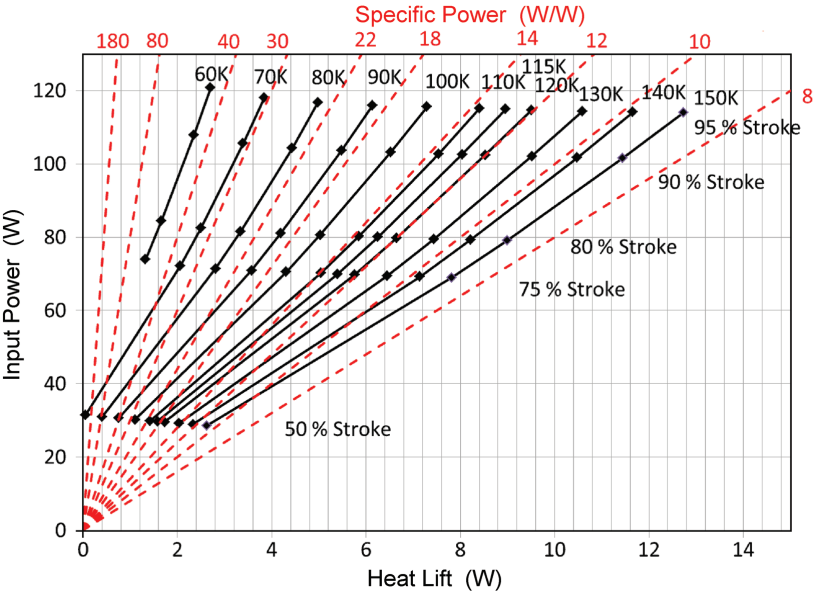


Figure 4. Ross plot for predicted performance of RAM-100 with non-rotating flexure.

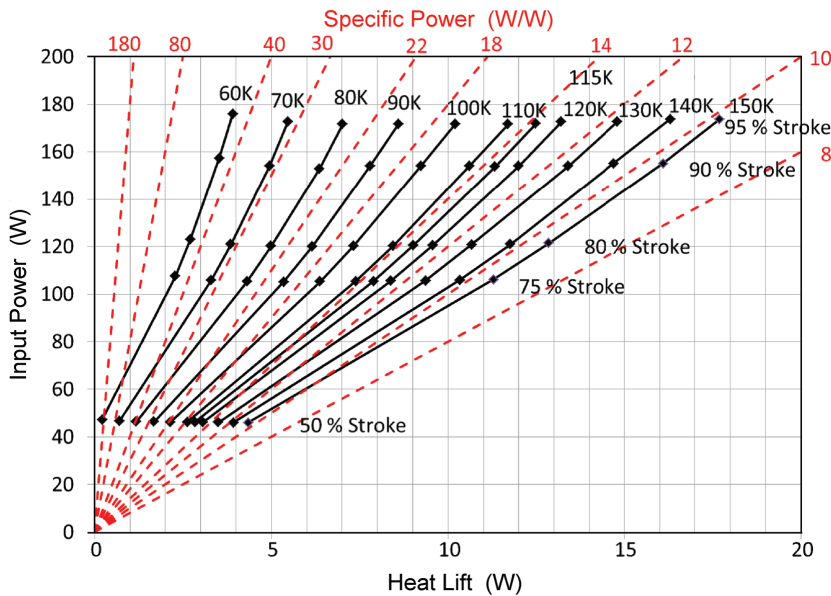


Figure 5. Ross plot for predicted performance of RAM-100 with rotating flexure.

As shown in Figure 4, the RAM-100 is predicted to reach a maximum input power of 110W – 120W with the non-rotating flexure bearing. With the slightly longer stroke afforded by the traditional rotating flexure, shown in Figure 5, the maximum predicted input power increases to approximately 180W. In both figures, predictions are made for a range of compressor strokes which are presented by percentage of the maximum attainable stroke. The data points predicted for 95% stroke therefore represent a good approximation of the maximum usable stroke for the RAM-100. The predicted input powers in both figures represent electrical power delivered to the TMU and are margined by 10% above the raw model result as a measure of conservatism prior to initial build and test.

CONCLUSIONS

The RAM-100 cryocooler system is being developed as a miniaturized, production ready derivative of the DUC. It incorporates many legacy design features from other Raytheon space cryocoolers and is optimized to take full advantage of the Raytheon advanced regenerator, particularly through higher frequency operation at 100 Hz. Design details and performance predictions for the RAM-100 have been presented along with test and model correlation data for the DUC and advanced regenerator. Testing of the RAM-100 with its brassboard electronics is anticipated before the end of 2014.

ACKNOWLEDGMENTS

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