Pulse Tube Cooler with Remote Cooling

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ABSTRACT

Space pulse tube coolers are very efficient, but like all regenerative high frequency Stirling and pulse tube coolers, the cold head needs to be located near the compressor in order to minimize the input power to the cooler. For applications that require cooling some distance from the cooler or that require vibration isolation from the cooled object, the cooling can be effectively transferred with a fluid loop rather than with a higher mass conduction bar. This can greatly ease integration into a payload as well as readily transmit the cooling to multiple cooling points. In this paper we report on a proof of concept test in which we added cold reed valves to the pulse tube cold block of our flight proven high efficiency cooler (HEC) so that cold gas could be circulated without the need for an additional circulation pump and additional heat exchangers to cool the gas. In this test, the measured remote cooling and the parasitic heat loads were compared to our previously reported tests using warm reed valves. The two previous tests circulated gas from either a second circulator compressor or from the pulse tube compressor that also acted as a circulator and cooled the gas with a heat exchanger connected to the pulse tube cold head.

INTRODUCTION

Sixteen Northrop Grumman efficient space pulse tube coolers are currently operating in orbit while cooling both IR focal planes and/or optics and/ or filter wheels. In all of these payloads, like all regenerative high frequency Stirling and pulse tube coolers, the cold head needs to be located near the compressor in order to minimize the input power to the cooler. This results from the fact that "ac" pneumatic power is transmitted between the compressor and cold head, and too large a transfer line length adds parasitic dead volume and pressure drop. For applications that require cooling that is some distance from the cooler or that require vibration isolation from the cooled object, the cooling can be effectively transferred with a circulating (dc) fluid loop rather than with a higher mass conduction bar or thermal strap. For larger distances, use of a massive conduction bar or thermal strap can cause large payload system issues because of the competing requirements of thermal isolation and launch vibration survival. Use of a cold circulating fluid loop can greatly ease integration into a payload as well as readily transmit the cooling to multiple cooling points or multiple payloads.
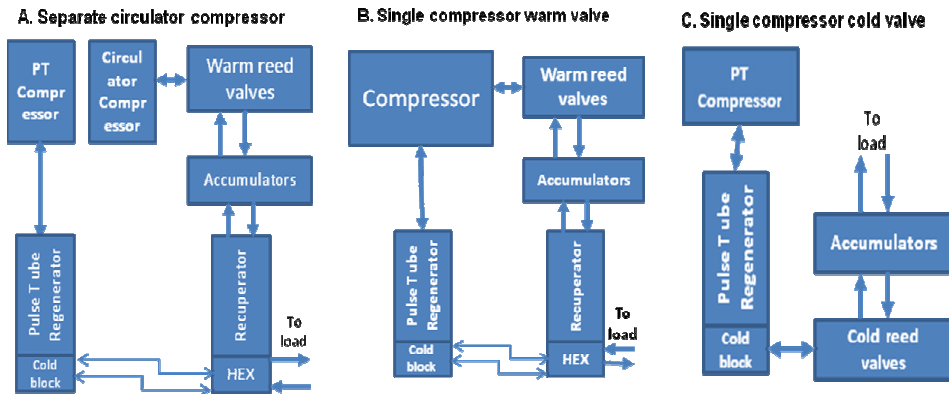
Figure 1. Remote cooling configurations

The Northrop Grumman JWST/MIRI 6K cooler[1] uses a dedicated circulator compressor with the gas then precooled to 17K by a three temperature stage pulse tube cooler in the configuration shown in Figure 1A. The cold gas is finally cooled remotely to 6K in a Joule-Thomson cooling stage at a distance of 10 meters. In the JWST/MIRI case, the working fluids are not shared, and the pulse tube precooler and the independent circulator are thermo-dynamically coupled only through heat exchange. This circulating flow was produced by adding (rectifying) warm reed valves to the HEC cooler[2] flight compressor after removal of the pulse tube cold head. We previously reported[3] on a remote cooling test configuration (Figure 1B) in which a single vibrationally balanced compressor served double duty as both the HEC pulse tube cooler[2] "ac" compressor and as the circulator "dc" compressor. In this case, the circulator and pulse tube cooler share the working He^4 fluid. After rectification by the warm reed valves the circulating gas is then cooled in a recuperated heat exchanger that is cooled by the pulse tube cold head prior to transmission to the remote load via small diameter tubing. In the single compressor remote cooling configuration, in contrast to the separate circulator compressor configuration, the cooler and circulator are strongly coupled pneumatically as well, constraining the maximum circulating flow and transmitted cooling because of its effect on the pulse tube cooler performance. The single compressor configuration has the system advantage of reduced compressor and drive electronics hardware compared to the two compressor configuration. From a payload system hardware viewpoint, the single compressor configuration trades a conduction bar or strap for warm reed valves and a recuperative heat exchanger.

In the third configuration (Figure 1C) that is reported in this paper, the hardware is further simplified by removing the recuperative heat exchanger. The cold circulating gas is now rectified with cold reed valves located on the HEC pulse tube cooler[2] cold block. In this configuration the pulse tube cold head regenerator serves double duty as both the pulse tube cold head regenerator and the circulating gas heat exchanger.

Northrop Grumman provided Atlas Scientific with the cold head interface. The cold valves and cold surge volumes were then designed, manufactured and provided to Northrop Grumman by Atlas Scientific. Northrop integrated the Atlas hardware onto a laboratory HEC pulse tube cooler and performed the tests.

This paper reports the proof of concept test data for this configuration in which cold gas is circulated without the need for an additional circulation pump and additional heat exchangers to cool the gas. Experimental data are presented and analyzed to characterize the efficiency of this remote cooling configuration. The measured remote cooling and the parasitic heat loads were then compared to our previously reported configuration B tests that used warm reed valves. The results were analyzed in order to guide further development.
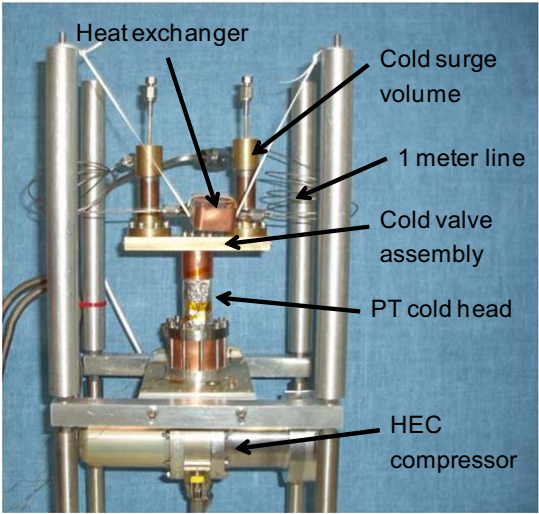
Figure 2. Cold Valve Remote cooling test setup

TEST SETUP

Figure 2 shows the cold valve remote cooling test setup. The cold valve assembly and surge tank (accumulator) that were supplied by Atlas were bolted to an HEC test pulse tube cold head. The cold valve assembly interface formed part of the flow turner inside the pulse tube cold block. The integral pulse tube cold head was mounted to its flight like HEC compressor. Flow from the outlet cold reed valve was transported through the high pressure accumulator and a 1 meter line to a cold heat exchanger, which acted as a thermal load prior to return through the low pressure accumulator to the cold inlet valve.

TEST RESULTS AND ANALYSIS

Figure 3 shows the proof of concept raw test results demonstrating that the cold valve configuration can produce remote cooling. The net cooling load obtained was less than its maximum because of additional parasitic and dead volume losses in this unoptimized test. The hardware design was not optimized for parasitic heat loads or for size optimization and tuning of the pulse tube cooler. Two cold valve assembly issues that affect net thermal performance were identified. The valve envelope is much larger than needed, which has imposed an extra radiation parasitic on the cooler. The internal valve and buffer volumes are also oversized, producing additional dead volume that reduces the efficiency of the pulse tube cooler.

To characterize the extra losses in the test setup, we compared the measured performance to the measured performance of the pulse tube cooler without the cold circulation loop, and we measured the performance of the test hardware under different test setups and conditions. The results are shown in Figure 4. By comparing the performance of the remote cooling tests to that of a standalone cooler, we can identify the losses in the remote cooling tests. To determine the extra radiation parasitics, the cold valve and the remote cooling line were thermally linked to the pulse tube cold head without gas flow through it. In another test, the cold valve and buffer volume were connected to the pulse tube cold head, but gas flow was shut off from the remote cooling loop.

Based on these tests Table 1 shows a comparison of the performance of the pulse tube cooler with and without remote cooling and identifies the losses. The remote cooling test load line has a higher no load temperature and a lower slope than the pulse tube cold head only load line. The
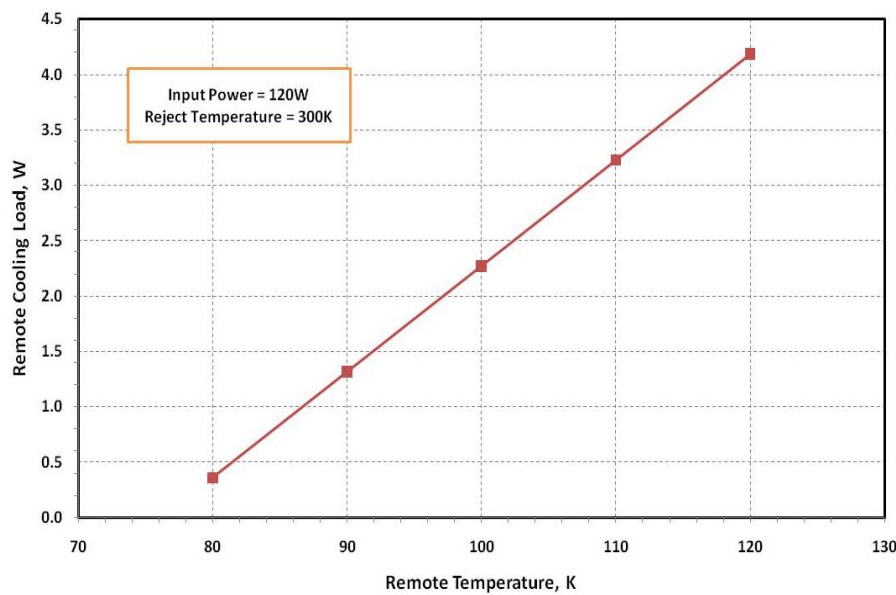
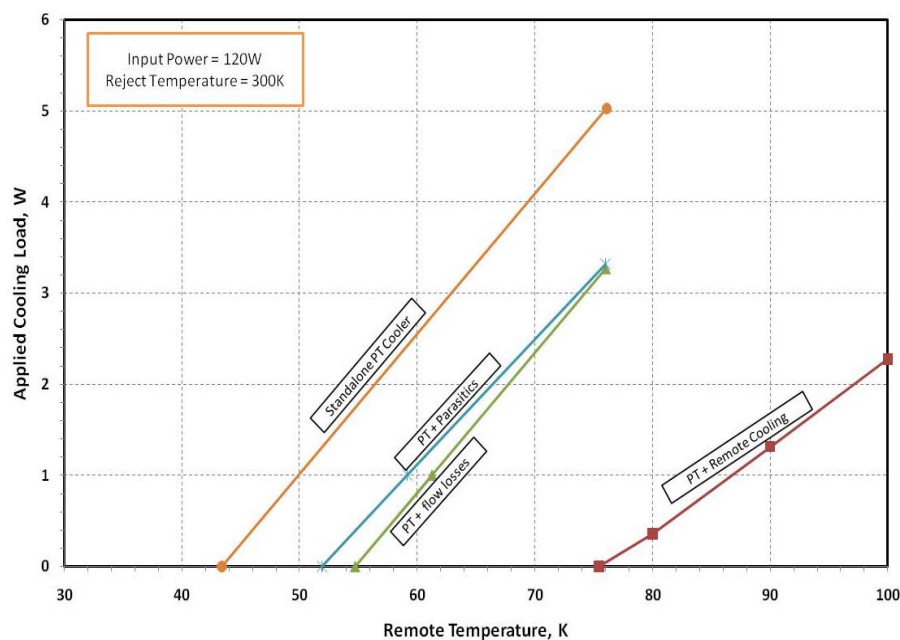**Figure 3.** Remote cooling as a function of the remote temperature

Figure 4. Remote cooling test diagnostic load lines

higher no load temperature is caused by the extra parasitic losses and cold valve leakage. The lower slope of the load line is expected, since the remote cooling hardware addition has added extra cold dead volume to the pulse tube cooler, reducing its cooling power. The load line for the remote cooling parasitic test has a no load temperature of 51.9K. At that temperature, the standalone cooler has a cooling capacity of 1.2 W. This cooling load can be allocated to the extra

Table 1. Remote Cooling Energy Balance for Unoptimized and Optimized Designs

	As Tested		Optimized Design	
		Measurement method		Comments
Remote temperature	75.00 K		75.00 K	
Pulse Tube Cooler Only	5.00 W	Measured Data	5.00 W	Measured Data
Remote cooling load	0.00 W			
Losses due to remote cooling loop				
Radiation to cold rectifier	-0.90 W	Measured data	-0.20 W	Optimize cold valve design
Radiation to remote cooling loop	-0.30 W	Measured data	-0.30 W	No change
PT detuning effect	-3.00 W	Remote cooling data	-1.50 W	Retune cold head with optimized remote cooling volume
Effect of leaky valve	-0.5 W	Measured data	0.00 W	Optimize valve design for cryogenic operations
Total Losses	-5.00 W		-2.00 W	
Remote Cooling Load	0.00 W		3.00 W	Improved remote cooling capacity with optimized system

parasitic loss in the remote cooling test. Similarly, the loss due to the cold valve leakage is approximately 0.5 W. We conducted an energy balance at 75K, which is the measured no load point for the cold valve tests at the constant 120W power level used in the test. Since the measurements were taken at constant input power, we summarize the measured and estimated losses at this operating temperature and input power in Table 1. At this temperature the unoptimized test pulse tube cooler in the absence of any circulation hardware is capable of 5W of cooling for 120W of compressor input power. As can be seen from the table, the two major losses arise from what we believe is an unoptimized design and from the fact that the pulse tube cold head was not retuned to accommodate the cold circulator hardware.

We estimate that an optimized remote cooling design would have a cooling capability of 3W at 75K for an input power of 120W.

CONCLUSION

Remote cooling using the High Efficiency Cooler (HEC) has been demonstrated. The system efficiency has been analyzed including the losses due to the unoptimized test hardware. Losses can be reduced by valve improvement to reduce leakage, a smaller volume to reduce parasitic heat leaks and an optimized retuned pulse tube cooler/remote cooling system. Once these optimizations are completed, we believe that the remote cooling option with a cold valve provides a viable path for an efficient space cooling system.

ACKNOWLEDGEMENTS

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