5 W at 77 K without Breaking the Bank

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ABSTRACT

Chart Industries has developed a small cryocooler for mass production at a cost far less than prior state of the art, using a novel external-stator motor and magnetic-piston construction that eliminates electrical feedthroughs, springs, and flexures, combined with a coldfinger that eliminates all brazing and welding. This new acoustic Stirling cooler operates directly on 60 Hz AC power, with direct forced air rejection to ambient (no other support services or equipment is required). Developed for local liquefaction of medical gases, this breakthrough in affordable, small cryocooling is now available in initial samples for any application. This paper presents the novel construction, price estimates, performance maps, and ongoing development of this cooler.

INTRODUCTION

Chart Industries has undertaken the endeavor of developing a novel, low-cost cryocooler to address the need for local, on-demand, cheap liquefaction of medical gases. This cryocooler, combined with Chart's cryogenic storage dewars and gas concentrators can provide consumers with a compact, on-site gas liquefaction appliance that is the perfect combination of quality, performance and affordable. Given the intended marketplace, cost is the single biggest challenge associated with the acoustic Stirling (or 'pulse-tube') cryocooler. In order to meet the strict cost requirement making use of existing, 'off-the-shelf' cryocoolers is simply not an option. Therefore, a new external-stator based electro-acoustic motor[1] was devised to significantly reduce the production time, complexity, and cost of this motor compared to traditional flexure or spring-based reciprocating motors. This motor concept further reduces the cryocoolers estimated cost by eliminating the need for electrical feed-throughs, as its electrical connections, which provide power to the motors, are moved outside of the pressure vessel. In addition to the above mentioned cost saving features, this cryocooler makes use of no copper components, with the exception of the motor coils, or braze joints and uses only a limited number of motor tube and inertance coil weld joints to achieve a cost-effective, helium tight pressure vessel. The low cost cryocooler design coupled with the prototype performance test results that will be discussed, make this cryocooler an ideal option for researchers and OEMs looking to achieve 5 to 12 watts of cooling in the 77K to 100K range without 'breaking their bank.'

LOW COST CRYOCOOLER COMPOSITION

Basic Cryocooler Components

The cryocooler makes use of two, opposed, external-stator motors that are directly coupled to its coldfinger. The motors alternately compress and expand the working helium gas, 'driving' the coldfinger. Each motor consists of a thin-walled motor tube which serves the purpose of the pressure vessel wall, a reciprocating magnet core-piston, an iron stator assembly including wound bobbins and a back volume. Figure 1 shows a solid model of the motor.

The coaxial coldhead portion of the cryocooler consists of a stacked-plate warm heat exchanger (or aftercooler) which serves as the main heat rejection point, a coiled inertance tube, a compliance tank and a coldfinger. The coldfinger itself houses the regenerator, which is composed of low cost stainless-steel, random fiber filter material, a slotted/finned cold heat exchanger, and a phenolic (Garolite 10) thermal buffer tube with integrated, sintered screen or wire-knit puck flow straighteners at each end. Figure 2 shows the basic low cost cryocooler components. The solid model shown in Figure 2 represents something close to the preferred embodiment of a product (or OEM system) minus integrated air or water cooling.

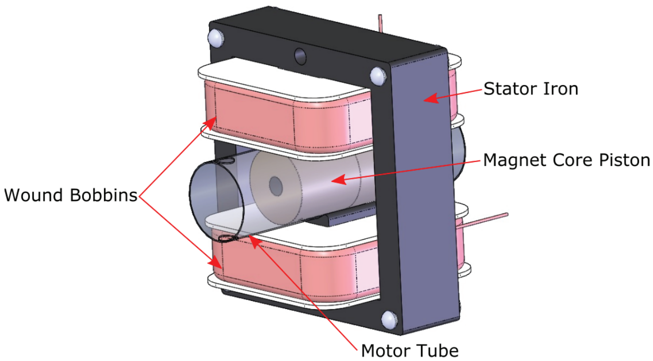

Figure 1. Novel magnetic reciprocating piston, external-stator motor used in the low cost cryocooler. The motor 'tube' is made transparent here to show the relationship between the motors external stator and magnet core-piston. Two of these motors comprise the acoustic drive or pressure wave generator portion of the cryocooler and drive its coldfinger (acoustic load).

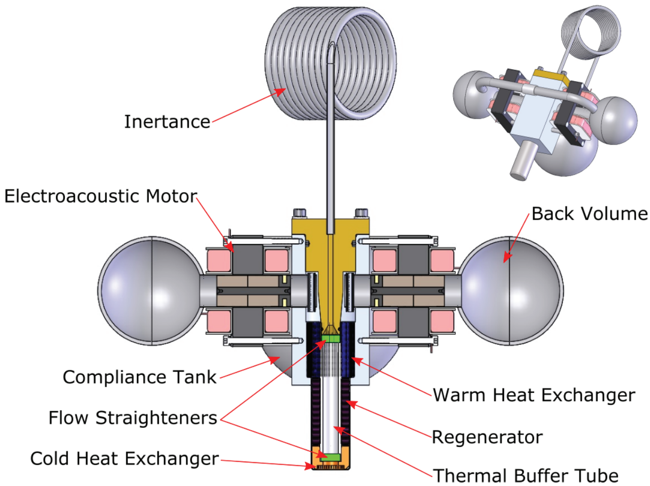

Figure 2. Section view with inset solid model (top right) of the low cost cryocooler. In the sectioned view the compliance tank is hidden from view. Neither water nor air heat reject options are shown attached to the warm heat exchanger. Space volume is approximately 38 cm x 38 cm x 26 cm.

Cryocooler Cost Estimate

Based on the manufacturing cost analysis that we have carried out, which includes direct material costs, labor costs and manufacturing overhead, and the estimated market volume, we believe when this cryocooler becomes commercially available, its sale price will be in the $3000 range, if not less. This price includes integrated air or water cooling based on the end users specifications.

EXPERIMENTAL RESULTS TO DATE

In addition to achieving its target production cost we believe that the cryocooler also has to be able to achieve a cooling capacity of ~5W at ~77K in order for it to be commercially viable for a small liquefaction appliance. Figure 3 shows a prototype cryocooler in an experimental performance load test set up. Figure 4 shows a close up of the prototype cryocooler on a vacuum can with certain visible components identified.

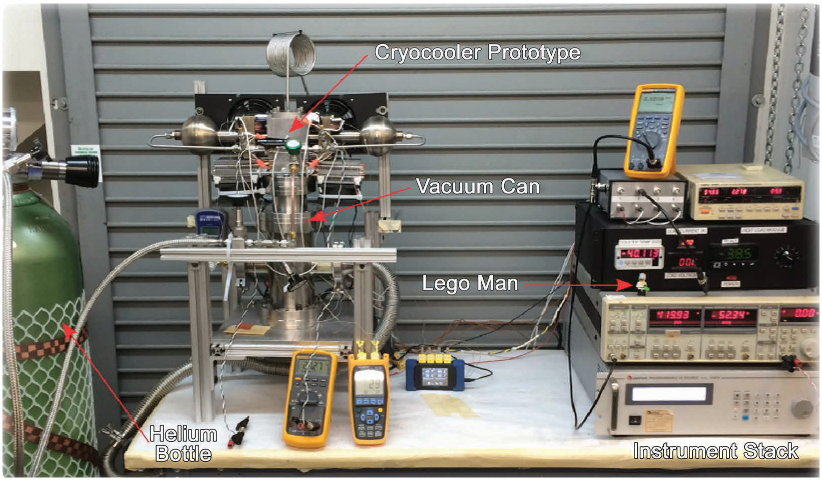

Figure 3. A prototype cryocooler in test. Note Lego Man on instrument stack for scale.

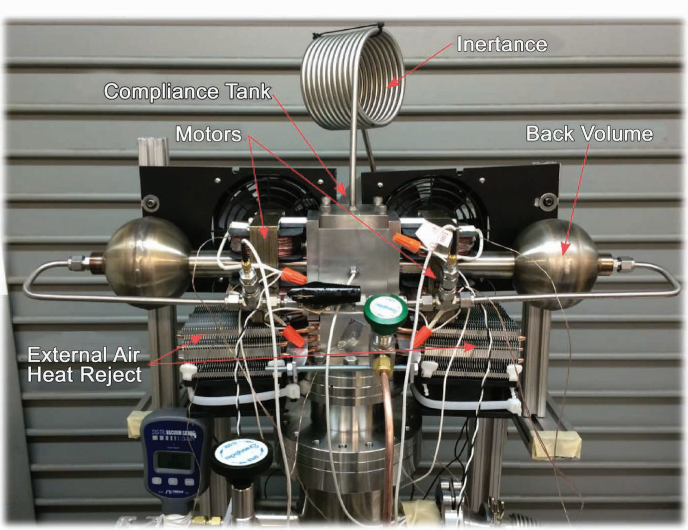

Figure 4. Close up of experimental cryocooler prototype. The coldfinger is not visible as it is inserted into a vacuum can for testing.

Analysis of available data

Before integrating the cryocooler into a full liquefaction appliance, it is important to evaluate its cooling power to assure that it will meet the performance target of 5W at 77K. The experimental test set up pictured in Figure 3 is used to make a series of heat load measurements at various operating conditions. Figure 5 shows two, two point load curves for the cryocooler with electrical inputs of 200We and 250We. The performance is measured at 77K and 100K as these are the approximate liquefaction points of nitrogen at Standard Temperature and Pressure (STP) and oxygen at 18 psig, respectively. We then measured the cryocoolers heat load at several other electrical input points, while maintaining a coldfinger tip temperature of 77K. Figure 6 shows the measured power curves. If we assume that the curves in Figure 6 are linear, we can conclude that the cryocooler should be able to achieve ~7W of cooling at 77K and over 14W of cooling at 100K with an electrical input of 350We, which is the allocated electrical input power limit for the project.

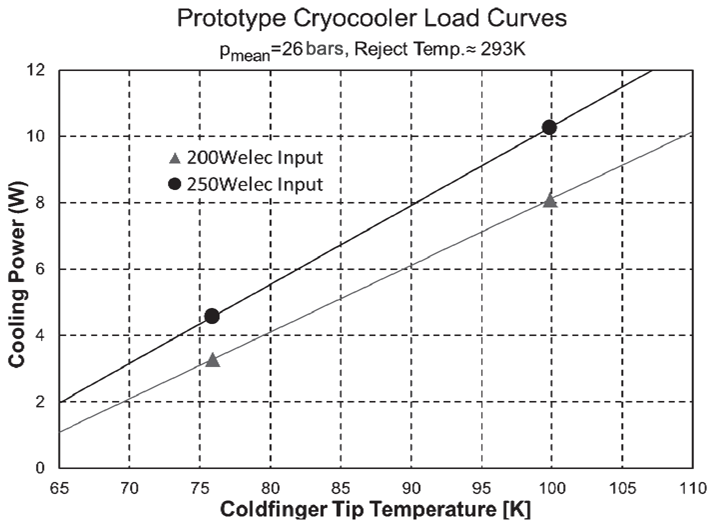

Figure 5. Load curve for prototype cryocooler.

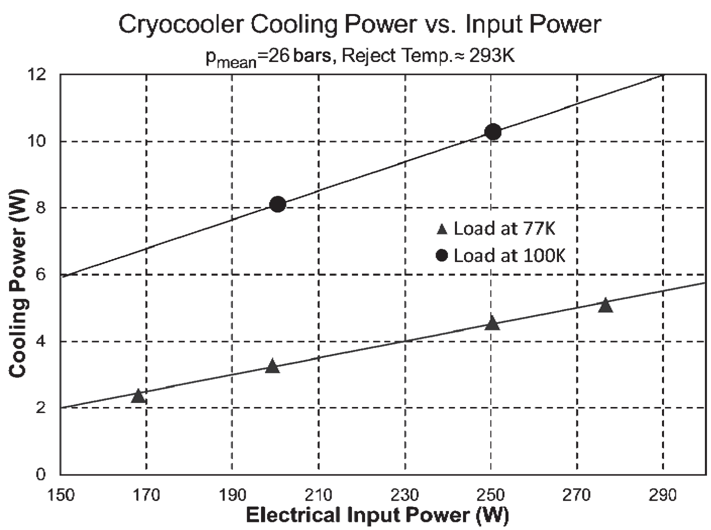

Figure 6. Cooling capacity of the prototype cryocooler versus electrical input power.

CONCLUSIONS

Chart, Inc. has successfully constructed a low cost cryocooler that is able to achieve 5W of cooling at 77K and won't 'break the bank' to purchase. While these test results are very encouraging there is still more experimental work that needs to be carried out to fully characterize the prototypes performance. Additional power curve testing (up to an input of 350We), testing at higher reject temperatures (up to 351K) and evaluating the heat leak of the experimental set up still needs to be completed. Additionally, the construction and performance testing of several more prototypes to confirm repeatability of the design, its manufacturing methods, and performance must be carried out. Furthermore, oxygen and nitrogen liquefaction testing to determine the necessary cooling capacity based on desired appliance specific production rates (liters/day, gallons/day, etc.) also needs to be completed. Development work on a liquefaction appliance is currently underway.

REFERENCES

1. Corey, J.A., Douglas, A.W., "Cryocooler with magnetic reciprocating piston," U.S. Patent Application 14/450,142.