TRILLIUM: AN INLINE THERMOACOUSTIC-STRILING REFRIGERATOR

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Introduction

Construction has been completed on an inline refrigerator we call Trillium. It is a prototype for a split-system commercial refrigerator that does not use HCFC or other fluorine based F-gas refrigerants.

Description

The refrigerator is shown in Figure 1. It consists of three thermal stages driven by three linear motors arranged in a row. Vibration balance and quiet operation is achieved by keeping the moving masses of the three stages the same and driving each of the motors 120° out of phase from the others. The 11 bar helium working gas within each thermal stage is compressed and translated by pistons and flexure seals above and below each stage. Each linear motor is rigidly attached to the piston above and below it, except that the bottom motor drives the uppermost piston of the top thermal stage through a lightweight rigid aluminum yoke. The pistons attached to the top and middle motors are heavier than those attached to the bottom motor to compensate for the mass of the yoke. A pressure vessel surrounds the components shown in the figure. Operation is at 82 Hz.

The regenerator at the center of each thermal core is a rolled, 51 micron thick Kapton ribbon that has been dimpled to produce gaps of 60 microns between successive layers. Vacuum brazed aluminum microchannel tube-fin heat exchangers are above and below each regenerator. The fins are folded from 100 micron 3003 aluminum foil with 790 micron outer peak-to-peak amplitude and fin pitch (fin-fin center spacing) of 320 microns. This gives a hydraulic radius of only 84 microns for nearly regenerator-like performance in the heat exchangers. Brazing did not go well and the heat exchangers have suffered multiple helium leaks, which have since been plugged.

In a bid towards commercialization, the flexure seals between the moving pistons and the heat exchangers are made from injection molded fatigue-resistant AvaSpire PAEK or KetaSpire PEEK thermoplastic. Both types have survived for 113 hours or 27 million cycles of a 110% of full amplitude fatigue test. The linear motors are from Qdrive of Chart Industries. They are driven by an off-the-shelf three-phase motor controller.

Unfortunately, the refrigerator and its instrumentation had to be moved before testing could be done, and testing has barely started as of this writing. We expect a COP of 1.4 (37% of Carnot) for 3.5 kW of refrigeration at a refrigerated load temperature of –29°C and heat rejection at 35°C ambient temperature.

The machine as a whole can be considered as a lumped-element version of a looped thermoacoustic-Stirling device, or as three alpha-Stirling devices in-line.

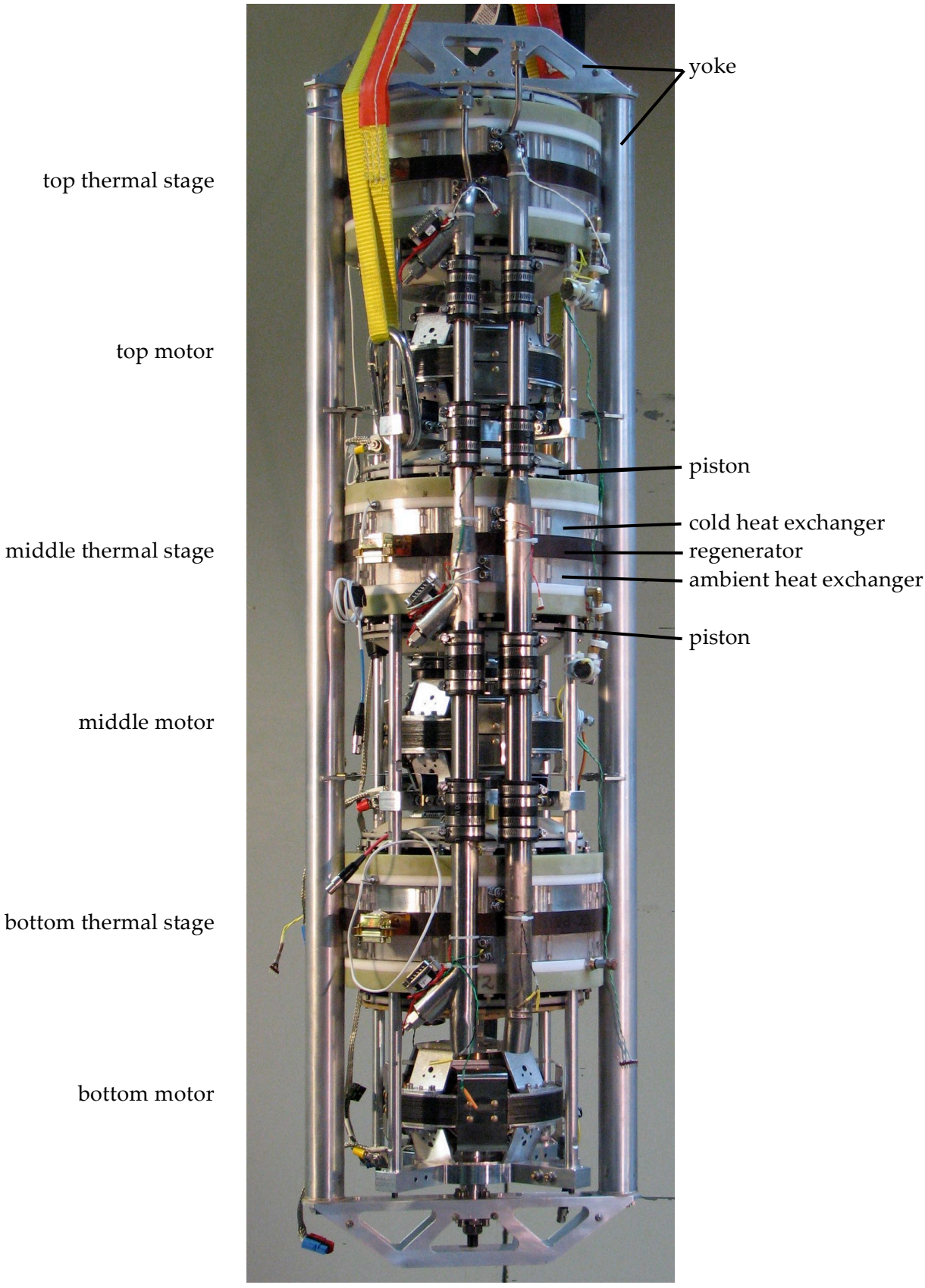

Figure 1: *Internal components of the Trillium refrigerator. Heat exchanger and regenerator OD is 254 mm.*

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