Free Piston Stirling Cryocooler

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Transmission Guitar ™

Abstract

The Stirling Cycle is a thermodynamic process that was developed by the Scottish inventor Robert Stirling in 1816. In the original engine design, heat is introduced to the system that expands to displace a piston which in turn creates work. This project goal is to reverse the Stirling cycle in order to remove heat from an insulated vessel. Work is added to a closed system by means of a linear motor that actuates a free piston-displacer assembly and removes heat. Industrial applications of Free Piston Stirling Cryocoolers include temperature critical medical transportation, missile guidance electronic cooling systems, liquefying natural gas processes, and space applications. Low power requirements, minimal moving parts, and compactibility make Stirling Cryocoolers ideal for cooling applications in harsh remote settings.

Project Goals

The design goal is to build an experimental model that will explore thermodynamic properties of the Stirling Cycle to be used within Experimental Methods Laboratory ME 495. Project highlights also include:

- Display framework designed and assembled.
- Motor control center (MCC) programed to provide adjustable speed capabilities.
- Touchscreen Human Machine Interface (HMI) integration for easy operation.
- Temperature and pressure sensing instrumentation.
- Cooling vessel design to maximize heat removal.

Customer Requirements

Adjustable Speed Capabilities	Transfers Heat from Cooler
Benchtop Compatible Thermal Sciences Laboratory	Operates on 120 Volt Wall Power
Safe to Operate and Adjust Motor Speed Settings	Manufacturable By NAU Machine Shop
Downloadable Data Acquisition	Replaceable Linear Motor
Ability to Change Working Fluid (Air/Helium)	Replaceable Regenerator Material

Design Modifications

Modifications to overall design include:

- Piston/Cylinder clearance decreased from 0.008 in to 0.003 in.
- Shaft diameter reduced from 0.375 in to 0.187 in. (Effectively increasing piston surface area by 20%.)
- Displacer reconstructed in PVC rather than aluminum.

Key Manufacturing Processes

All cooler parts custom manufactured using NAU Fabrication Shop lathe for turning and boring procedures. Precision bolt hole alignment performed using Tormach 1100 CNC machine provided by Transmission Guitars fabrication shop.

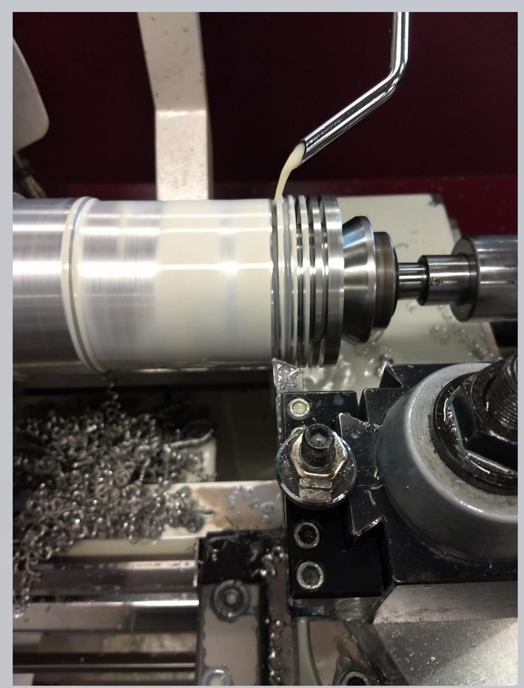


Figure 1. Turning outer shell component with heat fins on lathe.

Figure 2. Bolt pattern drilling using Tormach 1100.

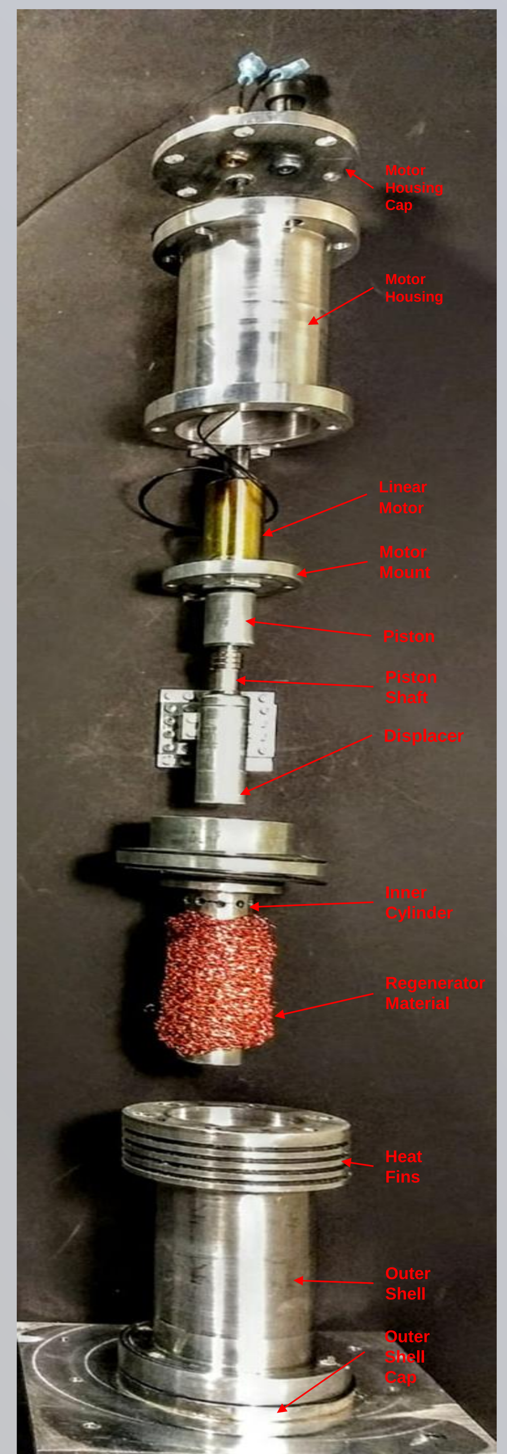


Figure 3. Final motor cooler assembly. Exploded view to show internal parts.

Final Design

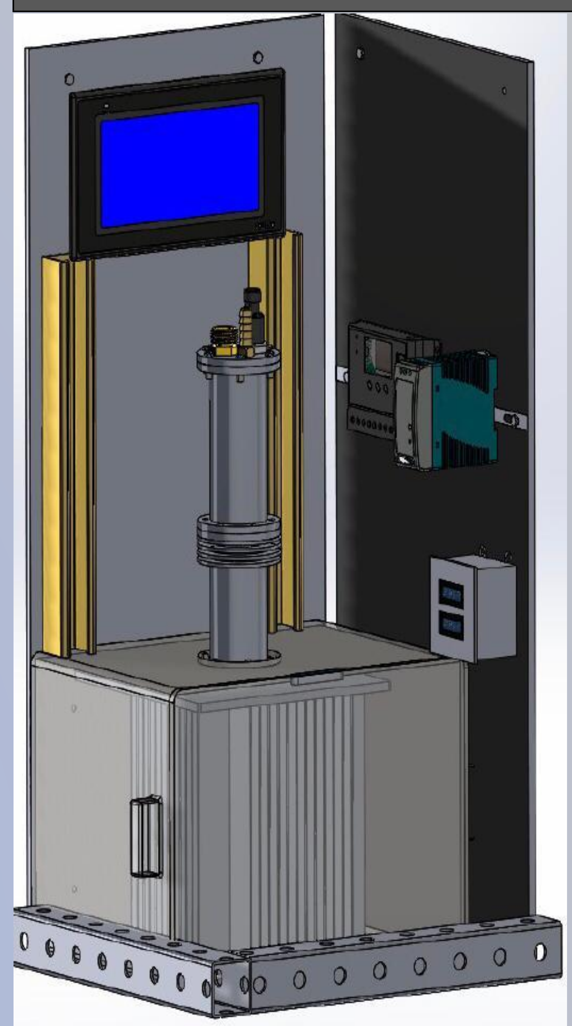


Figure 4. Final CAD assembly

Figure 5. Final Design assembly

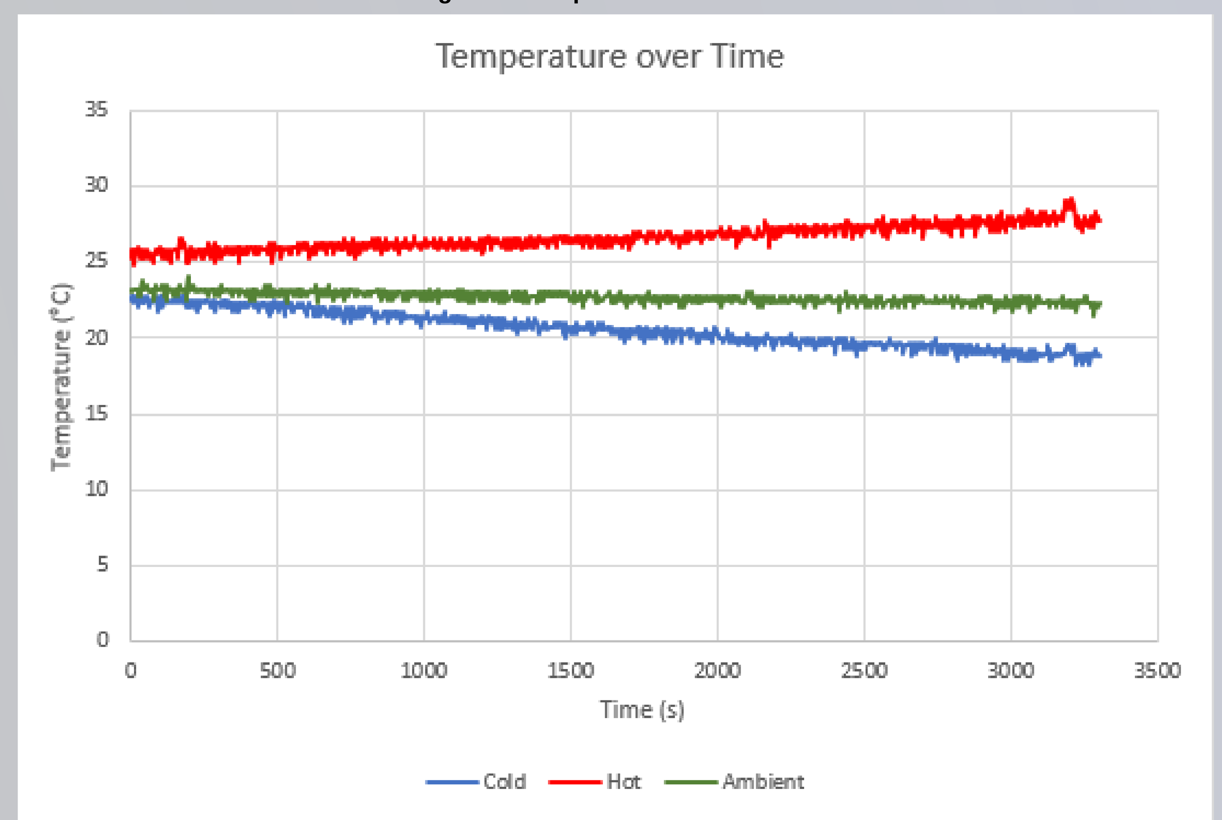
Testing Procedures and Results

The testing procedures were conducted by plugging in and operating the Stirling cooler. The cooler has an integrated human machine interface (HMI) that allows for the user to specify the duty cycle and frequency. Temperatures were recorded by using the MAX6675 library on the Arduino Integrated Development Environment (IDE) platform. A 24 V power supply was used to adjust the power delivered to the motor.

Table 1. Testing Parameters and Implementation Methods

Test Parameter	Implementation
Motor Speed Adjustment	Touchscreen HMI Adjustment of Stroke Frequency and Pulse Length
Variable Voltage Input and Amperage Monitoring	Utilization of Adjustable Power Supply 0-30V, 0-5 Amps
Pressure Testing	Compressed Air Addition and Leak Check With Soapy Water
Temperature Change	Arduino Interface with LCD Readout. K-type Thermocouples.
Data Collection	Arduino IDE Platform Converted to Microsoft Excel
Coefficient of Performance	COP = Qc/Watts

Figure 6. Temperature VS Time

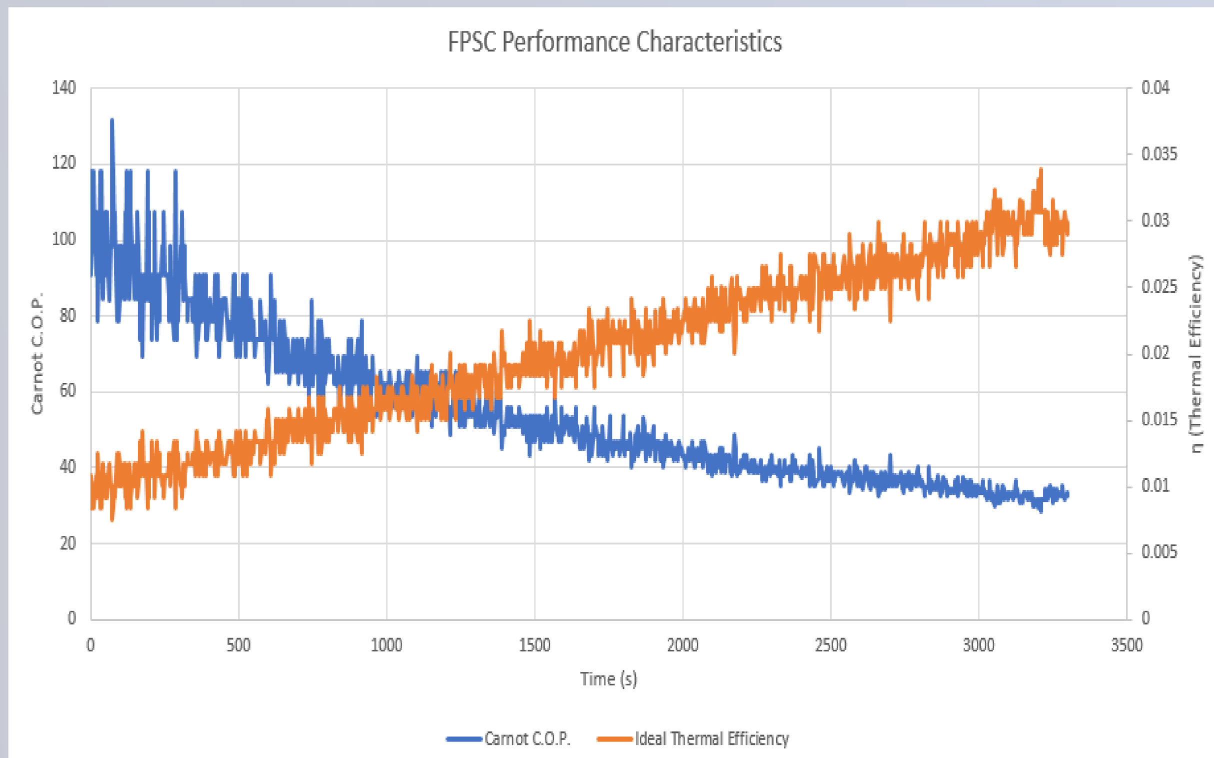


Results of operational testing are displayed in Table 2. Temperature reduction of only 4.4 °C was achieved after nearly an hour of operation. This resulted in a coefficient of performance (COP) of 0.13. Lower results are due to inefficient operation of the system. Compared to existing designs that obtain much larger temperature reductions (-40 °C) and a higher COP (1.1). [1]

Table 2. Test Settings and Result Interpretations

Parameter Setting	Translation
Time Between Strokes: 15 ms Pulse Length: 20 ms	Duty Cycle: 62.5% Frequency: 25 Hz
Voltage: 24 V Amperage: 0.4 Amps	Cooling Capacity: 9.6 Watts
Initial Pressure: 80.16 kPa	Final Pressure: 89.16 kPa
Ambient Temperature (T1): 22.3 deg C Fin Temperature (T2): 23.0 deg C Cold Head Temp (T3): 23.0 deg C	T1 (Avg): 22.7 deg C T2 (Max): 29.3 deg C T3 (Min): 18.3 deg C
Existing COP: 1.1 [1]	COP: 0.13

Figure 7 Coefficient of Performance



References

"TWINBIRD Free Piston Stirling Cooler / ABOUT FPSC," Free Piston Stirling Cooler. [Online]. Available: http://fpsc.twinbird.jp/c/about_fpsc.php. [Accessed: 29-Nov-2018].

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