Closed Cycle Refrigerator (CCR)

Physics 590B Fall 2018
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Many choices for CCRs

Thermodynamics of CCRs

For a closed system with fixed boundaries.

First Law: \[ \dot{Q}_a = P + \dot{Q}_L \]

Second Law: \[ \dot{S} = \frac{\dot{Q}_a}{T_a} - \frac{\dot{Q}_L}{T_L} \geq 0 \]

\[ \Rightarrow \quad P = \frac{\dot{Q}_L}{\xi} + T_a \dot{S} \]

In this case, \[ \xi = \xi_c = \frac{T_L}{T_a - T_L} \]

More generally, \[ \xi = COP = \frac{\dot{Q}_L}{P} \]

- \( P \) is the power supplied to the system
- \( \dot{S} \) is the rate of change of internal entropy
- \( \dot{Q}_a \) is the rate which heat at temperature \( T_a \) is released from the system
- \( \dot{Q}_L \) is the cooling power at temperature \( T_L \) of the system
- COP is the Coefficient of Performance
Stirling Cycle

- Cooling power occurs during c-d
- Warm piston is kept at $T_a$
- Regenerator acts as a reversible heat exchanger
- Working gas is an ideal gas
Gifford-McMahon (GM) cycle

- Can operate from 4 K to 300 K
- Displacer works at about 1 Hz
- He working gas is about 10-30 bar
- Other than heat, compressor can be isolated from the rest of the system.

Cooling power all during b to c.

Pulse Tube

Can be GM or Stirling type

Regenerator

Is an arrangement of solid material which conducts heat to and from the working fluid of the CCR.

Ideal Regenerator has

- High surface area.
- High heat capacity compared to the heat capacity of the working gas.
- Zero resistance to flow of the working gas, equivalently no pressure drop across the regenerator.
- Zero heat flow parallel to the flow of the working gas.
- If using an ideal gas then the change in enthalpy should be also zero.
Regenerator

Consist of porous material arranged in beds, as metal screens, perforated plates, wire meshes, etc.

Heat capacity of solids drops off much faster than gases at low temperatures.

For Further Reading


Many different kinds CCRs

Figure 1. Schematics of the three most common recuperative cycles.

Figure 2. Schematics of the most common regenerative cycles.

Images from NIST
https://trc.nist.gov/cryogenics/cryocoolers.html
Stirling Cycle

- Typically operate above 20 K
- 15 Hz
- Good efficiency
- Able to be miniaturized
- Relatively poor cooling power

Figure from Stirling Cryogenics