PHY524 Cryogenics-3

Cryocoolers

11/13/2025

Material adopted from

1. https://www.stonybrook.edu/commcms/case/courses/PHY695
2. http://cryocourse2016.aalto.fi/#program
3. http://cryocourse2011.grenoble.cnrs.fr/spip.php%3Frubrique13.html
4. USPAS | Materials | by Year | 21onlineSBU | Cryogenic Engineering
5. USPAS | Materials | by Year | 10MIT | Cryo Engineering

Cryo-coolers

Different types:

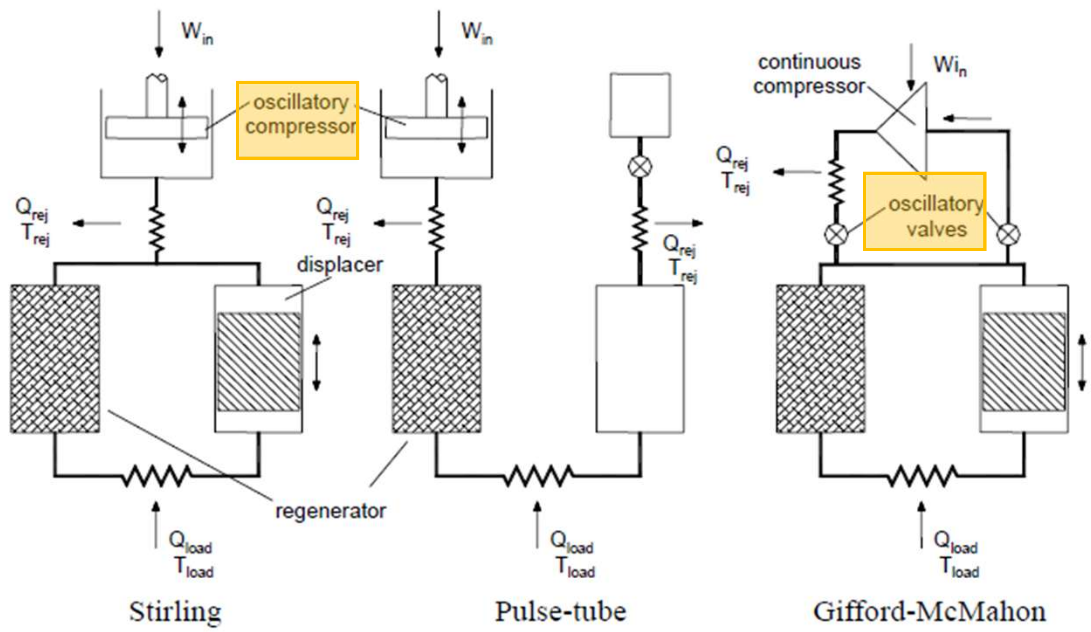
Oscillating gas flow cryocoolers

- **Stirling refrigerators**
- **Gifford-McMahon (GM) refrigerators**
- **Pulse-tube refrigerators**

Constant gas flow cryocoolers (next lecture)

- **Joule-Thomson cooler**
- **Dilution refrigerators**

Regenerative Systems



Oscillatory flow: frequencies 1 - 100 hz

Regenerative heat exchangers: ideal – zero void volume, ΔP, high c_P

Phase modulation (between pressure and flow waves) is crucial for performance

Stirling cycle and Stirling engines

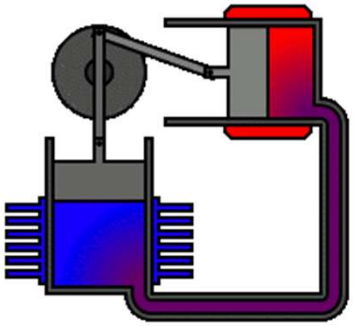
Stirling cycle engine:
– invented in 1815
– 1950's bid for auto industry
– Today: 2.5 kW generators

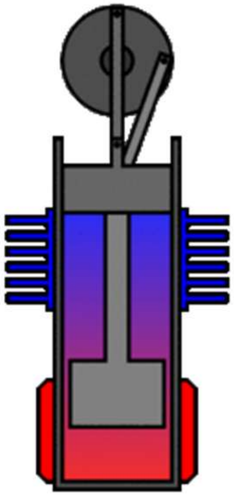
• Stirling cryocoolers: 1946 -
• Ideal efficiency = Carnot
– COP = $T_c / (T_h - T_c)$

• Primary uses:
– tactical and security IR systems
– medical and remote- location cryogen plants

• Potential cooling for large scale HTS applications

• Commercial sources:
– Stirling (www.stirling.nl)
– Sunpower (www.sunpower.com)
– Stirling Technology Company(www.stirlingtech.com)

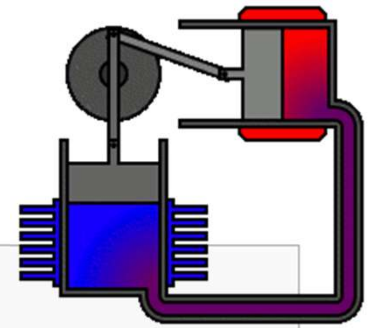


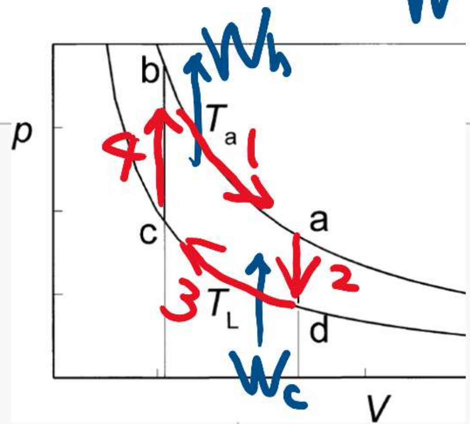


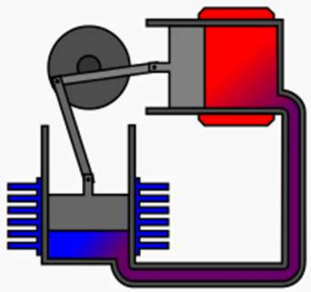
Stirling alpha engine

https://en.wikipedia.org/wiki/Stirling_engine

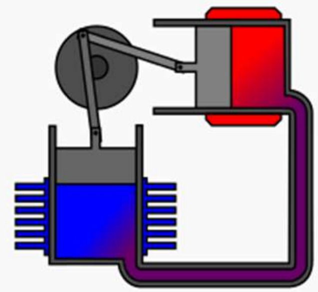
$W = \int F \cdot ds = P \cdot \Delta V$





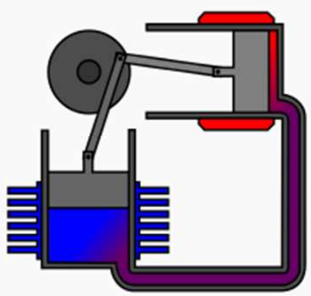


1. Most of the working gas is in the hot cylinder and has more contact with the hot cylinder's walls. This results in overall heating of the gas. Its pressure increases and the gas expands. Because the hot cylinder is at its maximum volume and the cold cylinder is at the top of its stroke (minimum volume), the volume of the system is increased by expansion into the cold cylinder.

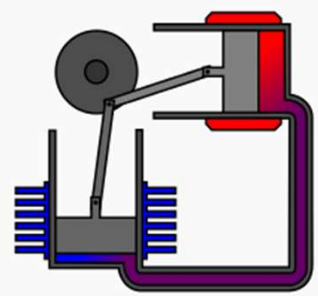


2. The system is at its maximum volume and the gas has more contact with the cold cylinder. This cools the gas, lowering its pressure. Because of flywheel momentum or other piston pairs on the same shaft, the hot cylinder begins an upstroke reducing the volume of the system.

CW: heat → work

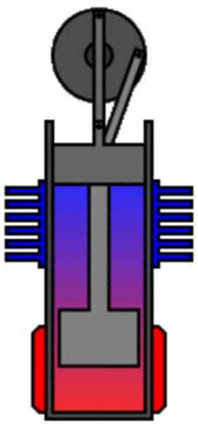


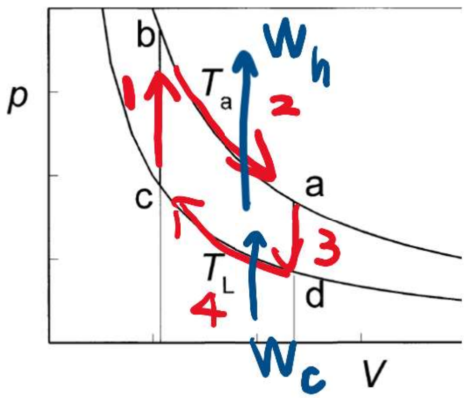
3. Almost all the gas is now in the cold cylinder and cooling continues. This continues to reduce the pressure of the gas and cause contraction. Because the hot cylinder is at minimum volume and the cold cylinder is at its maximum volume, the volume of the system is further reduced by compression of the cold cylinder inwards.



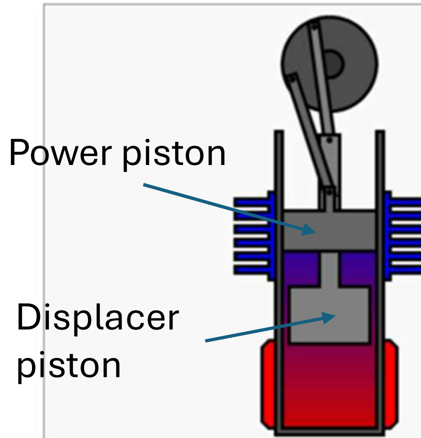
4. The system is at its minimum volume and the gas has greater contact with the hot cylinder. The volume of the system increases by expansion of the hot cylinder.

Stirling beta engine

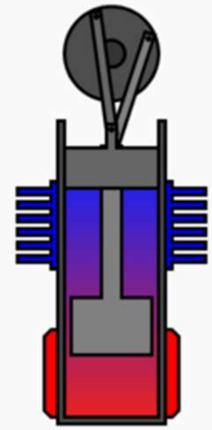




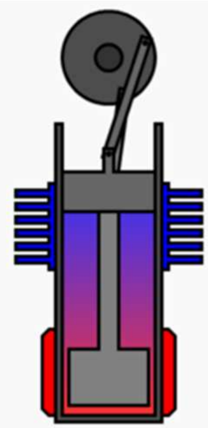
https://en.wikipedia.org/wiki/Stirling_engine



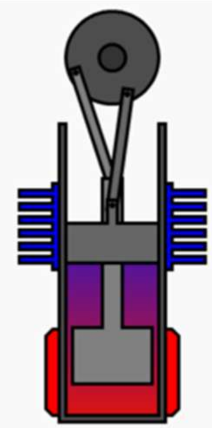
1. Power piston (dark grey) has compressed the gas, the displacer piston (light grey) has moved so that most of the gas is adjacent to the hot heat exchanger.



2. The heated gas increases in pressure and pushes the power piston to the farthest limit of the **power stroke**.



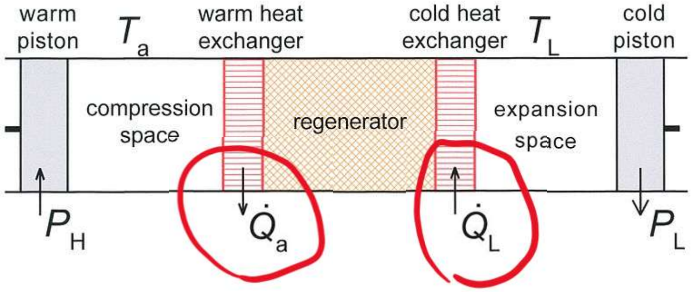
3. The displacer piston now moves, shunting the gas to the cold end of the cylinder.



4. The cooled gas is now compressed by the flywheel momentum. This takes less energy, since its pressure drops when it is cooled.

Stirling Coolers

The thermal contact with the surroundings at the temperatures T_a and T_L is supposed to be perfect so that the compression and expansion are **isothermal**. Constant volume: **isochoric.**



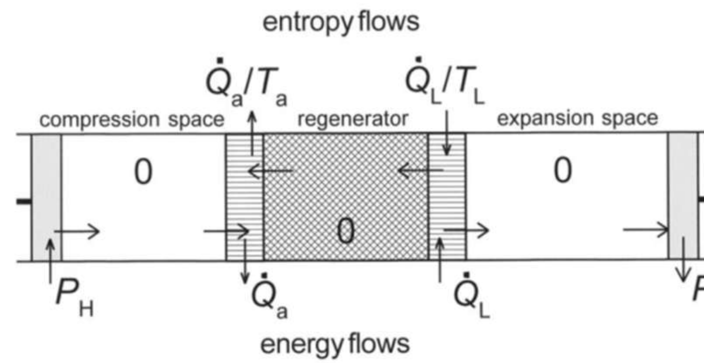
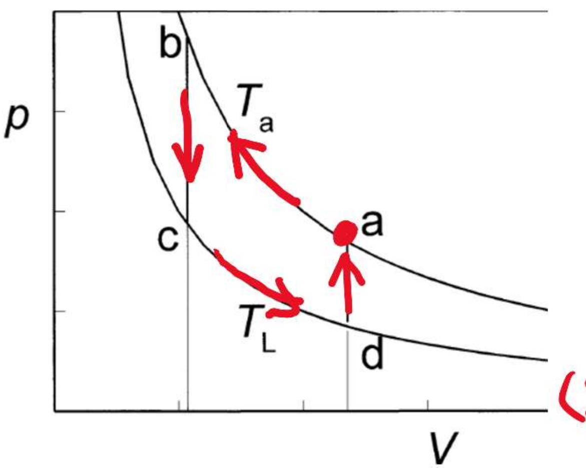
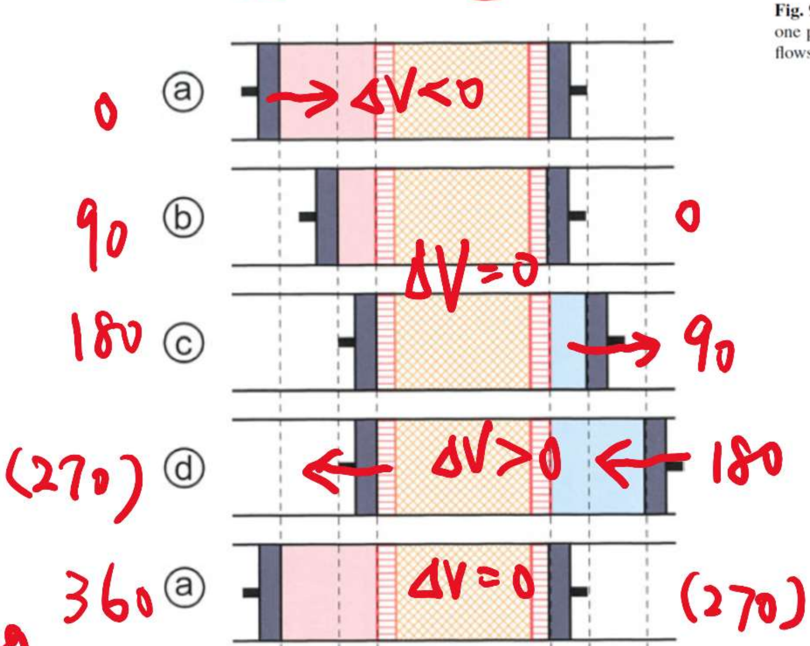


Fig. 9 Schematic diagram of a Stirling cooler. The system has one piston at ambient temperature T_a and one piston at low temperature T_L. The upper half shows the entropy flows and the lower half the energy flows





CCW: Work→cooling

$$\frac{\dot{Q}_a}{T_a} = \frac{\dot{Q}_L}{T_L}.$$

$$\xi = \frac{\dot{Q}_L}{P_H - P_L} = \frac{T_L}{T_a - T_L}.$$

https://en.wikipedia.org/wiki/File:Schematic_Stirling_Cooler.jpg

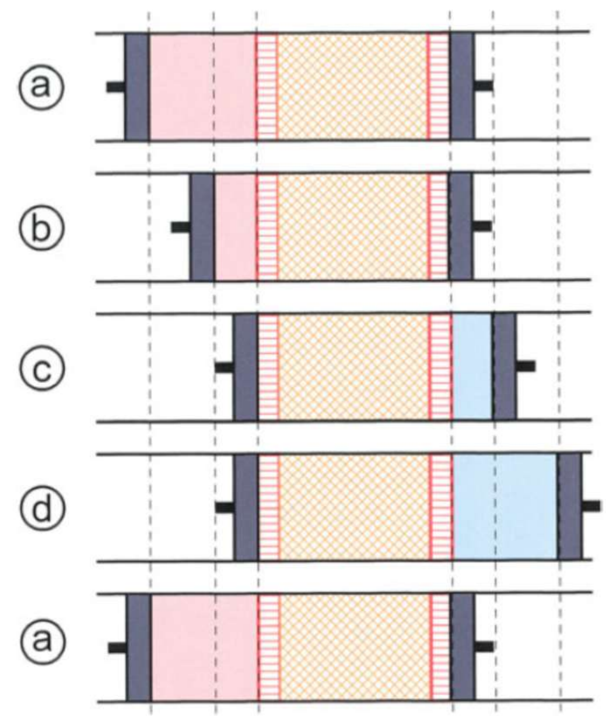
Stirling Coolers

1. From a to b. The warm piston moves to the right over a certain distance while the position of the cold piston is fixed. The compression at the hot end is isothermal by definition, so a certain amount of heat *Qa* is given off to the surroundings at temperature *Ta*.

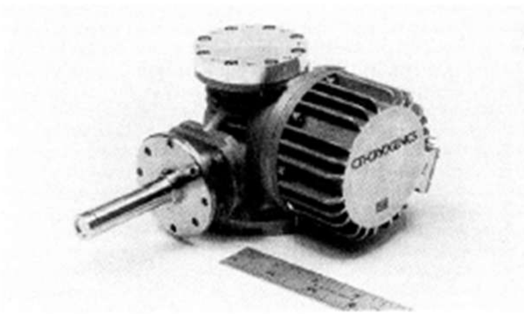
2. From b to c. Both pistons move to the right so that the volume between the two pistons remains constant. The gas enters the regenerator at the left with temperature *Ta* and leaves it at the right with temperature T_L. During this part of the cycle heat is given off by the gas to the regenerator material. During this process the pressure drops and heat has to be supplied to the compression and expansion spaces to keep the temperatures constant.

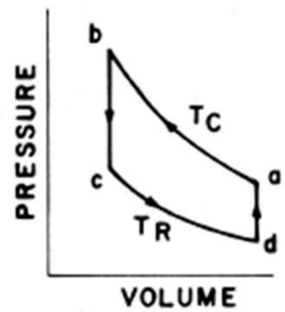
3. From c to d. The cold piston moves to the right while the position of the warm piston is fixed. The expansion is isothermal so heat *QL* is taken up from the application.

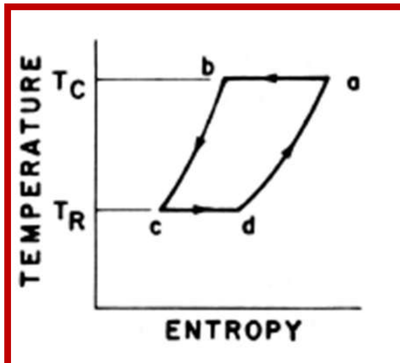
4. From d to a. Both pistons move to the left so that the total volume remains constant. The gas enters the regenerator at the right with temperature T_L and leaves it at the left with *Ta* so heat is taken up from the regenerator material. During this process the pressure increases and heat has to be extracted from the compression and expansion spaces to keep the temperatures constant. In the end of this step the state of the cooler is the same as at the start.

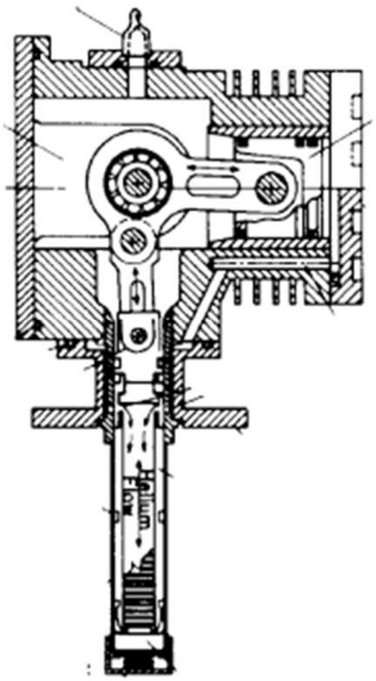


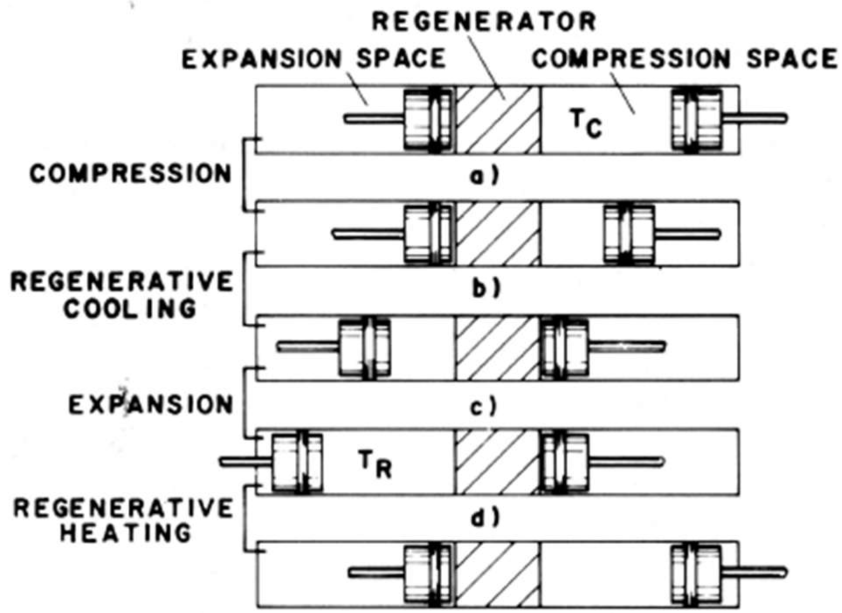
Stirling Cryocoolers



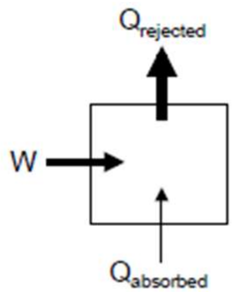




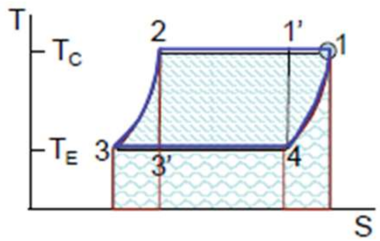




Stirling Cycle: Zero'th Order (ideal gas) Analysis



- Compare work and heat transfer for Stirling and Carnot cycles
- Use helium gas as quantitative example: T_C=300 K, T_E=100 K, P_1=1 atm., P_2=20 atm.
- Note that for an ideal gas in isothermal compression we have: $$s_2 - s_1 = -R\ln\left(\frac{P_2}{P_1}\right)$$

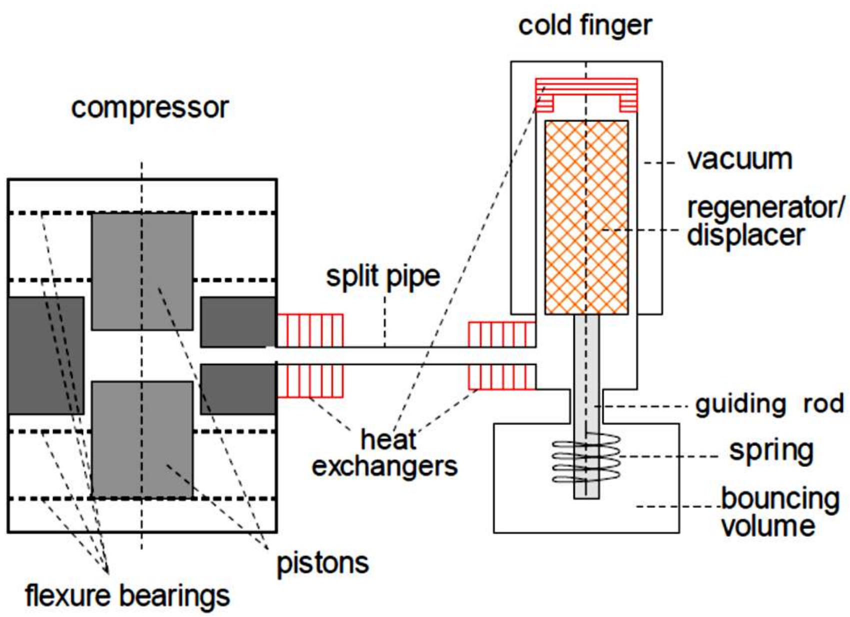


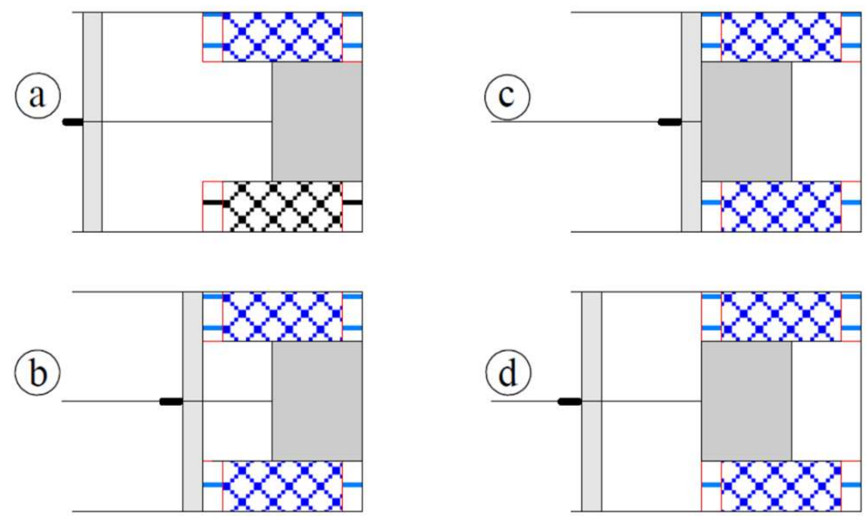
For an ideal cycle

$$W_{net} = Q_r - Q_a$$
$$= \oint \delta Q$$
$$= \oint T dS$$

	Carnot		Stirling	
process	ΔQ	helium (J/ mol)	ΔQ	helium (J/ mol)
1(1') – 2	$T_C(s_2-s_{1'})$	-627	$T_C R\ln(P_1/P_2)$	-4732
2 – 3(3')	0	0	$C_v(T_E-T_C)$	-2500
3(3') – 4	$T_E(s_4-s_{3'})$	209	$T_E R\ln(P_3/P_4)$	1577
4 – 1(1')	0	0	$C_v(T_C-T_E)$	2500
Net	$(T_C-T_E)(s_2-s_1)$	-418	(T_C-T_E)x $R\ln(P_1/P_2)$	-4981
COP	$T_E/(T_C-T_E)$	0.5	$T_E/(T_C-T_E)$	0.5

Stirling cycle processes more heat than Carnot cycle, but same efficiency free-piston Stirling cooler



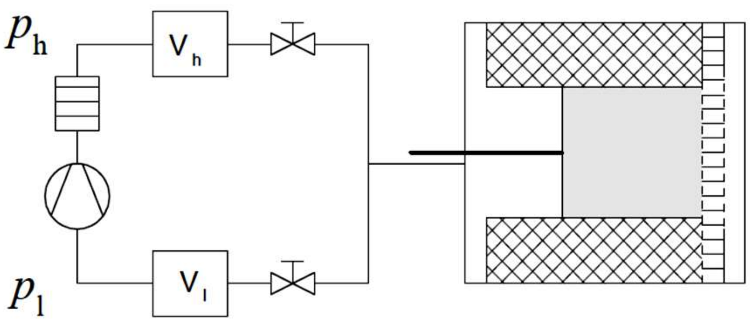


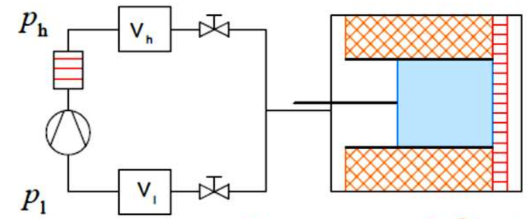
Modified Stirling cycle. The cold piston is replaced by a displacer.

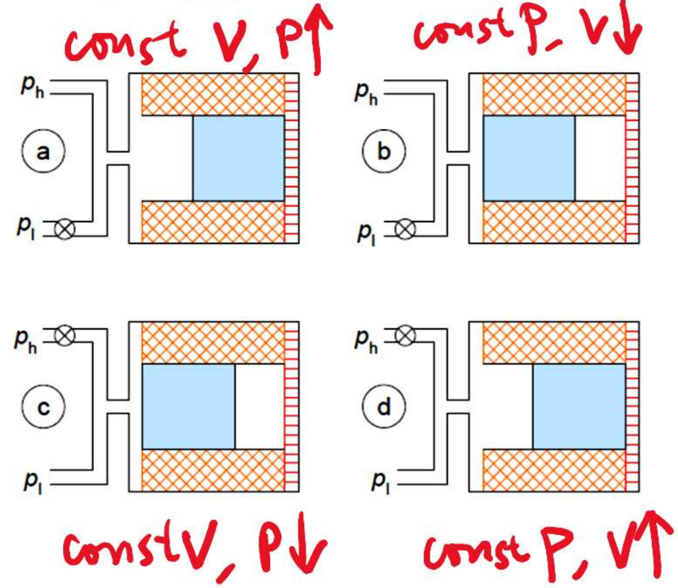
Gifford-McMahon Cryocooler

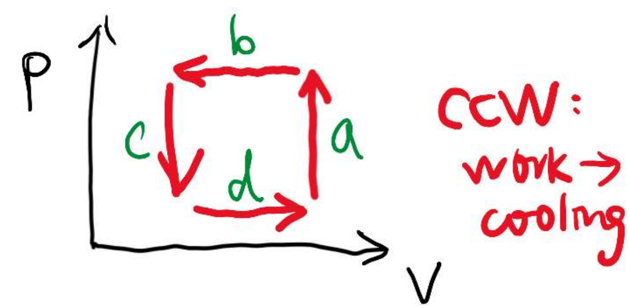
- Alternative to Stirling cryocoolers
  - Valving allows use of inexpensive compressors, and separation between cold head and compressor
  - Typical frequency 1 – 2 Hz
  - Somewhat reduced efficiency
  - Cooling power range:
    - ~ 1 watt @ 4.2 K : recondenser
    - 200 watts @ 80 K: cryo-pumps
- Primary uses:
  - Liquid nitrogen plants
  - Cryopumps
  - Conduction cooled s/c magnets - MRI, μSMES, HTS
  - Large scale HTS applications

Gifford-McMahon (GM)-coolers









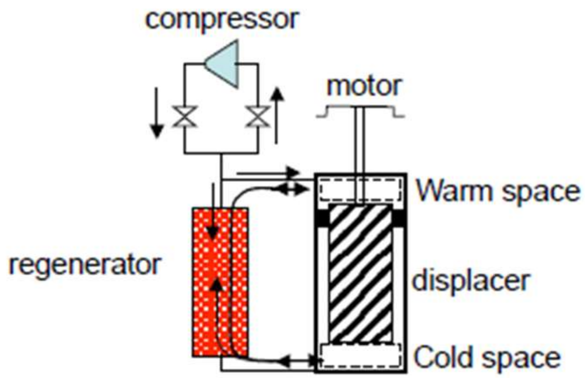
V_l and V_h are buffer volumes of the compressor.

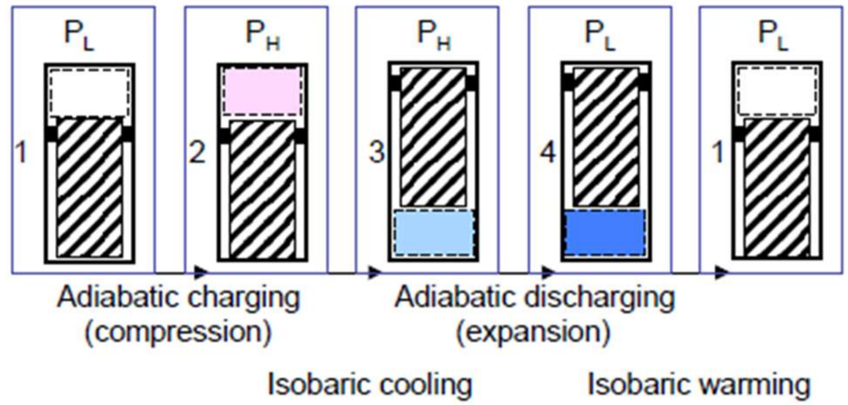
The two valves alternatingly connect the cooler to the high- and the low-pressure side of the compressor.

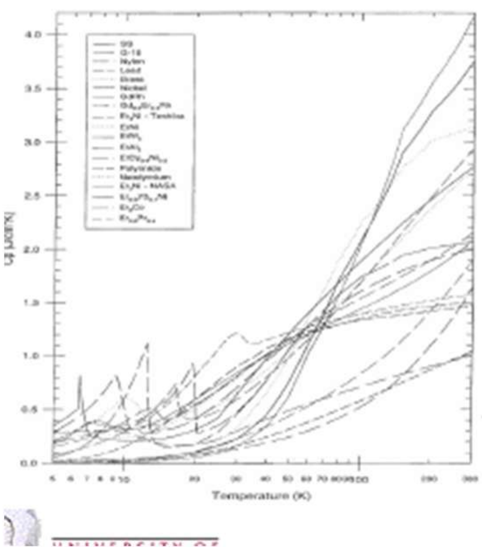
Usually the two valves are replaced by a rotating valve.

Gifford-McMahon Cryocoolers

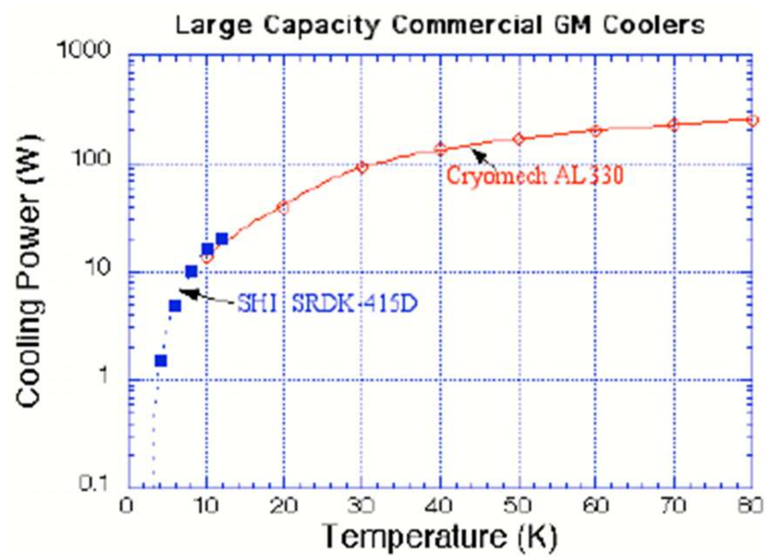
- Cycle description:

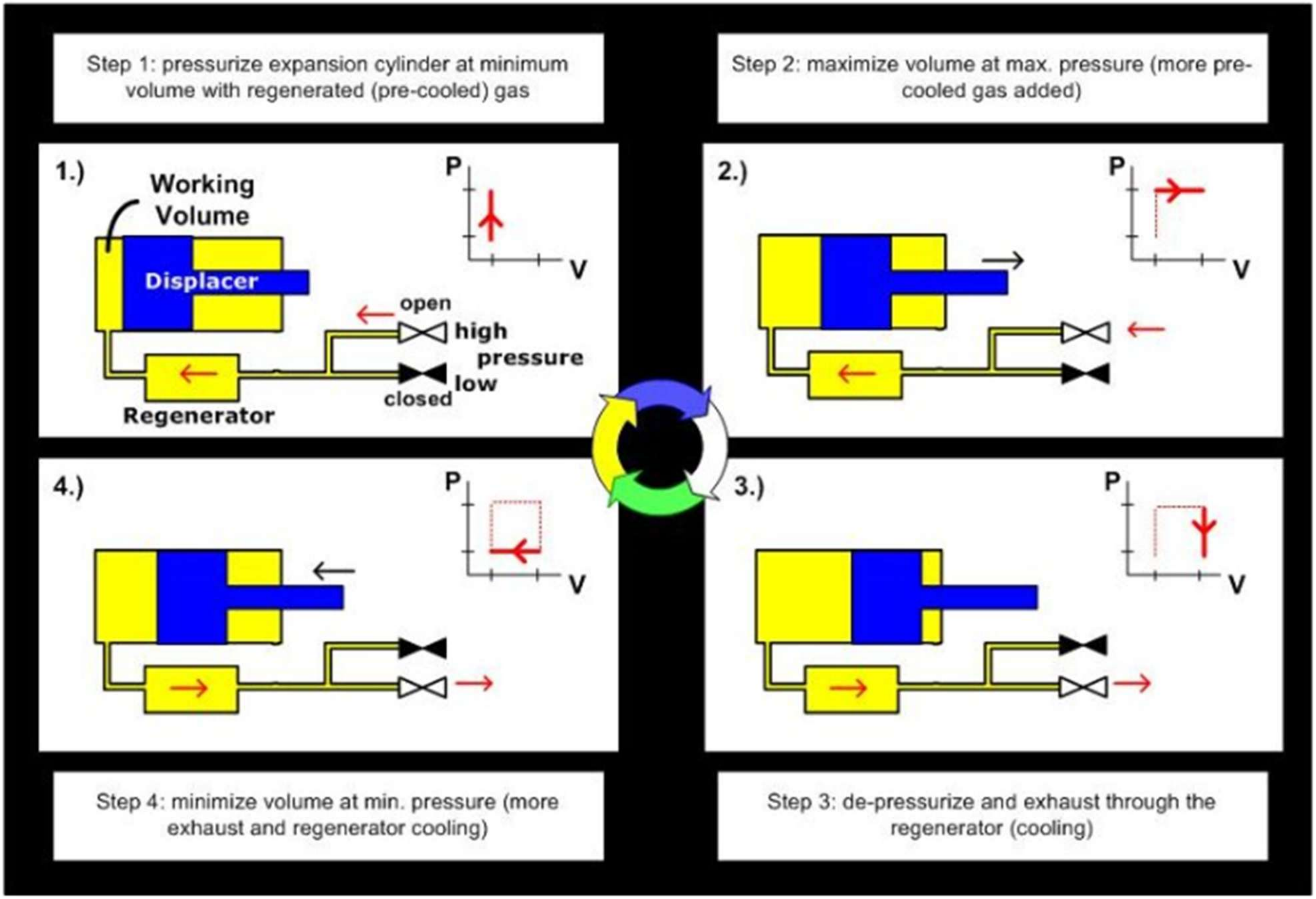






Materials research in the 80's and 90's has enabled 4 K GM machines with cooling capacity ~ 1 watt





Step 1: pressurize expansion cylinder at minimum volume with regenerated (pre-cooled) gas
Step 2: maximize volume at max. pressure (more pre-cooled gas added)
1.)
Working Volume
Displacer
open
high
pressure
low
closed
Regenerator
P
V
2.)
P
V
4.)
P
V
3.)
P
V
Step 4: minimize volume at min. pressure (more exhaust and regenerator cooling)
Step 3: de-pressurize and exhaust through the regenerator (cooling)

Usually the two valves are replaced by a **rotating valve:**

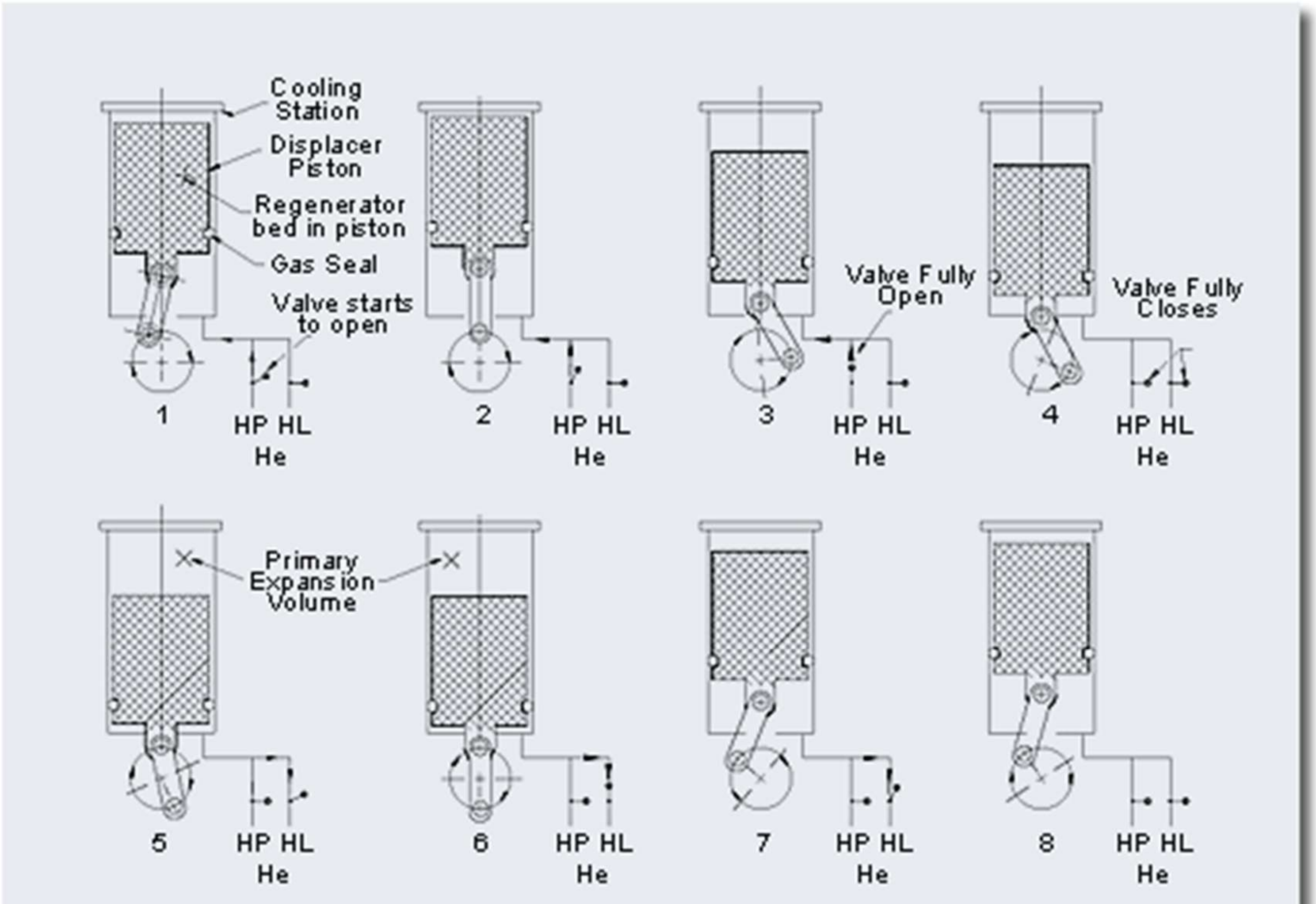
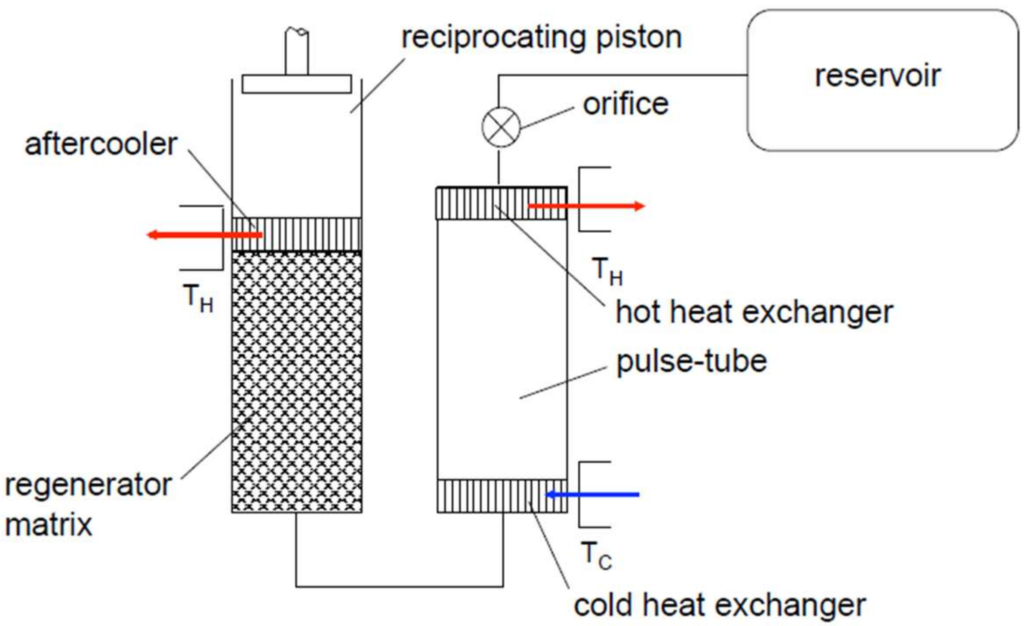
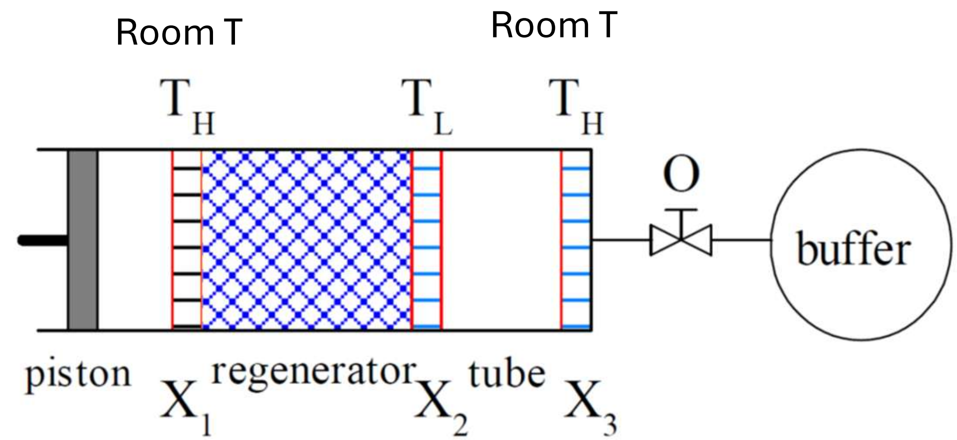


Figure 2. Displacer Operated in Forward Direction

Stirling type single-orifice Pulse-Tube Refrigerator (PTR)





From left to right the system consists of a

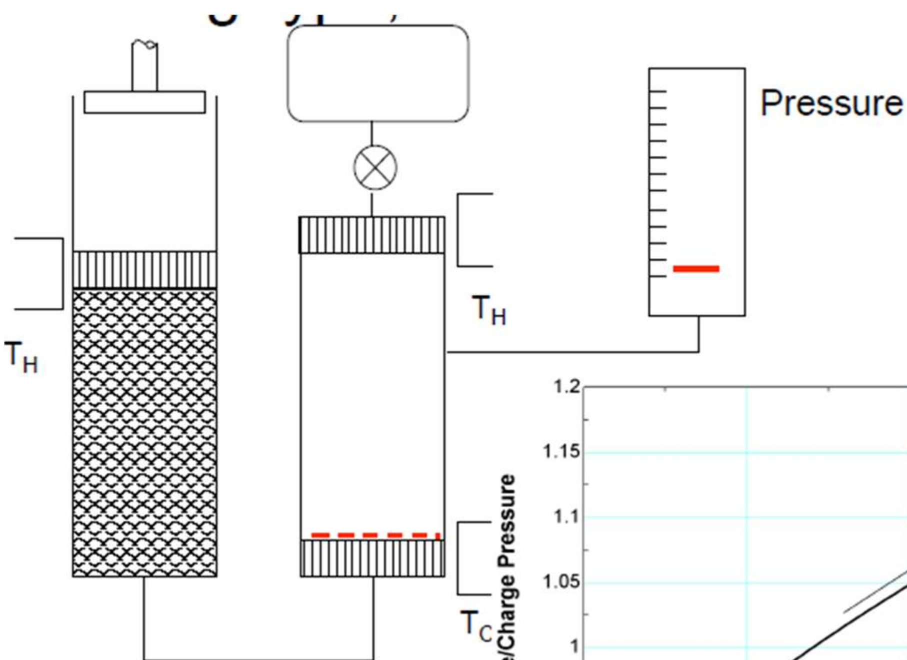
- A compressor with moving piston (piston),
- the after cooler (X_1), a regenerator,
- a low-temperature heat exchanger (X_2),
- a tube (tube),
- a second room-temperature heat exchanger (X_3),
- an orifice (O), and
- a buffer.

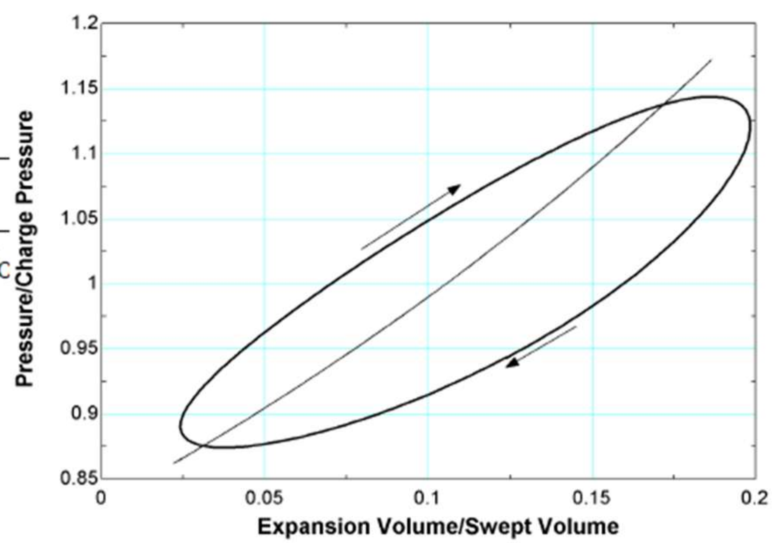
The system is filled with helium at an average pressure of typically 20 bar. .
Room temperature is T_H.
The cooling power is generated at the low temperature T_L.
The part in-between the heat exchangers X_1 and X_3 is below room temperature.

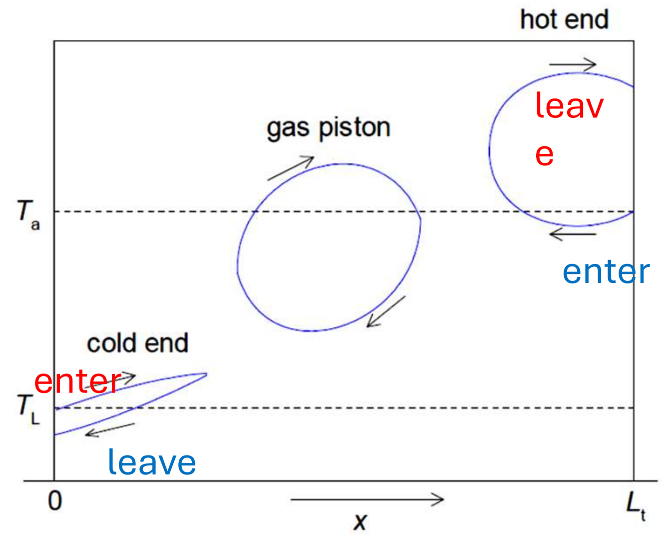
Usages:

- Directly liquefy helium gas and recondense boil-off in liquid cryostat
- Direct conductive cooling in dry cryostats (including low vibration options)

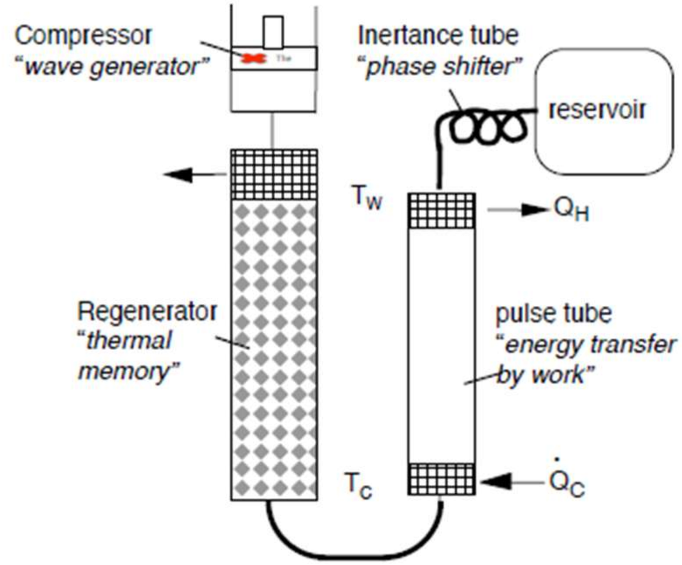
Stirling-type, Orifice Pulse-Tube



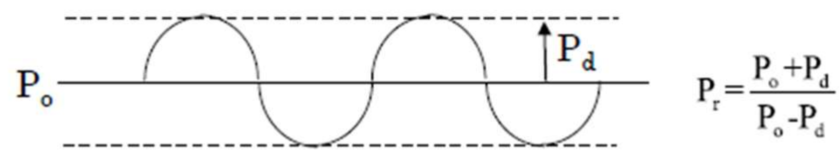




Design Starting Point



- Desired performance:
  - $\dot{Q}_C$ @ T_C 25 watts @ 80 K
- Required definition:
  - T_w 300 K
  - P_o 2.5 MPa
  - P_r 1.3
  - f 60 Hz

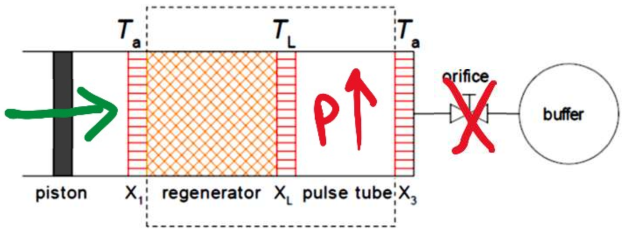


P_d = dynamic pressure amplitude

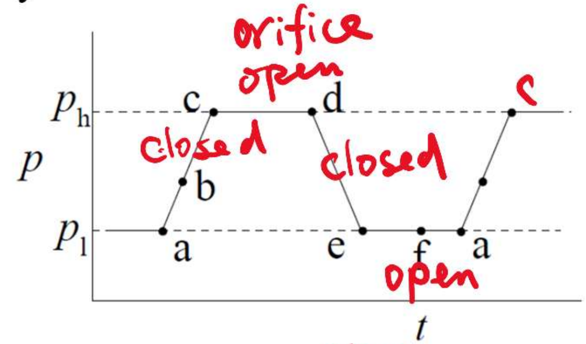
- Design goals:
  - geometry (L, D) for each component
  - Acoustic power
  - θ : phase angle between mass flow & pressure oscillations

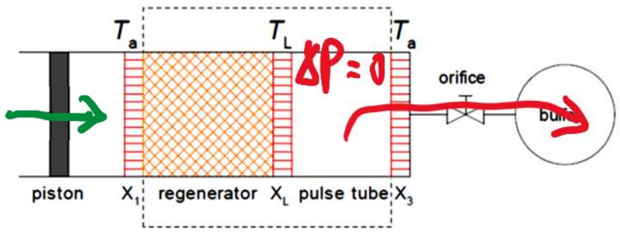
An idealized cycle

The piston moves the gas back and forth and generates a varying pressure in the system.

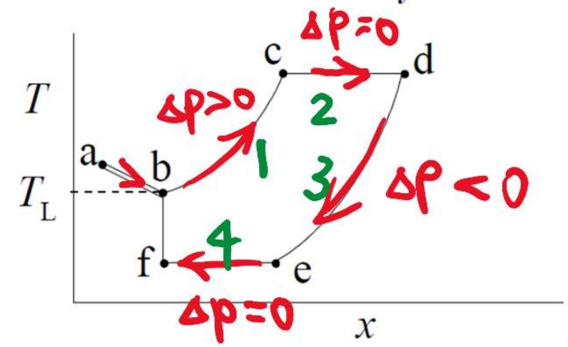


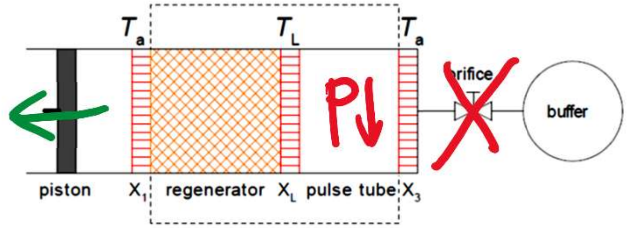
1. from a via b to c. The piston moves to the right with the orifice is closed. The pressure rises.





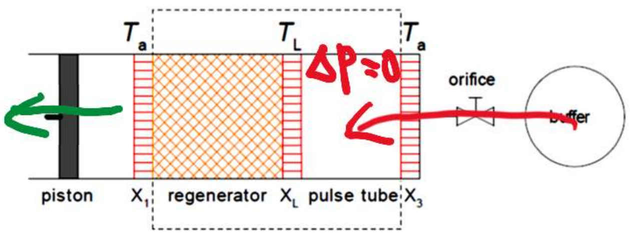
2. **c to d.** The orifice is opened so that gas flows from the tube to the buffer. At the same time the piston moves to the right in such a way that the pressure in the tube remains constant.





3. d to e. The piston moves to the left with the orifice is closed. The pressure drops.

x: fraction of gas in the pulse tube

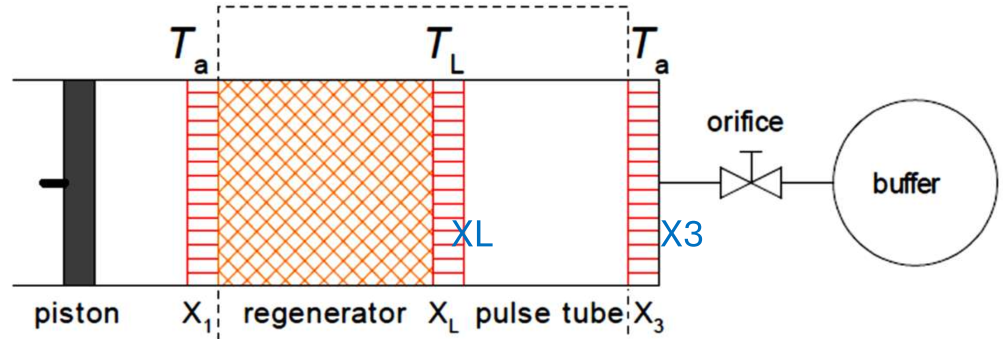


4. **e via f to a**. The orifice is opened so that gas flows from the buffer into the tube. At the same time the piston moves to the left so that the pressure in the tube remains constant.

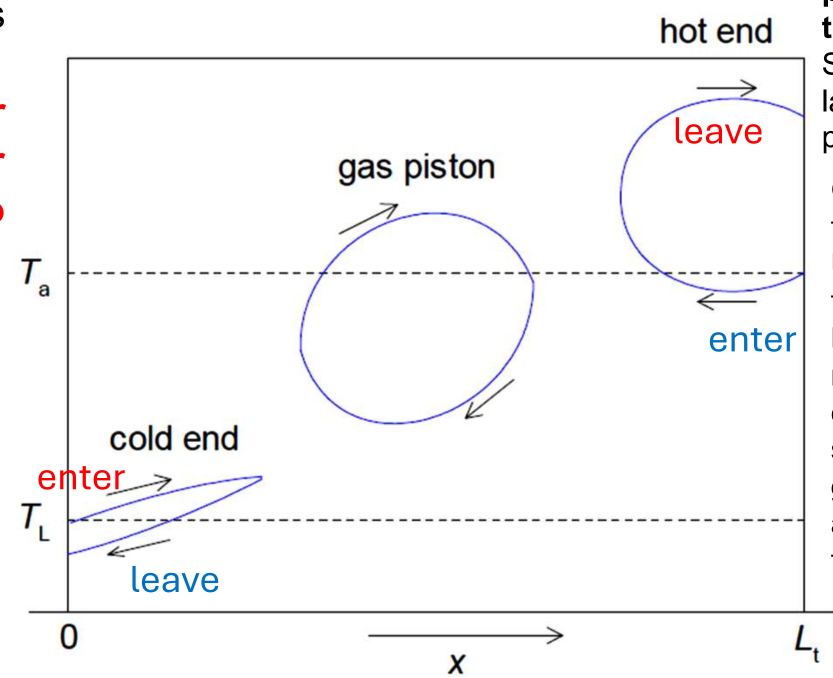
The piston moves the gas back and forth and generates a varying pressure in the system. The pressure varies smoothly at f=1-50Hz

- There are no acoustic effects, such as travelling pressure waves, or fast pressure changes (pulses).
- In the regenerator and in heat exchangers, the gas is in good thermal contact with its surroundings *while* ***in the tube the gas is thermally isolated***.

Gas elements inside the tube are compressed or expanded adiabatically and reversibly, so their entropy is constant. Compression leads to heating and expansion to cooling.



Gas enters the tube if p_t < p_B and leaves the tube if p_t > p_B . So the final pressure is larger than the initial pressure.



Temperature-position curves of two gas elements (one at the cold end and one at the hot end)

Ga enters the tube at temperature T_H and leaves it at a higher temperature producing **heating.** Heat is released via the heat exchanger X3 to the surroundings and the gas flows to the orifice at ambient temperature.

At the **cold end** of the tube, the gas leaves the cold heat exchanger X_L, and enters the tube when the pressure is high and temperature T_L. **It returns to X_L, when the pressure is low** and the temperature is below T_L. Hence producing cooling.

Thermodynamics of PTR's

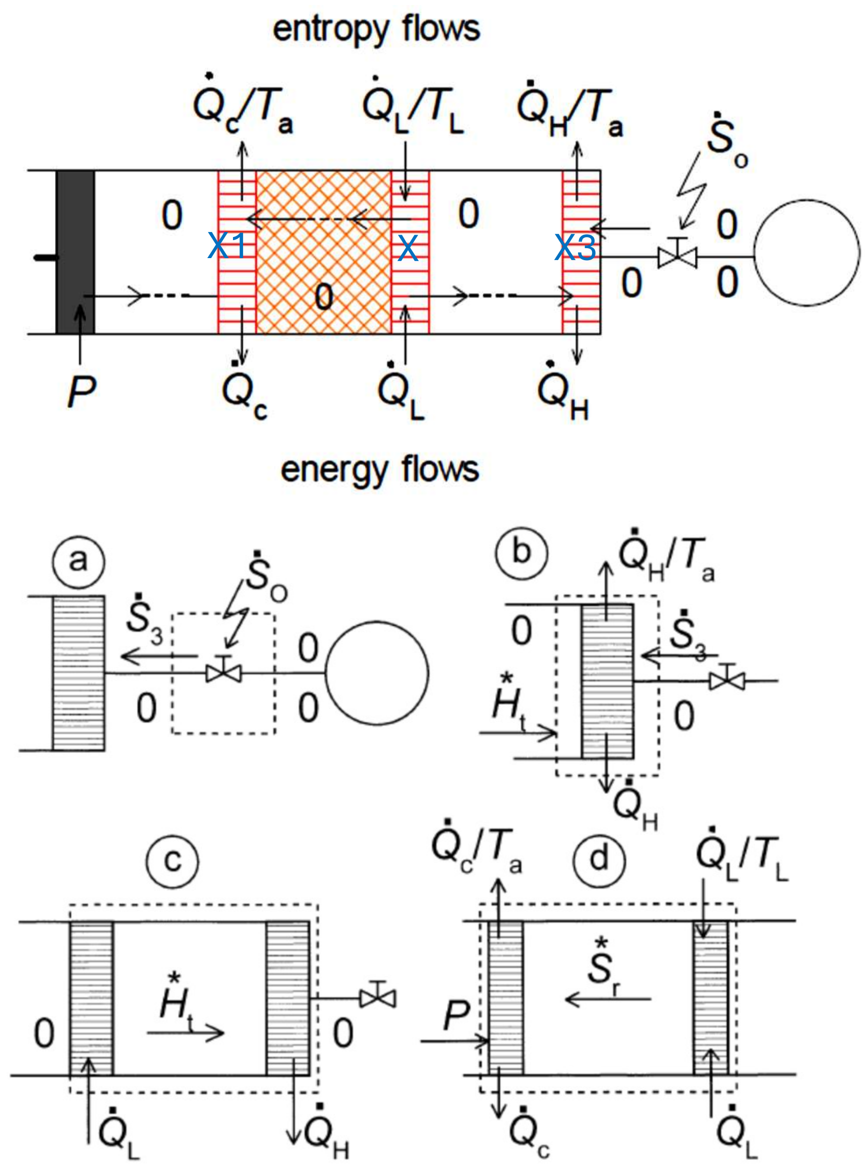
(a) At the **hot end,** gas flows from the buffer via the orifice into the tube with a temperature T_H if the pressure p_t is below the pressure in the buffer p_B ($p_t < p_B$).

If $p_t = p_B$ the gas at the hot end comes to a halt.
If $p_t > p_B$ the gas moves to the hot end of the tube and through the heat exchanger X and the orifice into the buffer.

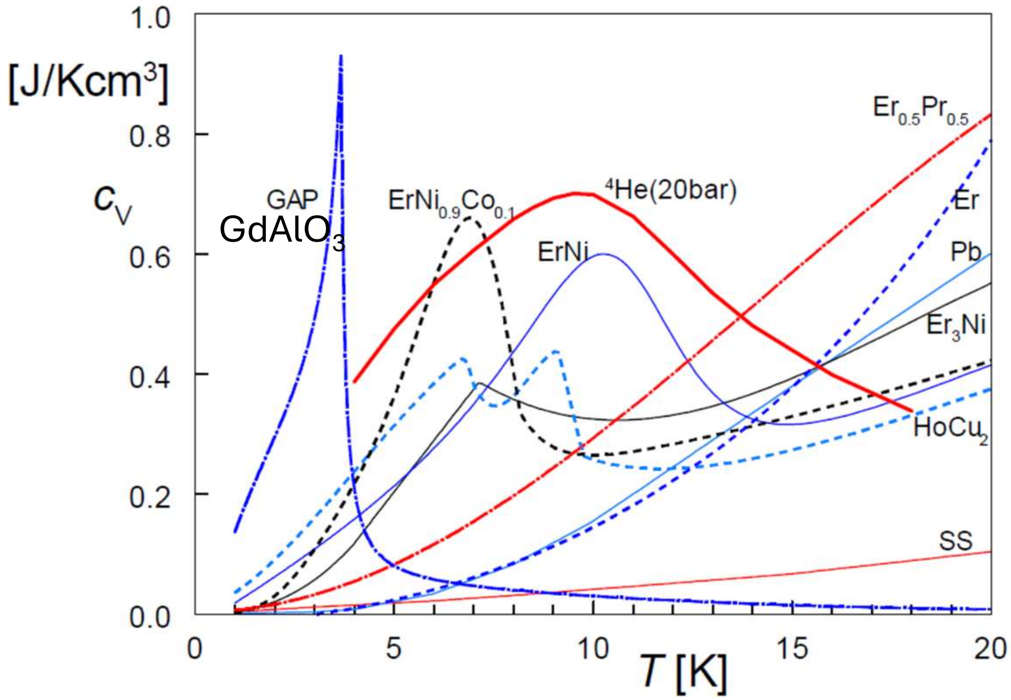
So gas elements enters the tube if $p_t < p_B$ and leaves the tube if $p_t > p_B$.
So the final pressure is larger than the initial pressure.
Consequently, the gas leaves the tube with a temperature higher than the initial temperature T_H.
(b) Heat is released via the heat exchanger X3 to the surroundings and the gas flows to the orifice at ambient temperature.

(c) At the **cold end** of the tube, the gas leaves the cold heat exchanger X, and enters the tube when the pressure is high and temperature T_L. It returns to X, when the pressure is low and the temperature is below T_L. Hence producing cooling.

The analysis of the situation at the cold end is a bit more complicated due to the fact that the velocity at the cold end is determined by the velocity of the gas at the hot end and by the elasticity of the gas column in the tube. Still the situation is basically the same.



Regenerator: materials



The thermodynamic and hydrodynamic properties of regenerators usually are extremely complicated. In many cases it is necessary to make simplifying assumptions.
In its most extreme form in an ideal regenerator:

1. the **heat capacity of the matrix** is much larger than of the gas;
2. perfect heat contact between the gas and the matrix
3. the gas in the regenerator is an ideal gas;
4. Zero flow resistance of the matrix;
5. Zero axial thermal conductivity;
6. Zero void volume of the matrix is zero.

If conditions 1 and 2 are satisfied, then the gas **temperature at a certain point in the regenerator is constant.**

If, in addition, condition 3 is satisfied as well, then the **average enthalpy flow in the regenerator is zero.**

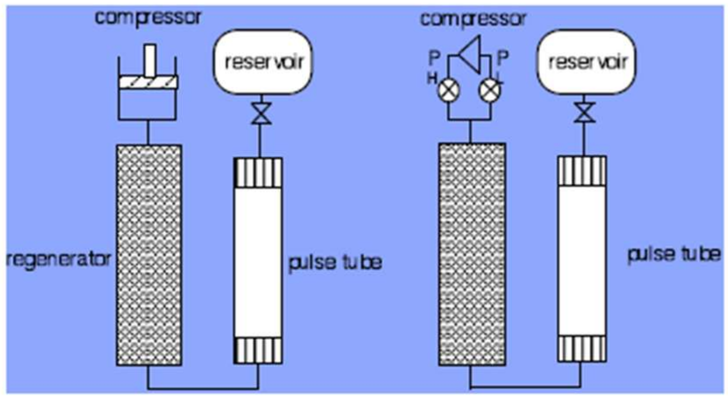
If conditions 2, 4,and 5 are satisfied, there are no irreversible processes in the regenerator.

Ideal PTR: dissipation only occurs in the orifice

PTR

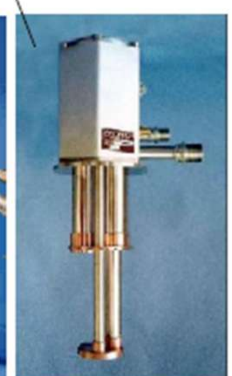
Two general types

- Stirling type
  - High frequency ~ 60 Hz
  - High efficiency: 25% of Carnot
  - Operation down to 10 K
- GM type
  - Low frequency ~ 1-2 Hz
  - Split design = very low vibration
  - Ideal for 4 K operation (≤ 1 watt)

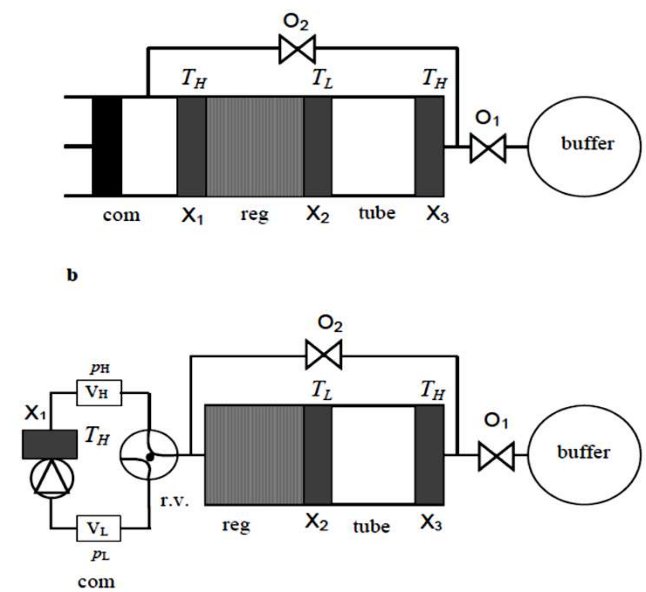


Stirling Type GM Type

MD 200



Cryomech PT405



1. Two types of the PTR. (a) A Stirling-type PTR. From left to right it consists of a compressor aftercooler (X_1), a regenerator (reg), a cold heat exchanger (X_2), a pulse tube (tube), a hot heat (X_3), an orifice (O_1), and a buffer. Orifice O_2 connects the hot end of the regenerator and the hot pulse tube. (b) A GM-type PTR. Except for the compressor - rotary valve (r.v.) combination, the ponents of the GM-type PTR are the same as of the Stirling PTR.

Stirling-type PTR

GM-type PTR

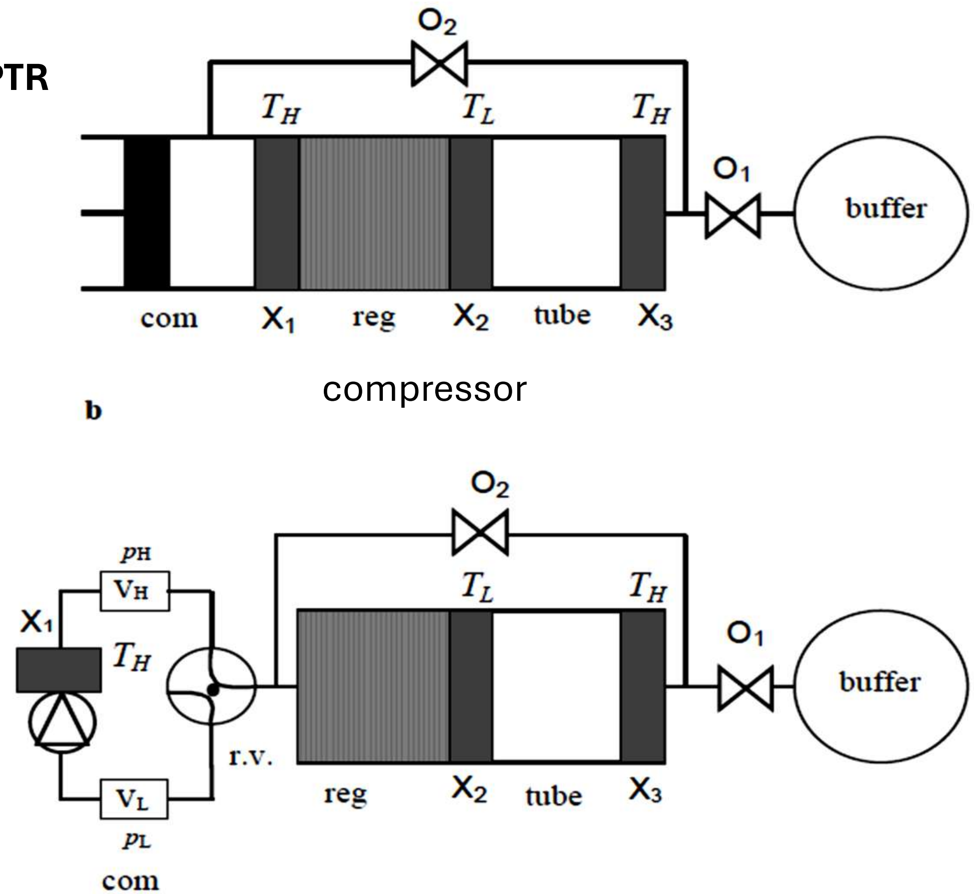
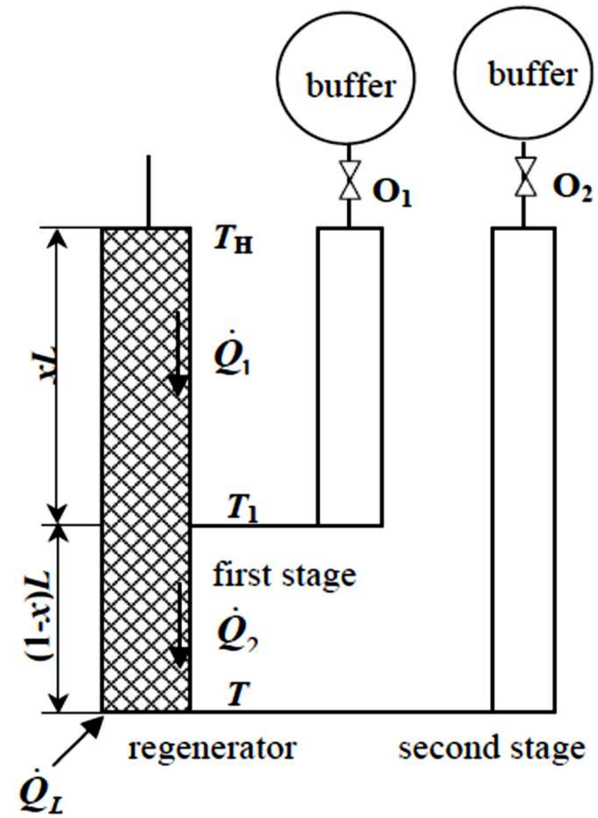
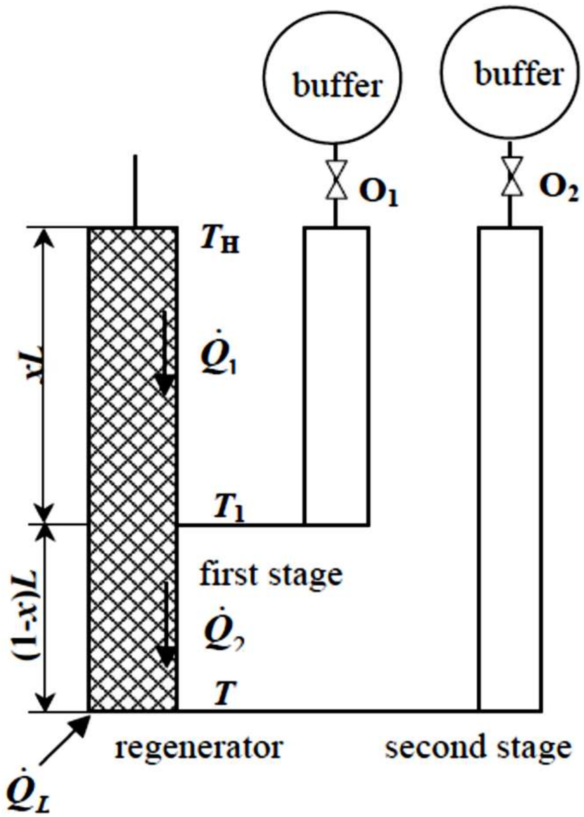


Figure 2. 1. Two types of the PTR. (a) A Stirling-type PTR. From left to right it consists of a compressor (com), an aftercooler (X_1), a regenerator (reg), a cold heat exchanger (X_2), a pulse tube (tube), a hot heat exchanger (X_3), an orifice (O_1), and a buffer. Orifice O_2 connects the hot end of the regenerator and the hot end of the pulse tube. (b) A GM-type PTR. Except for the compressor - rotary valve (r.v.) combination, the main components of the GM-type PTR are the same as of the Stirling PTR.



Two-stage single-orifice PTR. It has a cooling power $\dot{Q}_L$ at T_2. The heat flow $\dot{Q}_1$ and $\dot{Q}_2$ are caused by heat conduction.



- The PTR has no moving parts in the low-temperature region, and, therefore, has a **long lifetime and low mechanical and magnetic interferences**. →
  - Long mean time between maintenance
  - Minimal general maintenance
  - Ideal for vibration sensitive applications

- A typical average pressure in a PTR is 10 to 25 bar, and a typical pressure amplitude is 2 to 7 bar.

- A piston compressor (in case of a *Stirling type PTR*) or a combination of a compressor and a set of switching valves (*GM type PTR*) are used to create pressure oscillations in a PTR.

Standard 4K Cryomech Single-Stage Pulse Tube Cryorefrigerators

All models have remote-motor options available, Air or Water Cooled

PT 10
- 12W @ 80K

PT 60
- 60W @ 80K

PT 63
- 23W @ 40K

PT 90
- 90W @ 80K

PT 403
First Stage 7W @ 65K
Second Stage 0.25W @ 4.2K

PT 405
First Stage 25W @ 65K
Second Stage 0.5W @ 4.2K

PT 407
First Stage 25W @ 55K
Second Stage 0.7W @ 4.2K

PT 415
First Stage 40W @ 45K
Second Stage 1.5W @ 4.2K

CRYOMECH

Cryorefrigerator Specification Sheet

PT405 with CP2850

Cold head	PT405
Cooling capacity @ 50 and 60 Hz:	
2^{nd} stage and 1^{st} stage combined	0.5W @ 4.2K with 25W @ 65K
Lowest temperature	2.8K with no load
Cool down time	60 minutes to 4K
Weight	32 lb (14.5 kg)
Dimensions	See cold head line drawing
Compressor package	CP2850, available as water or cooled
Water cooled:	
Weight	243 lb (110 kg)
Dimensions - L x W x H	19 x 18 x 24.5 in (48 x 46 x 62 cm)
Electrical rating	200/230 or 440/480VAC, 3Ph, 60Hz // 200 or 380/415VAC, 3Ph, 50Hz
Power consumption @ steady state	4.9 kW // 5.4 kW
Cooling water flow rate	Minimum flow 2.3 GPM (9 LPM) @ 80°F (27°C) maximum temperature
Air cooled:	
Weight	384 lb (174 kg)
Dimensions - L x W x H	23.5 x 21 x 43 in (60 x 54 x 109 cm)
Electrical rating	200/230 or 440/480VAC, 3Ph, 60Hz // 200 or 380/415VAC, 3Ph, 50Hz
Power consumption @ steady state	5.5 kW // 6.0 kW
Flexible lines	
Standard length	10 ft (3 m)
Weight per pair	9.2 lb (4.2 kg)
System parameters	
Helium pressure	220 ± 5 PSIG (15.2 ± .34 bar) @ 60 Hz
	250 ± 5 PSIG (17.2 ± .34 bar) @ 50 Hz
Ambient temperature range	45°F to 100°F (7 to 38°C)
Maximum sound level	
Water cooled	70 dBA @ 1 meter
Air cooled	74 dBA @ 1 meter
Shipping crate	Wood box
Water cooled:	
Weight	455 lb (206 kg)
Dimensions - L x W x H	48 x 40 x 38 in (122 x 102 x 97 cm)
Air cooled:	
Weight	635lb (288 kg)
Dimensions - L x W x H	48 x 40 x 59 in (122 x 102 x 150 cm)

113 Falso Drive, Syracuse, NY 13211 USA
315.455.2555 v 315.455.2544 f cryosales@cryomech.com www.cryomech.com

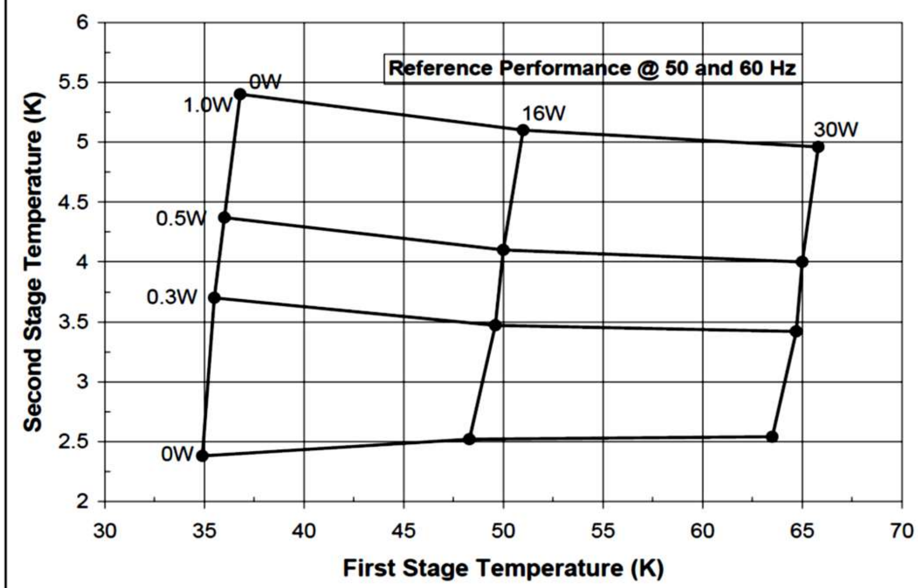
Specifications subject to change without notice. Revised 29AUG13

PT 405

PT 405
First Stage 25W @ 65K
Second Stage 0.5W @ 4.2K

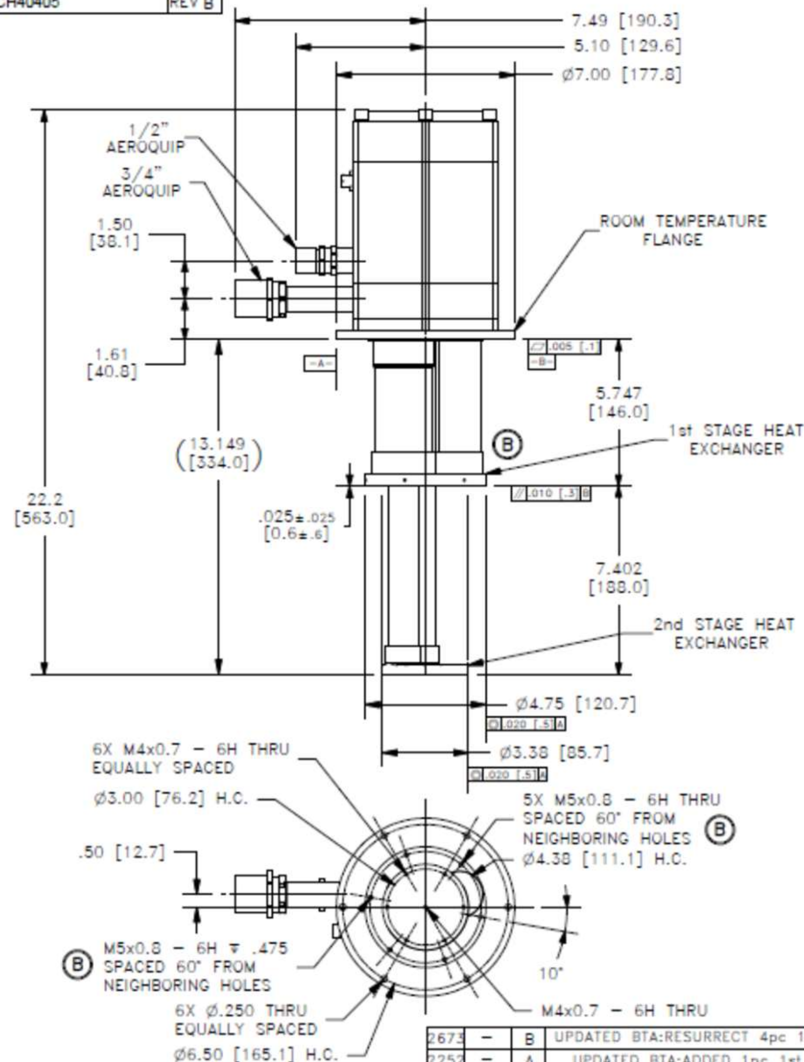
CRYOMECH

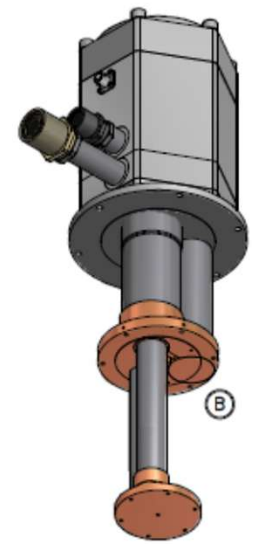
PT405 Cryorefrigerator Capacity Curve



Certified Performance: 0W < 2.8K
0.5W@4.2K with 25W@65K

CH40405 REV B





SPECIAL NOTE: COLDHEAD MUST BE OPERATED COLD END DOWN

THIS DRAWING SUPERSEDES CHPT405

ECN	ZONE	REV	DESCRIPTION	DATE
2673	–	B	UPDATED BTA:RESURRECT 4pc 1st STAGE HT EX	19AUG11
2252	–	A	UPDATED BTA:ADDED 1pc 1st STAGE HT EX	05OCT10
1100	–	–	INITIAL RELEASE	25MAY06

THIRD ANGLE PROJECTION

CRYOMECH, INC
113 FALSO DRIVE SYRACUSE, N.Y. 13211
Tel: (315)455-2555 Fax:(315)455-2544

ALL DIMENSIONS ARE IN INCHES
TOLERANCES: FRACTIONS ±1/32 DECIMALS XXX=±.005 XX =±.01 X=±.1
ANGLES ±.5° ALLOVER FINISH 25 Ra
CONCENTRICITY .005 TOTAL INDICATOR RUN OUT
PERPENDICULAR ±.002 (UNLESS OTHERWISE SPECIFIED)

NAME: CH40405 COLDHEAD OUTLINE			
DWG #: CH40405		SHT 1 OF 1	
MATERIAL: 103-18			
DWN BY: KDJ	DATE: 09JAN03	SCALE: .175	DWG SIZE: A
1ST CHK: KAH	DATE: 09JAN03	2ND CHK: RED	DATE: 09JAN03
CUST: -		BTA: BTA-PT405/PT407	

CH60405 | REV D

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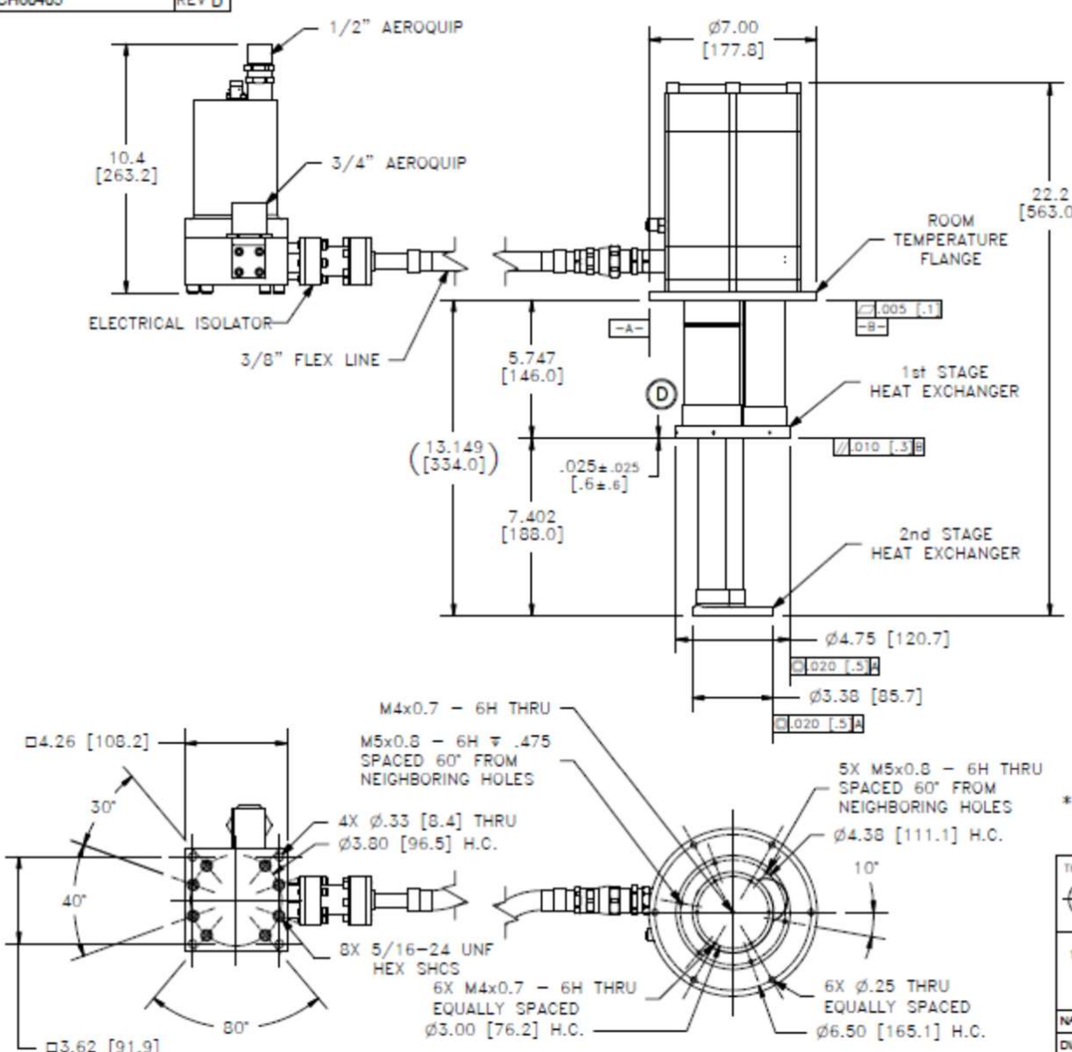

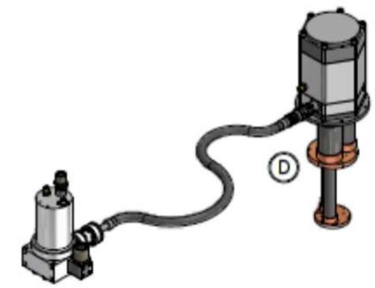

SPECIAL NOTE: COLDHEAD MUST BE OPERATED COLD END DOWN

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113 FALSO DRIVE SYRACUSE, N.Y. 13211
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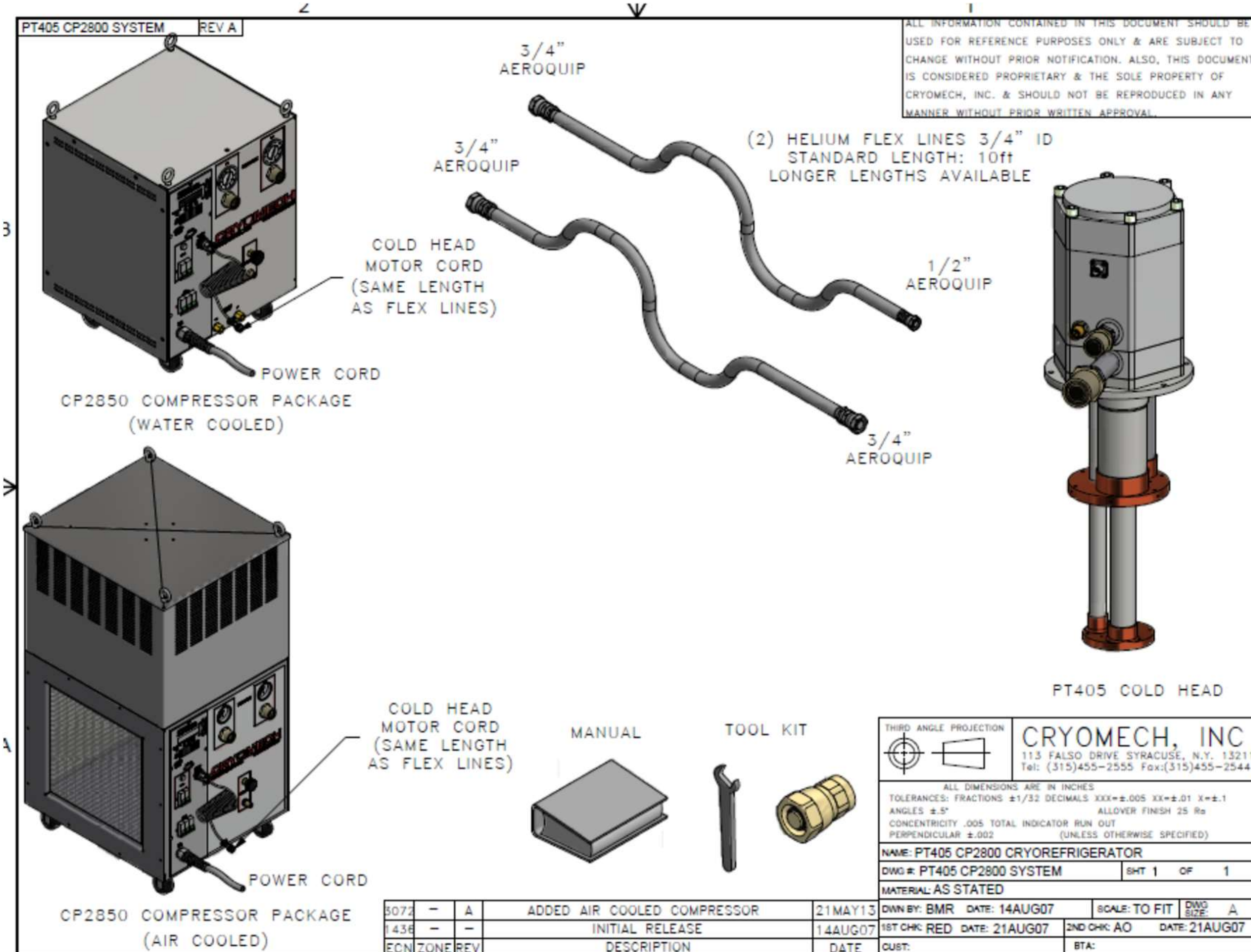
TOLERANCES: FRACTIONS ±1/32 DECIMALS XXX=±.005 XX =±.01 X=±.1
ANGLES ±.5° ALLOVER FINISH 25 Ra
CONCENTRICITY .005 TOTAL INDICATOR RUN OUT
PERPENDICULAR ±.002 (UNLESS OTHERWISE SPECIFIED)

ECN	ZONE	REV	DESCRIPTION	DATE
2673	-	D	UPDATED BTA: RESURRECT 4pc 1st STAGE HT EX	19AUG11
2286	-	C	UPDATED BTA W/ 1pc 1st STAGE HT EX	04NOV10
1669	-	B	ADDED DIMS. TO R.M.	12SEP08

NAME: PT405-RM COLDHEAD OUTLINE			
DWG #: CH60405		SHT 1 OF 1	
MATERIAL: 103-31			
DWN BY: KDJ	DATE: 17MAR04	SCALE: .16	DWG SIZE: A
1ST CHK: CW	DATE: 23MAR04	2ND CHK: BZ	DATE: 23MAR04
CUST: -		BTA: BTA-CH40405/407	


PT405 CP2800 SYSTEM
REV A
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3/4" AEROQUIP
3/4" AEROQUIP
(2) HELIUM FLEX LINES 3/4" ID
STANDARD LENGTH: 10ft
LONGER LENGTHS AVAILABLE
1/2" AEROQUIP
3/4" AEROQUIP
COLD HEAD MOTOR CORD (SAME LENGTH AS FLEX LINES)
POWER CORD
CP2850 COMPRESSOR PACKAGE
(WATER COOLED)
PT405 COLD HEAD
COLD HEAD MOTOR CORD (SAME LENGTH AS FLEX LINES)
MANUAL
TOOL KIT
POWER CORD
CP2850 COMPRESSOR PACKAGE
(AIR COOLED)
3072 | – | A | ADDED AIR COOLED COMPRESSOR | 21MAY13
1436 | – | – | INITIAL RELEASE | 14AUG07
ECN | ZONE | REV | DESCRIPTION | DATE
THIRD ANGLE PROJECTION
CRYOMECH, INC
113 FALSO DRIVE SYRACUSE, N.Y. 13211
Tel: (315)455-2555 Fax:(315)455-2544
ALL DIMENSIONS ARE IN INCHES
TOLERANCES: FRACTIONS ±1/32 DECIMALS XXX=±.005 XX=±.01 X=±.1
ANGLES ±.5° ALLOVER FINISH 25 Ra
CONCENTRICITY .005 TOTAL INDICATOR RUN OUT
PERPENDICULAR ±.002 (UNLESS OTHERWISE SPECIFIED)
NAME: PT405 CP2800 CRYOREFRIGERATOR
DWG #: PT405 CP2800 SYSTEM
SHT 1 OF 1
MATERIAL: AS STATED
DWN BY: BMR DATE: 14AUG07
SCALE: TO FIT
DWG SIZE: A
1ST CHK: RED DATE: 21AUG07
2ND CHK: AO DATE: 21AUG07
CUST:
BTA:

Sumitomo pulse-tubes

SHI Cryogenics Group

Specifications

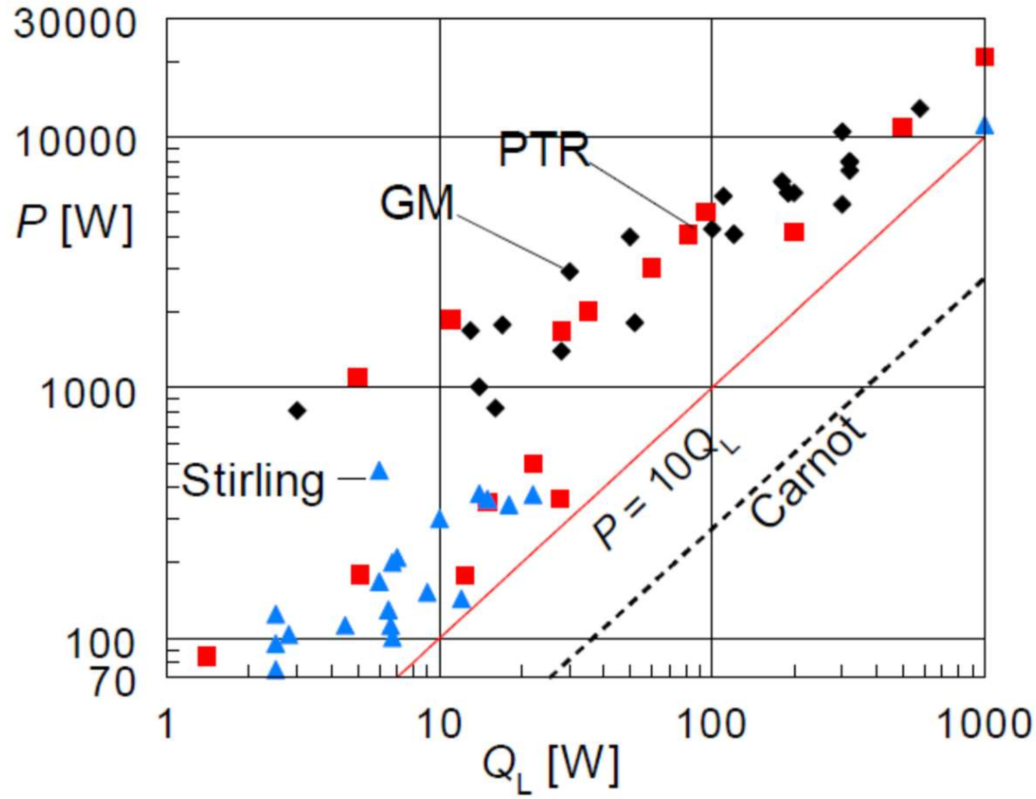
Cold Head Model		RP-062B	RP-062BS	RP-082B2	RP-082B2S
1st Stage Capacity	50 Hz	30 W @ 65 K	25 W @ 65 K	45 W @ 45 K	35 W @ 45 K
	60 Hz	30 W @ 65 K	25 W @ 65 K	45 W @ 45 K	35 W @ 45 K
2nd Stage Capacity	50 Hz	0.5 W @ 4.2 K	0.4 W @ 4.2 K	1.0 W @ 4.2 K	0.9 W @ 4.2 K
	60 Hz	0.5 W @ 4.2 K	0.4 W @ 4.2 K	1.0 W @ 4.2 K	0.9 W @ 4.2 K
Minimum Temperature[1]		<3.0 K	<3.0 K	<3.0 K	<3.0 K
Cooldown Time	50 Hz	<100	<100	<80	<90
	60 Hz	<90	<90	<80	<90
Weight		23.2 kg (51.2 lbs.)	23.5 kg (51.8 lbs.)	26.0 kg (57.3 lbs.)	26.0 kg (57.3 lbs.)

Helium Reliquefiers

Pulse Tubes: Future Directions & Commercial Sources

- R&D:
  - Phase shifting mechanisms - inertance tubes
  - Large capacity - modeling & losses
  - Performance improvements
- Sources:
  - GM-type
    - Cryomech, SHI (Sumitomo Heavy Industry), U of Giessen,
  - Stirling type
    - Atlas Scientific, STC, Sunpower, TRW, Martin-Marietta, Praxair, Sierra-Lobo

values at 80 K



Homework (before next Tuesday):

watch this youtube video to learn about superfluid helium:
[John Allen's Movie about Superfluid Helium]