CRYOGENIC ENGINEERING

Prof. Milind D. Atrey

Department of Mechanical Engineering,
IIT Bombay

Lecture No - 26

Current Topic

Topic : Cryocoolers

- Cryocooler fundamentals
- Different types and their applications
- Stirling, Pulse Tube, Gifford – McMahon Cryocoolers
- Regenerators, Heat exchangers, Compressors.

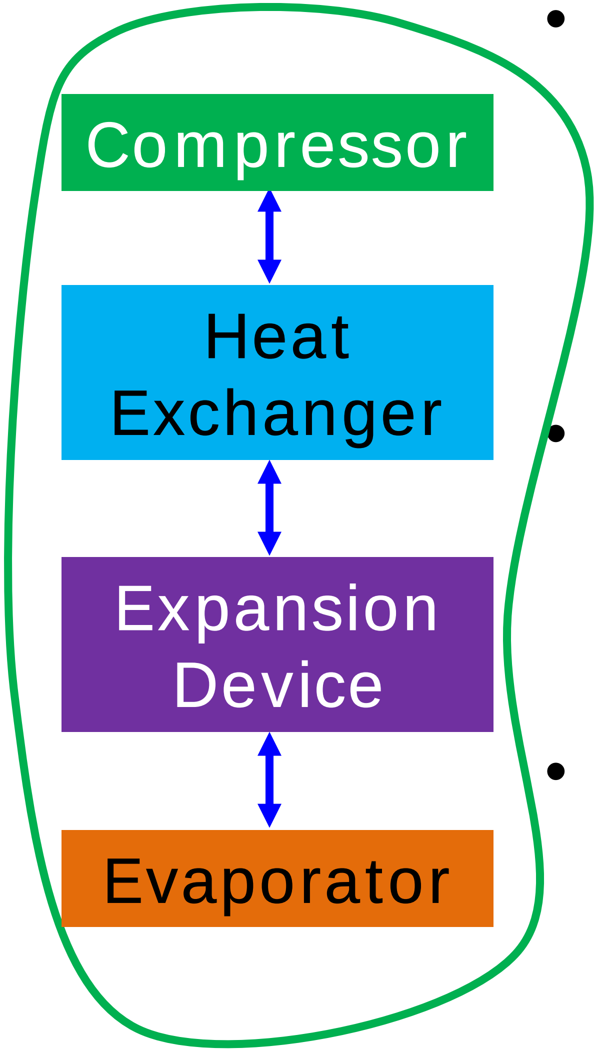
- The current topic will be covered in 6 to 7 lectures.
- Tutorials and assignments are included at the end of each lecture.

Outline of the Lecture

Topic : Cryocoolers

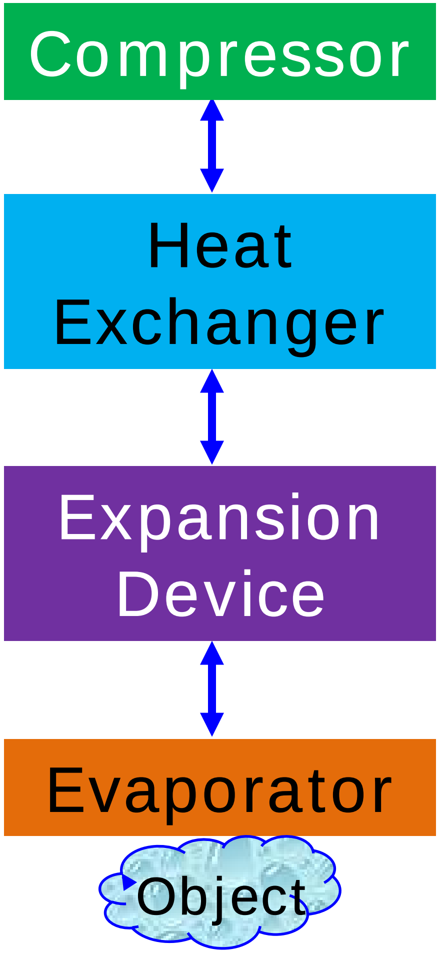
- What is a Cryocooler?
- Why do we need a Cryocooler?
- Classification and basics of Cryocoolers
- Applications

What is a Cryocooler?



- A Cryocooler is a mechanical device which generates low temperature due to compression and expansion of gas.
- It operates on a closed cycle manner, which means the mass of the working gas is constant.
- A cryocooler consists of a compressor, a heat exchanger and an expander as shown in the schematic.

What is a Cryocooler?



- The cold generated in the expander is exchanged between the cold end and the object to be cooled using an evaporator.

- Cryocoolers capable of producing temperatures as low as 77 K or 4.2 K are used to replace the cryogens (LN2, LHe respectively).

Why a Cryocooler?

'Earth's Helium Reserves To Run Out By 2030'

Aug 23rd, 2010 | PTI

Tags: 2030 Earth Helium

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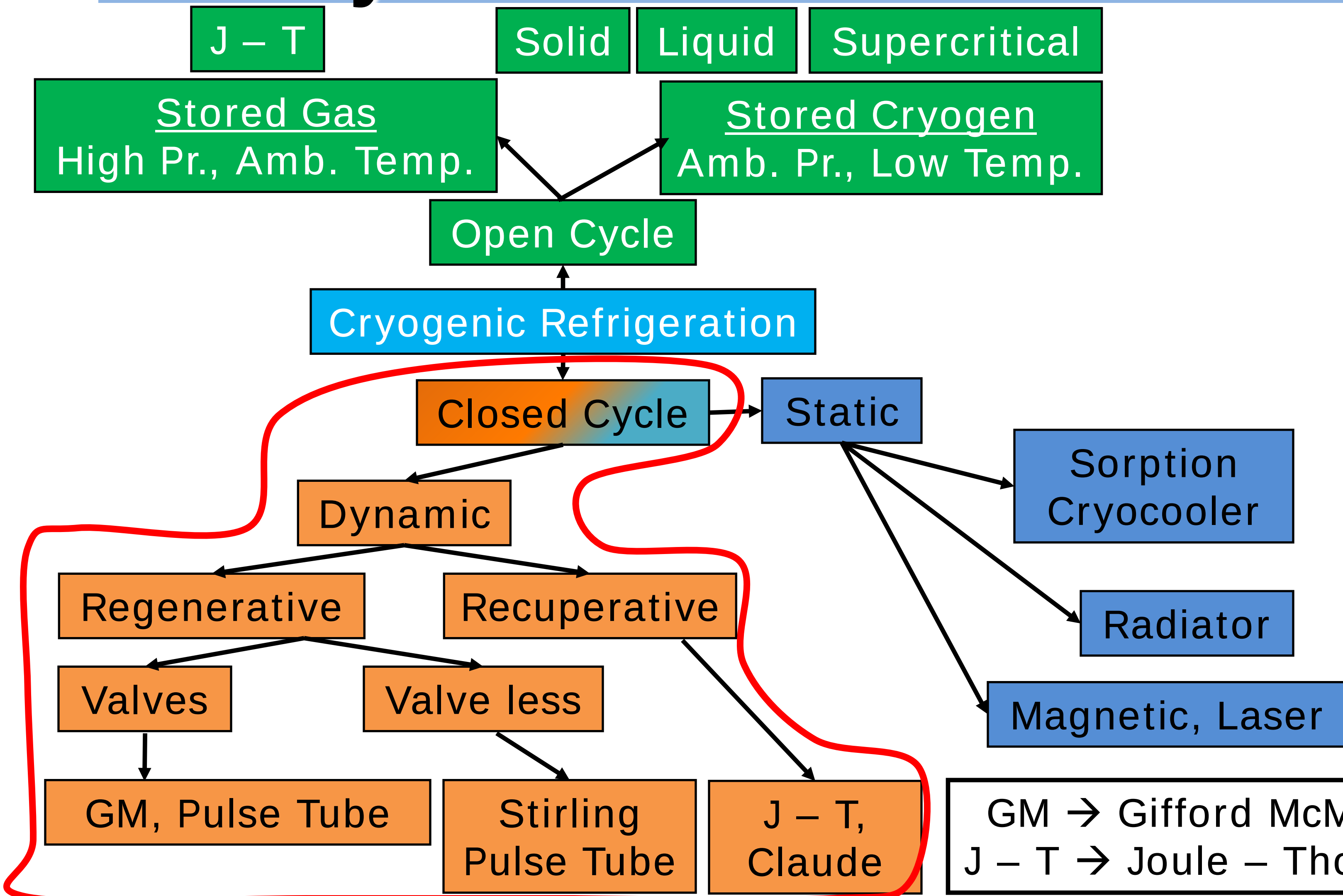
Earth's helium reserves will run out by 2030, a leading expert has claimed. According to Nobel laureate Prof. Robert Richardson of Cornell University, the US supplies 80 per cent of the helium used in the world at a very cheap rate and these supplies will run out in 25 to 30 years' time. And, once the helium reserves are gone, there will be no way of replacing it, the Professor of physics said. "There is no chemical means to make helium. The supplies we have on Earth come from radioactive alpha decay in rocks. Right now it's not commercially viable to recover helium from the air so we've to rely on extracting from rocks. "But if we do run out altogether, we will have to recover helium from the air and it will cost 10,000 times what it does today," Prof Richardson told the 'New Scientist'. A US law states that the biggest store of helium in the world — in a disused airfield in Texas — must be sold off by 2015 and is being sold at far too cheap a price. This means that the Earth's resources of helium are being depleted at an astonishing rate because it is too cheap to recycle. Helium is formed on Earth as rocks steadily decay and nearly all of our reserves have been formed as a by-product of the extraction of natural gas. The only way to obtain it will be to capture it from the decay of tritium — a radioactive hydrogen isotope, which the US stopped making in 1988. So what should the US do? "Get out of the business and let the free market prevail. The

- The article shown here is extracted from Asian Age, 23rd Aug' 2010.
- According to Prof. Robert (Cornell Univ.), Helium reserves would run out by 2030.
- Hence, closed cycle cryocoolers, generating low temperature is the need of time.

Why a Cryocooler?

- No Cryogen requirement.
- Cryocoolers offer reliable and maintenance free operation.
- The cost of cryogen is increasing, where as the cost of cryocooler is decreasing.
- There is a scope for new technology which would advance development towards invisible cryogenics.

Cryocooler Classification



GM → Gifford McMahon
J – T → Joule – Thomson

Cryocoolers

- Depending on the end use application, the basic requirements, as given below, have to be satisfied by the Cryocooler.

  - Less weight and small volume.

  - Fast cool down time and vibration less operation.

  - More Mean time between maintenance (**MTBM**), Mean time between failure (**MTBF**) and Mean time to failure (**MTTF**).

Cryocoolers

- Continuing further, the basic requirements of a Cryocooler are:

  - Minimal effect of orientation, gravity, acoustic noise and electromagnetic interference.

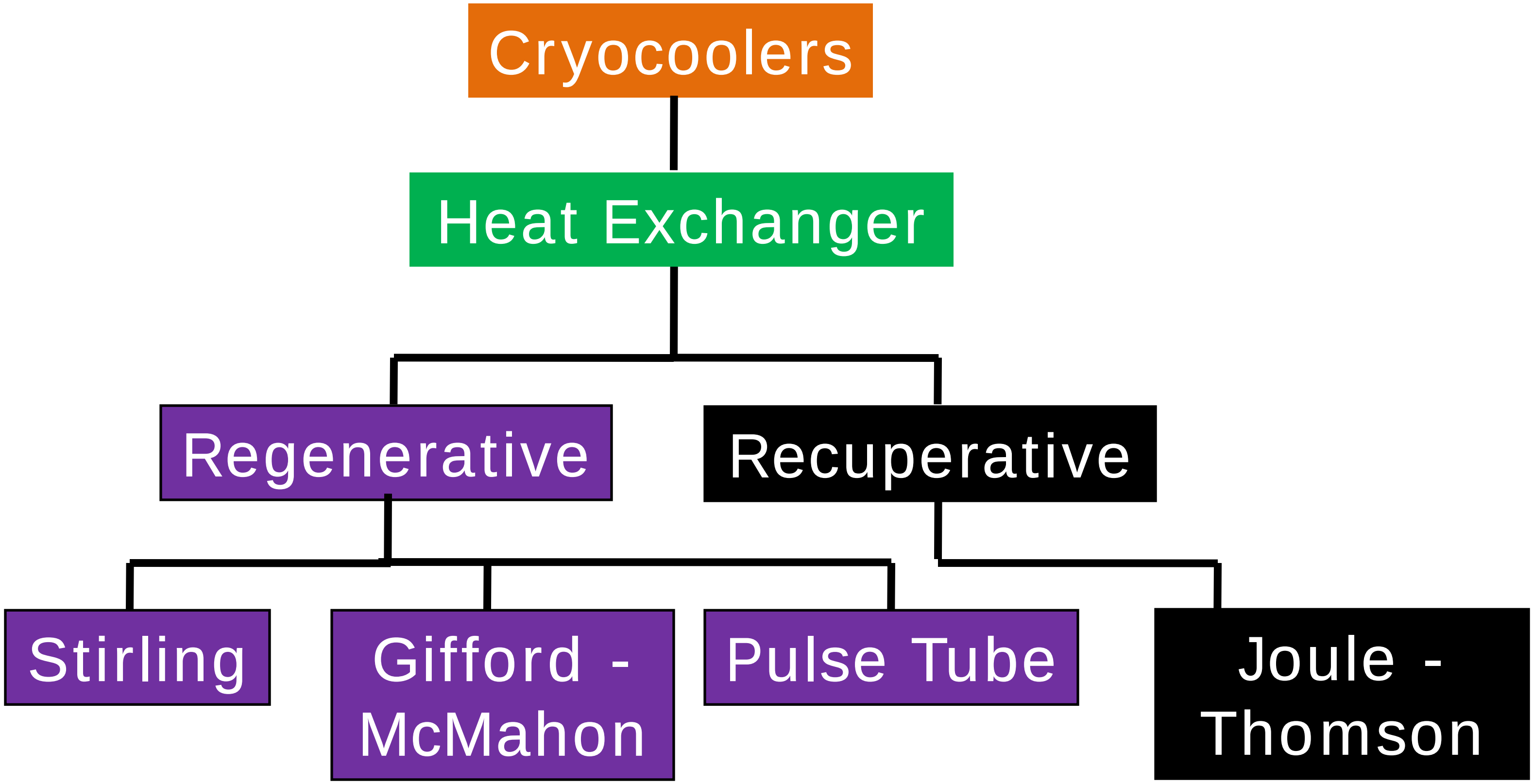
  - High reliability and shelf life

  - Cost effective as compared to existing systems.

Technical Parameters

- The technical parameters that govern the choice of a Cryocooler are as given below.
  - Cooling effect : ______ mW(W) @ ______K.
  - Compressor power requirement ______W(kW).
  - Cooling water requirement.
  - Service requirement of compressor.
  - Vibration level and cost.

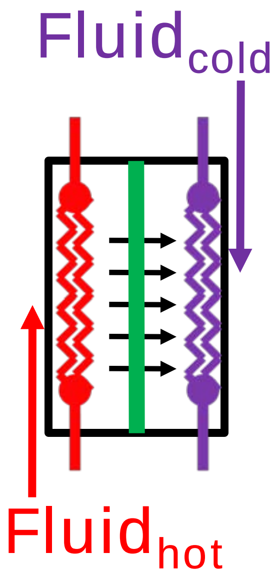
Classification



Heat Exchanger

- A heat exchanger is a device in which the warm fluid gets cooled due to heat exchange with the cold fluid.
- In most of the cases, the process of heat exchange occurs at a constant pressure.
- It can either be a regenerative or recuperative type of heat exchanger depending on the kind of heat exchange between the fluids.

Heat Exchanger

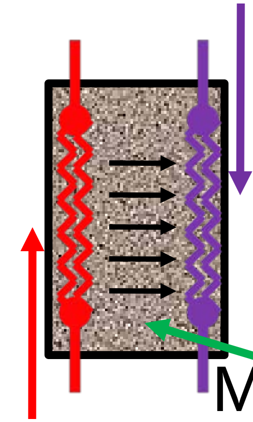


Recuperative HX

- In a recuperative heat exchanger, the flow direction of two fluids is constant and is simultaneous.
- The two fluids are separated by a solid boundary across which the warm and cold fluids exchange heat.
- The direction of the fluid flow may either be counter flow, cross flow or parallel flow as explained in earlier lectures.

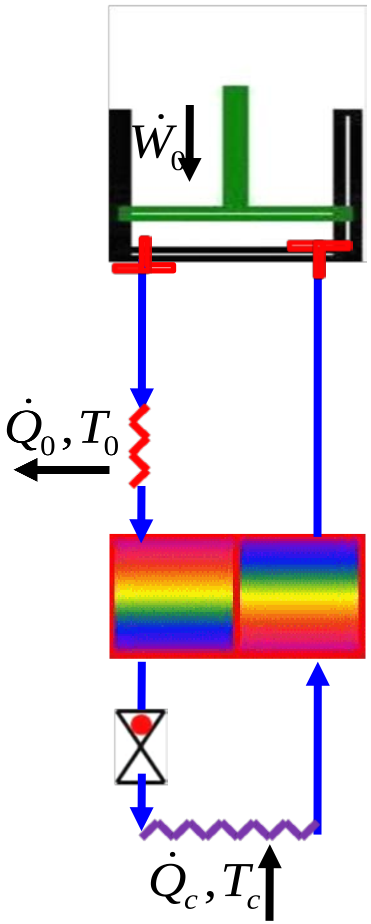
Heat Exchanger

Regenerative HX



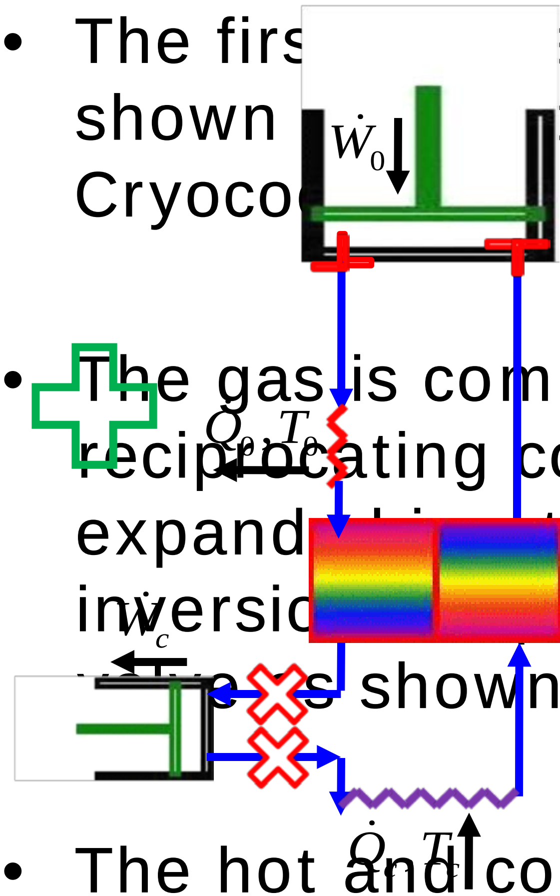
- In a regenerative heat exchanger, a matrix is used as an intermediate heat exchange medium between the warm and cold fluids.
- The flow is periodic in nature alternating between the warm and cold fluids across the matrix.
- It is important to note that, it is an example of indirect heat transfer.

Recuperative Cryocoolers



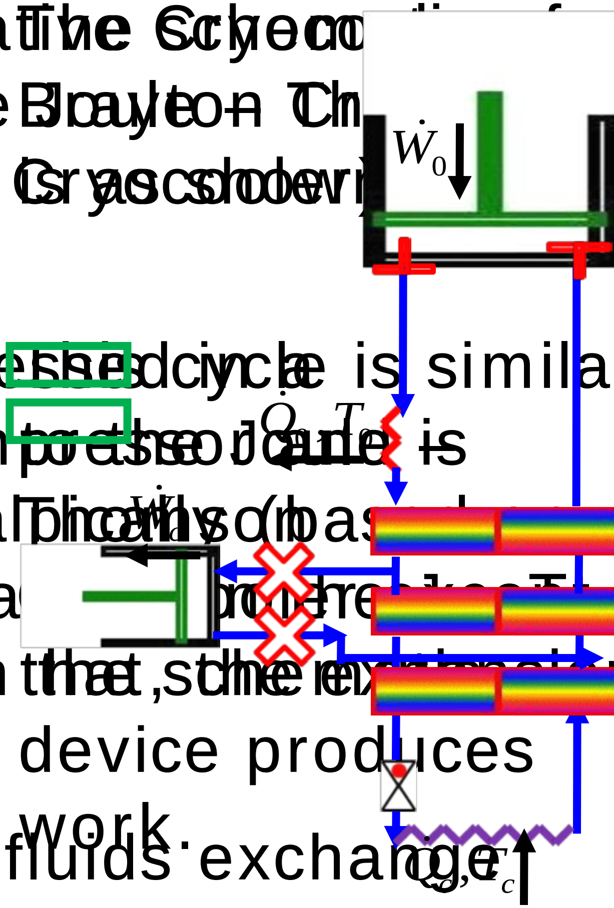
J – T

- The firs… …rative Cryoco… shown … the … Cryoco… T Cryocooler)
- The gas is compre… reciprocating comp… expand… …thalpic… inversi… …era… …es shown in the…
- The hot and cold fluids exchange heat in a recuperative heat exchang…



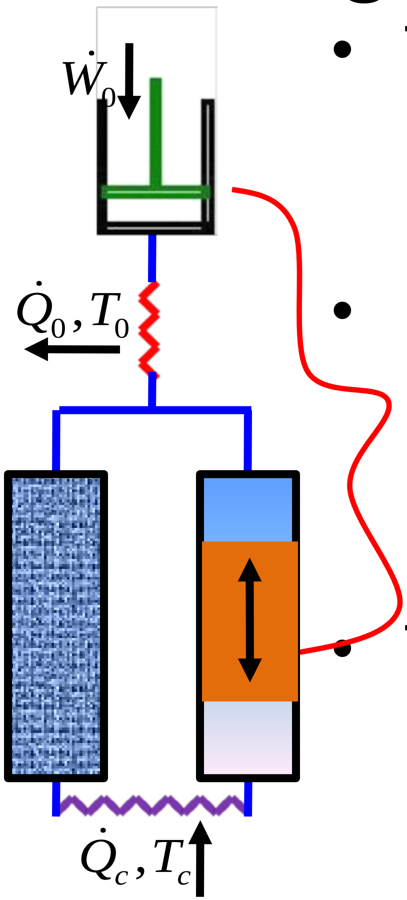
Brayton

- The Brayton Cr… is shown …
- The cycle is similar to the Joule – Thomson (bas… …, … that, the expansion device produces work.



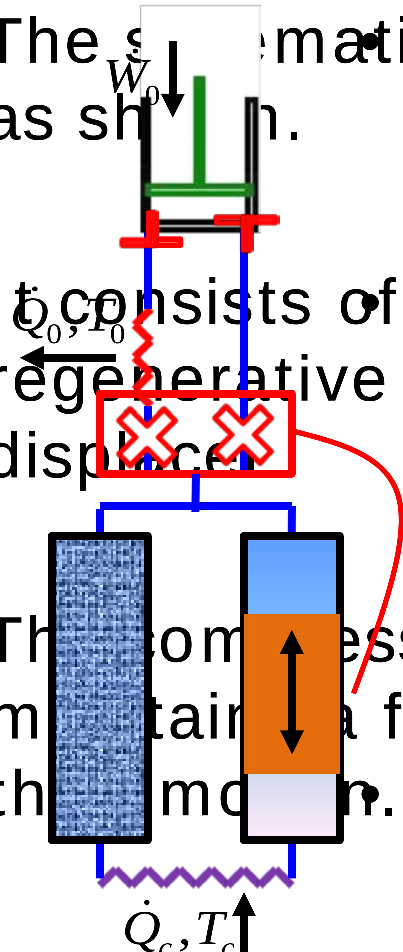
Claude

Regenerative Cryocoolers



Stirling

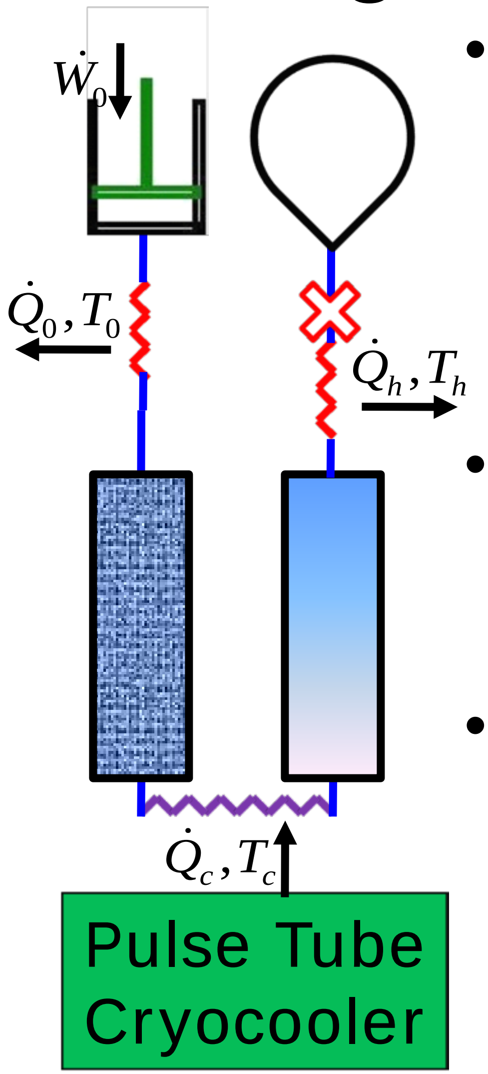
- The schematic of a Stirling Cryocooler is as shown.
- It consists of a compressor, a regenerative heat exchanger and a displacer.
- The compressor piston and the displacer maintain a fixed phase angle between their motion.
- This phase difference is vital to have an efficient operation.



G – M

- The schematic of a GM Cryocooler is as shown.
- The required phase difference is maintained by relative motion between the valve mechanism and the displacer motion.
- Stirling Cryocooler works at high frequency, while GM Cryocooler works at low frequency.

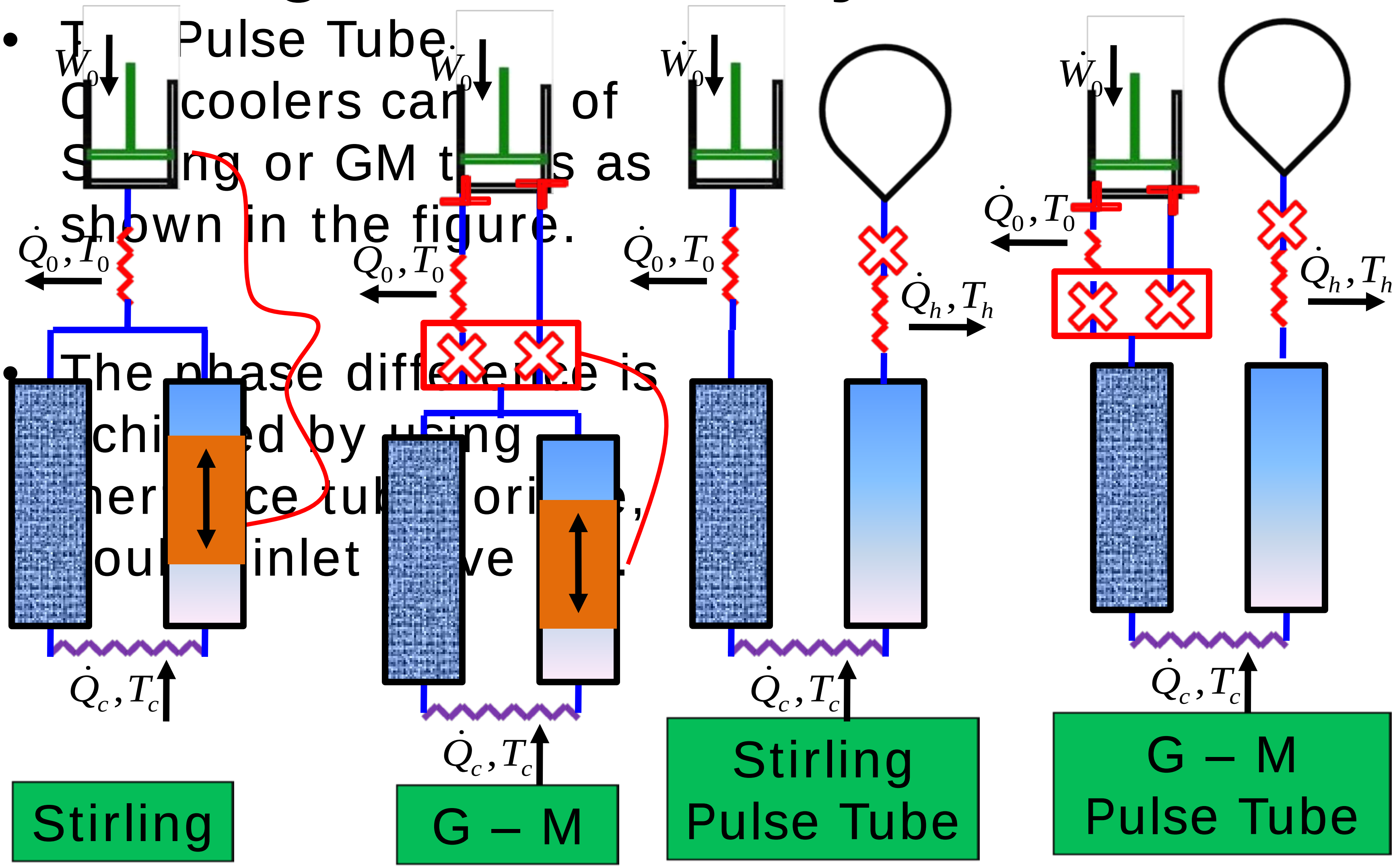
Regenerative Cryocoolers



- Pulse Tube Cryocooler works without having any mechanical displacer. Instead, gas works as a displacer.
- There is no need for a mechanical drive for the displacer.
- As a result, the magnitude of vibrations in the Pulse Tube Cryocooler is less as compared to Stirling and Gifford McMahon Cryocoolers.

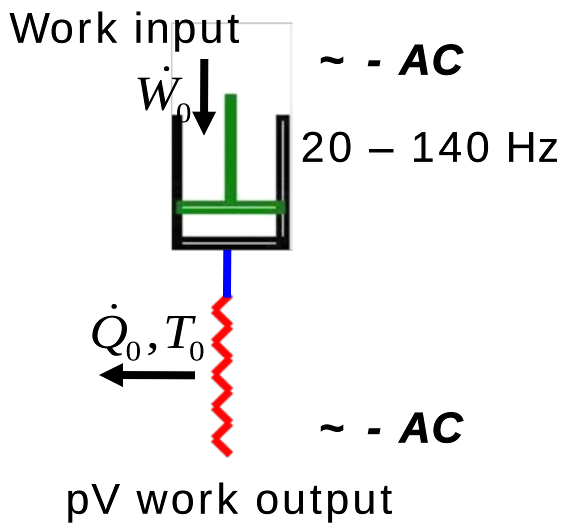
Regenerative Cryocoolers

- The Pulse Tube Cryocoolers can be of Stirling or GM types as shown in the figure.
- The phase difference is achieved by using inertance tube, orifice, double inlet valve.



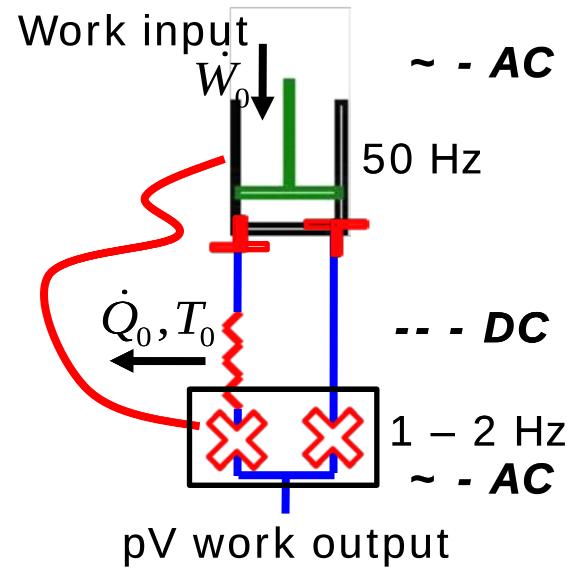
Comparison of Efficiencies

Stirling



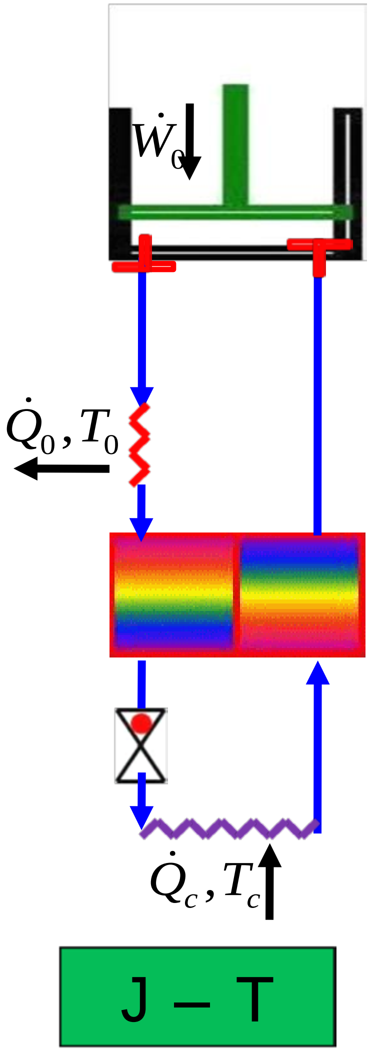
Efficiency: 85%

G – M



Efficiency: 25%

J – T Cryocooler



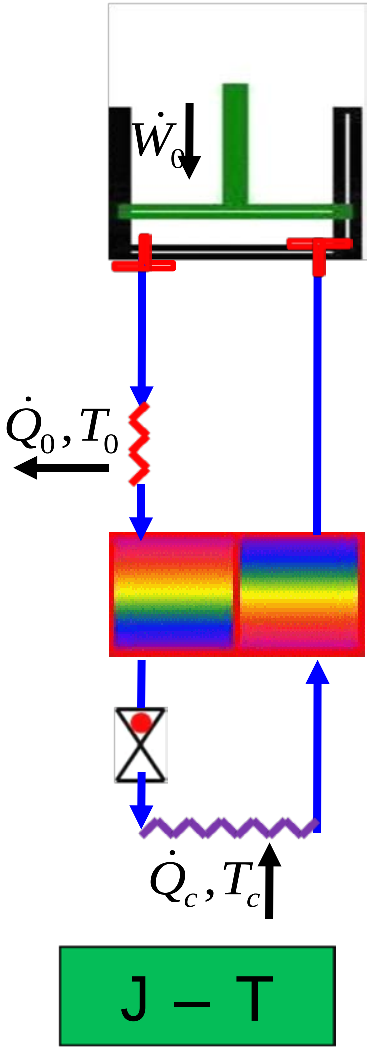
Uses

- Cooling IR sensors on missiles, surveillance cameras.
- Cooling semi conductor electronics.
- Cryosurgery.
- Liquefaction of natural gas.

Recent Developments

- Mixed refrigerants.
- Sorption compressor.

J – T Cryocooler



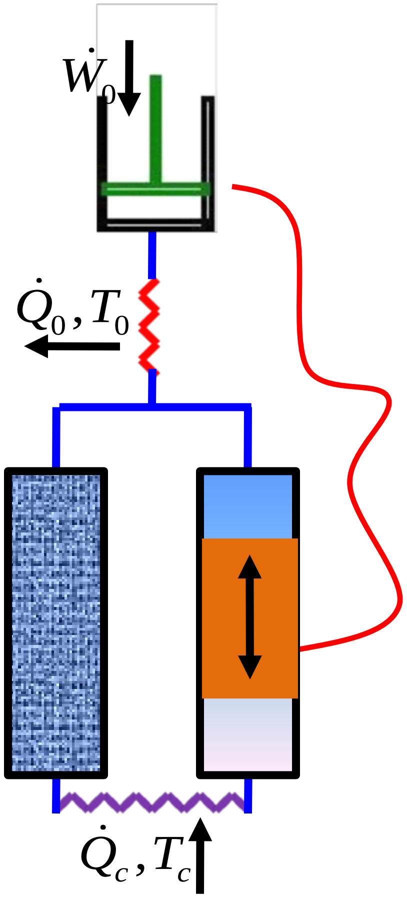
Advantages

- No cold moving parts.
- Steady flow operation, no vibration.
- Cold end can be miniaturized.

Disadvantages

- Relies on real gas behavior.
- Requires high pressures, in the order of 200 bar.
- Small orifice, susceptible to clogging.
- Low efficiency.

Stirling Cryocooler



Stirling

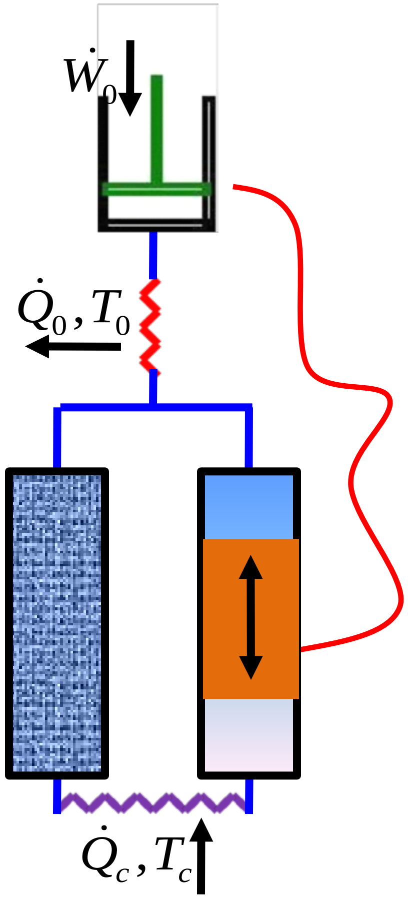
Uses

- IR sensors.
- Satellite experiments.
- High temperature superconductors.
- **N_2 / Air / H_2** liquefaction.

Recent Developments

- Flexure bearings.
- Gas bearings.
- Multistaging to reach down lower temperatures.

Stirling Cryocooler



Advantages

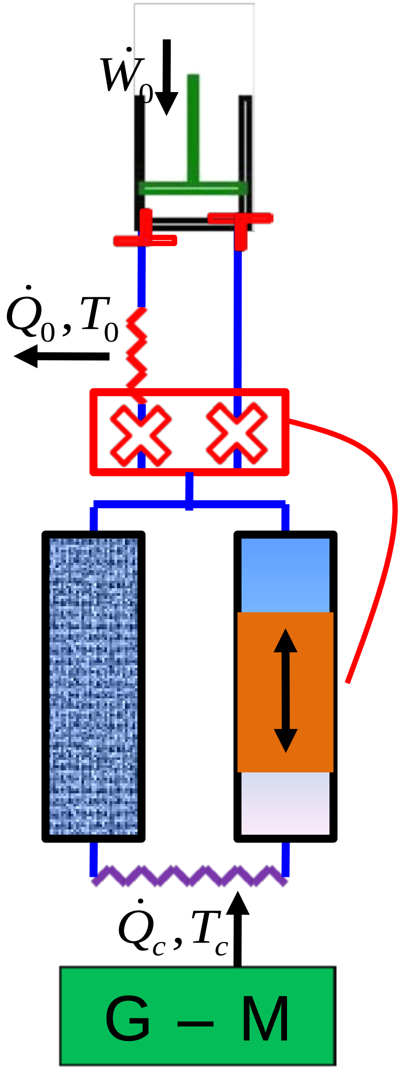
- High efficiency.
- Small size and weight.
- High reliability, practically zero maintenance.

Disadvantages

- Dry or no lubrication.
- Vibration due to mechanical displacer.

Stirling

G – M Cryocooler



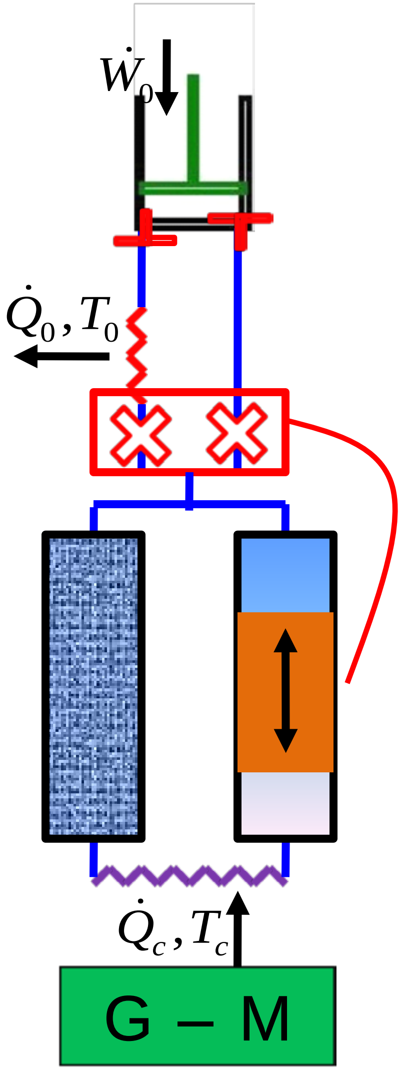
Uses

- Cryopumps.
- MRI, NMR equipments.
- Laboratory magnets.

Recent Developments

- 4 K operation.
- Rare earth regenerator materials.

G – M Cryocooler



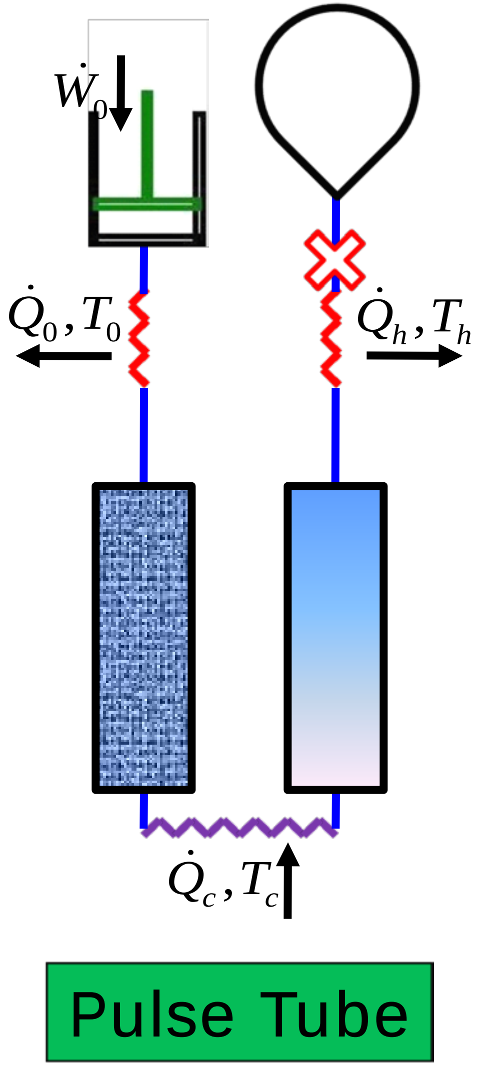
Advantages

- It can reach 4 K in two stages.
- Proven reliability.
- It is a low frequency machine.

Disadvantages

- High vibration.
- Less efficiency.
- Noisy operation.
- Requirement of sealing at low temperature.

Pulse Tube Cryocooler



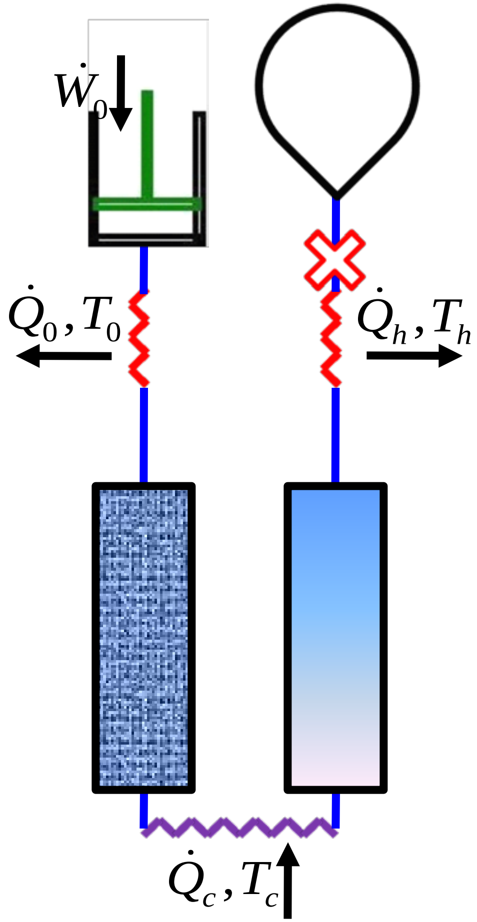
Uses

- Cooling of infrared sensors.
- Space applications.
- Re-condensing of **LHe** and **LN_2**.

Recent Developments

- Reached below 4 K.
- Miniaturization.

Pulse Tube Cryocooler



Pulse Tube

Advantages

- No cold moving parts.
- No sealing requirement at low temperature.
- Less vibration at the cold end.

Disadvantages

- No reliability data.
- Orientation effects.

Applications

- Cryocoolers are used in the following areas.
  - **Space**: Military – night vision IR cameras, IR detector cooling in space and satellite.
  - **Gas Industry**: Gas cooling, liquefaction, storage, cryopumps.
  - **Medicine**: Cryogenic catheter and cryosurgery.

Applications

- Continuing further, Cryocoolers are used in the following areas.

  - **Superconductivity**: MagLev trains, Superconducting transformer, motor and generator.

  - **Energy sector**: SMES, CERN.

  - Cooling of MRI, NMR and SC Magnets.

Summary

- A Cryocooler is a mechanical device which generates low temperature due to compression and expansion of gas.
- We need a Cryocooler because it eliminates cryogen requirement and offer reliable operation.
- Cost of cryogen is increasing where as, the cost of cryocooler is decreasing.
- Heat exchangers can either be regenerative or recuperative type, depending upon the kind of heat exchange.

Summary

- In a recuperative heat exchanger, it is a direct heat transfer where as, in a regenerative heat exchanger, it is an indirect heat transfer.
- Example of recuperative cryocoolers are J – T, Brayton and Claude Cryocoolers.
- Examples of regenerative cryocoolers are Stirling, Gifford – McMahon, Pulse Tube Cryocoolers.
- Cryocoolers are used in space, gas, medicine, superconductivity applications.

- A self assessment exercise is given after this slide.

- Kindly asses yourself for this lecture.

Self Assessment

1. Cryocooler operates on a _________ cycle.
2. MTBF stands for __________.
3. The units of cooling effect are ________.
4. Solid boundary exists in ____ heat exchanger.
5. ________ is the heat exchange medium in regenerative heat exchanger.
6. Mechanical expander is used in _______ cycle.
7. In Stirling cooler, _______ is important between piston and displacer motions.
8. Mechanical displacer is absent in ____ cryocooler.
9. Efficiency of G–M cooler is ___ than Stirling cooler.
10. Vibrations are absent in ____ cryocooler.

Answers

1. Closed
2. Mean time between failure
3. mw,(W)/K
4. Recuperative
5. Matrix
6. Brayton
7. Phase shift
8. Pulse tube
9. Less
10. Joule Thomson

Thank You!