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Systematic Review for Comparison Type of Pulse Tube Refrigerator

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What Is The Pulse Tube, and What Is The Difference Between Its Types

Abstract: A PTR (Pulse-Tubes-Refrigerator) is a cryocooler that could produce exceptionally low temperatures in one stage and even lower temperatures in two stages. Rather than utilizing the vapor compression cycle to achieve refrigeration, a PTR uses oscillatory compression and gas expansion within a closed space to obtain the required cooling. This paper discusses the significance of PTR and the many types of PTR. The most important feature of its primary varieties is recommended for large-scale cooling applications. Compared to Stirling pulse tube technologies, the equipment employed by GM pulse tube has been noted with low frequencies.

Keywords: *Pulse-Tubes-Refrigerator (PTR); Stirling Type Pulse Tube (STRP); Gifford McMahon Type Pulse Tube (GM)*

1. Introduction

The subject of achieving low temps is still a topic under improvement and research in cryocooler pulse tubes to connect to low temps. A Pulse-Tubes-Refrigerator (PTR) or pulse tube cooler is considered an advanced technology that appeared largely in the early eighties with a series of refrigerants. Such as Stirling coolers and the input of pulse tube coolers in many innovations broader than thermoacoustics. The difference was that they do not contain moving parts at low temperatures, which made them suitable for widespread uses [1]–[7]. It has a wide range of uses, including industrial (e.g., semiconductor production), military (e.g., infrared sensor cooling), and astronomical (e.g., infrared sensor cooling) (e.g., in the cooling of infrared sensors). Pulse (PTR) refrigerators are particularly frequent in lavender refrigerators due to their inherent properties.

1-2Application of Cryocooler

It will go over the most common applications for freezing coolers, which play an essential role in our daily lives, and how they might be utilized in the future for various purposes. The most common uses of cryocoolers are discussed in the following paragraphs. The most common uses of cryocoolers have been outlined in the following section [8].

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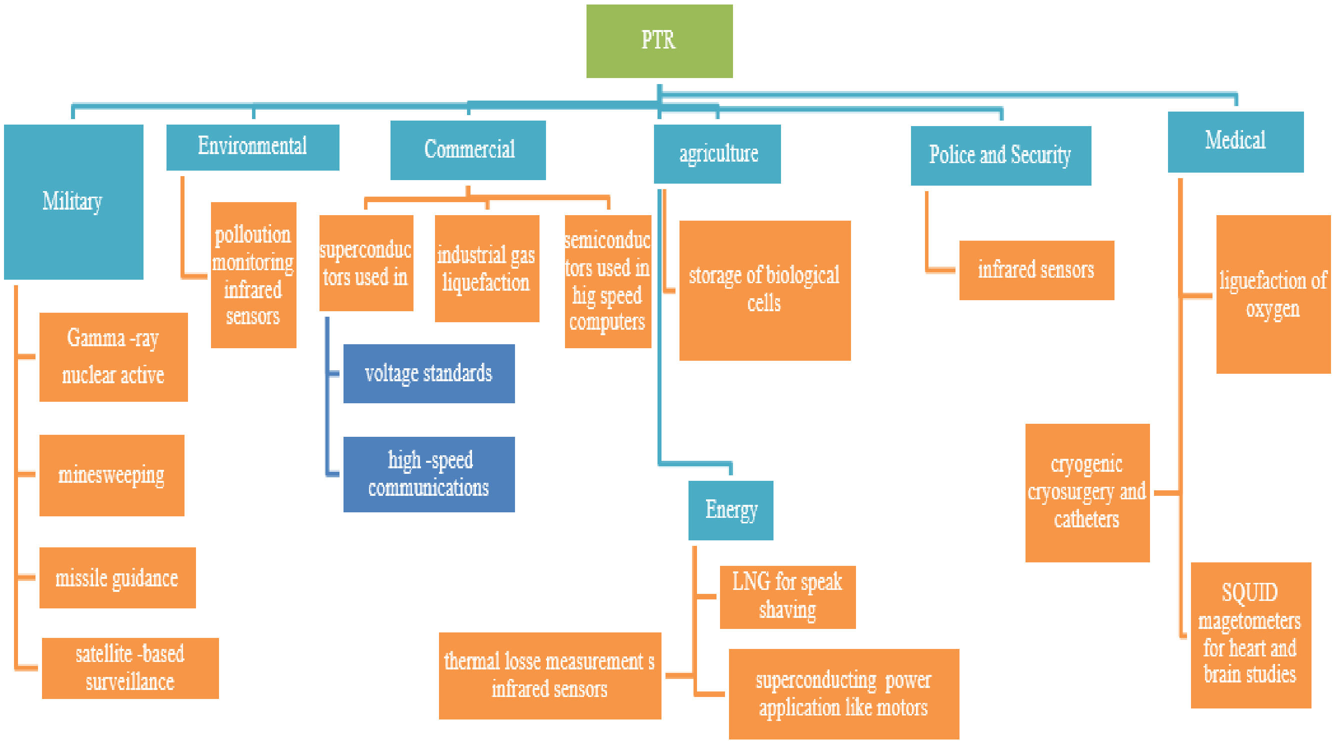
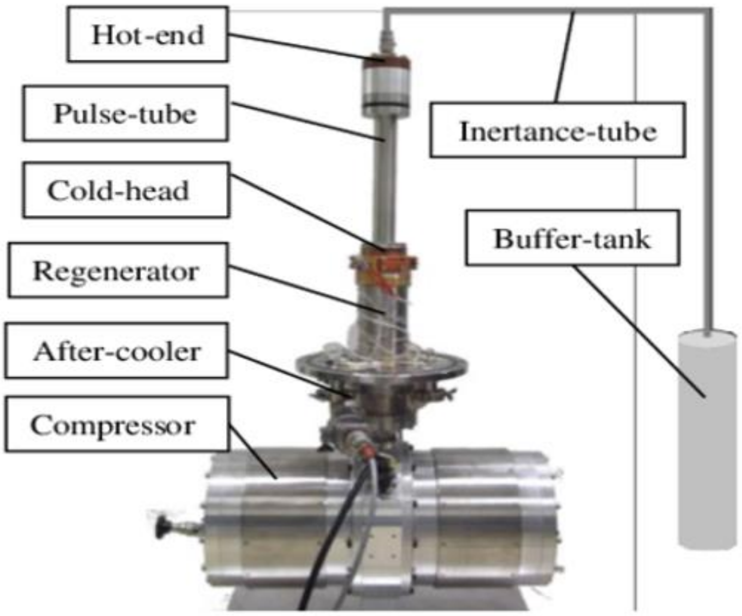


Flowchart 1 Application of Cryocooler PTR

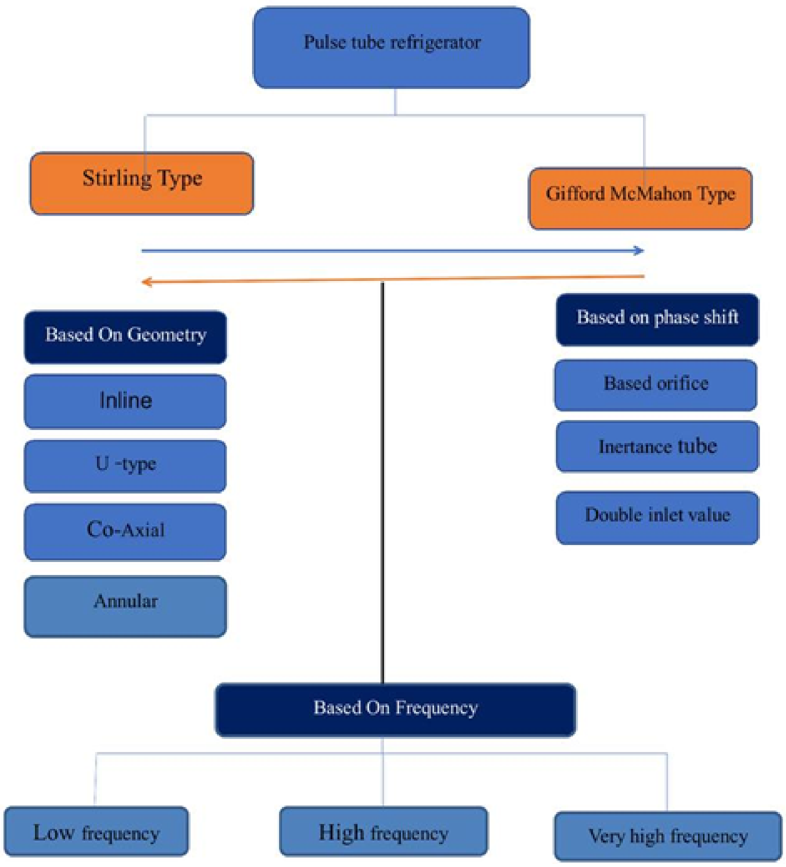
1.3 Pulse-Tubes-Refrigerator Components

The Pulse-Tubes-Refrigerator (PTR) components are as follows rotary magnitude, Surge Volume, Inertance Tube, Orifice magnitude, Hot Heating Exchanger, Pulse Tube, Cold Heating Exchanger, Regenerator, Compressor, After cooler [9]



pulse tube cryocooler

1.5 Categorization of Pulse-Tube-Refrigerators



Flowchart 2 Categorization of Pulse-Tube-Refrigerators [10]

2. Stirling Pulse-Tubes-Refrigerator

Stirling pulse tube cryocoolers (SPTCs) with many stages operating at liquid helium temperatures are appealing due to their possible tactical and space uses [11]. A Stirling-kind PTR is distinguished by minimal vibration, great frequency of operation, and long lifespan. The pulse tube's flow is difficult due to its pulsating nature [12]. In 2009, it was stated that a single-stage Stirling pulse tube for utilizing in a modified thermoacoustic model might provide around 18.6% of the Carnot efficacy[13]. Researchers looked into the impact of impedance volume on an SPTC in 2013. It was revealed that the impact of impedance volume on viscous and thermal losses is active, contributing to overall cooling efficacy [14]. Based on REGEN 3.2, a single-stage SPTC was built and fabricated for testing. The cooler could get a cooling capacity of 5.0 W at 79.1 K and create a no-load temp of 57.0 K when operated at a mean pressure=2.50 MPa and a frequency=60 Hz, according to the experimental results, which are extremely similar to the calculated magnitudes. In 8.5 minutes, the cryocooler could be cool down from ambient temp to 80 K. [15] In 2018, a large-capacity SPTC was constructed, and its performance was tested to attain a cooling capacity of 1 kW at 77 K and a pressure of 20 kPa [16]

2.1 Stirling- PTR with U kind

The linear PTR has the problem of placing the cold area in the center of the cryocooler system. It is desirable to have the cooling occur at the cooler's end for several uses. Bending the PTR at the regenerator cold end and the tube creates the U-shaped PTRs seen in Fig.1(a). Both hot ends could be installed on the vacuum chamber's flange at room temp. PTRs are most commonly found in this shape. The improvement of 2-stages Stirling kind PTR with a U design for both stages has been accomplished. At the second step, the PTR reached a min temp of 28.8 K. With a compressor input power of 320 W, the associated charge pressure and operating frequency are found to be 22 bar and 72 Hz, respectively. The PTR performance has been increased because of the employment of a twin inlet valve and flow straighteners in the second stage. [11] Furthermore, another group that designed Ukind3-stage in the regenerator and pulse tube along with the phase shifter was also observed. It was found that the refrigerant temp improves with refrigeration performance steadily. Range when there is no improvement in frequency, but it has been observed that the process of frequency optimization along with pre-temp is necessary to improve performance

[17]

2.2 Single-Stage inline Stirling- PTR

Mohanta et al. The experimental performance for various cold-end heating exchangers was assessed, with the lowest temperature and cooling force obtained at 80k. The performance of PTR is improved by substituting the coarse copper mesh with a solid mass, which promotes healing transmission from the gas to the copper outer component of the heating exchanger.[18] Tendolkar et al. investigated the pulse tube kind inline Stirling refrigerator, finding that the inline configuration has a shorter cooling time than the U configuration at the same charging pressure and input force, and the inline configuration has a lower minimum temp.[15] Xi Chen et al. It was discovered that with a single linear compressor, the parallel system might obtain lower temps in different locations, lowering the cryocooler's cost and weight. The cooling of the parallel system is better than the single system when there is greater input power.[19] as demonstrated in Fig. 1 (b)

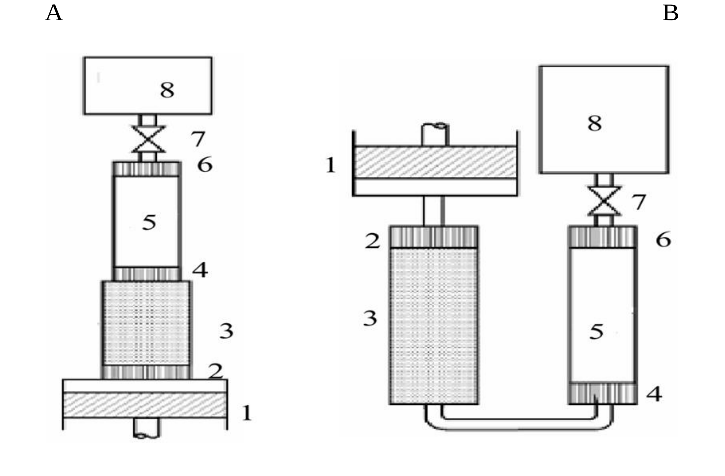


Fig.1 Sketch of pulse tube geometry (A) Linear, (B) U-kind 1) Compressor, 2) After cooler, 3) Regenerator, 4) Cold HX, 5) Pulse tube, 6) Hot XH, 7) Orifice valve, 8) Reservoir [5]

2.3 Co-axial Stirling- PTR

For several different uses, a cylindrical form is the most desirable option. As shown in Figure 2, the PTR might be constructed in a coaxial configuration, with the regenerator creating a ring-shaped region around the tube. This design option is shown in the figure. The fact that the tube and the regenerator only come into indirect touch with the heating is a limitation of this design. In a broad sense, the temps of the two components could be different. As a direct consequence, the regenerator's effectiveness is diminished. In order to get the required cooling for the next generation of very large-scale long-wave infrared focal plane arrays that are currently under improvement, a great-capacity single-stage coaxial pulse tube cryocooler operates at around 60 K and is thus developed. This cryocooler works at a temperature of around 60 K. When individuals get the most consequential outcomes With an input power of 180 W and a reject temp of 300 K, the cooler has a typical output power of 4.06 W at 60 K. The output power is 4.72 W when the input power is raised to 200 W, and the Carnot efficacy is above 9.4 percent while the temp is at 60 K [20]

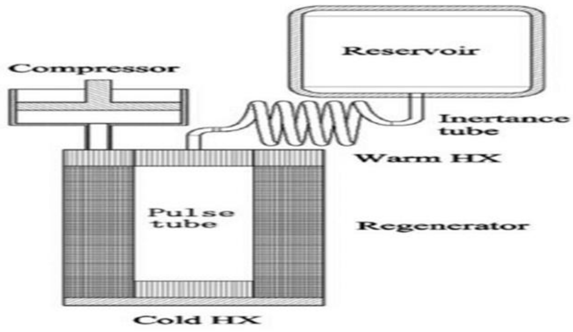


Fig. 2 Sketch of pulse tube geometry coaxial [20]

3 Gifford McMahon Kind Pulse-Tubes-Refrigerator

The GM-kind PTRs operate at a lower frequency than the Stirling-type, which results in differing flow and heating transfer coefficients in the pulse tube, which is the primary distinction between the two types of pulse tube radiometers. Gifford-McMahon coolers are used extensively in a variety of low-temp systems, including MRI and cryopumps, amongst others. Helium, with pressures ranging from 10 to 30 bars, serves as the working fluid (150–440 psi). The fact that the compressor and the displacer cycle frequencies are not connected is an advantage, allowing the compressor to run at the power line frequency between 50 and 60 Hz. In contrast, the frequency at which the cold head operates is 1. It has proven possible to develop a 2K Gifford-McMahon (GM) cryocooler specifically to chill electronic equipment, including Superconducting Single Photo Detectors (SSPD). The heating exchangers and regenerators have been upgraded thanks to a new numerical simulation created for 4K GM cryocoolers.

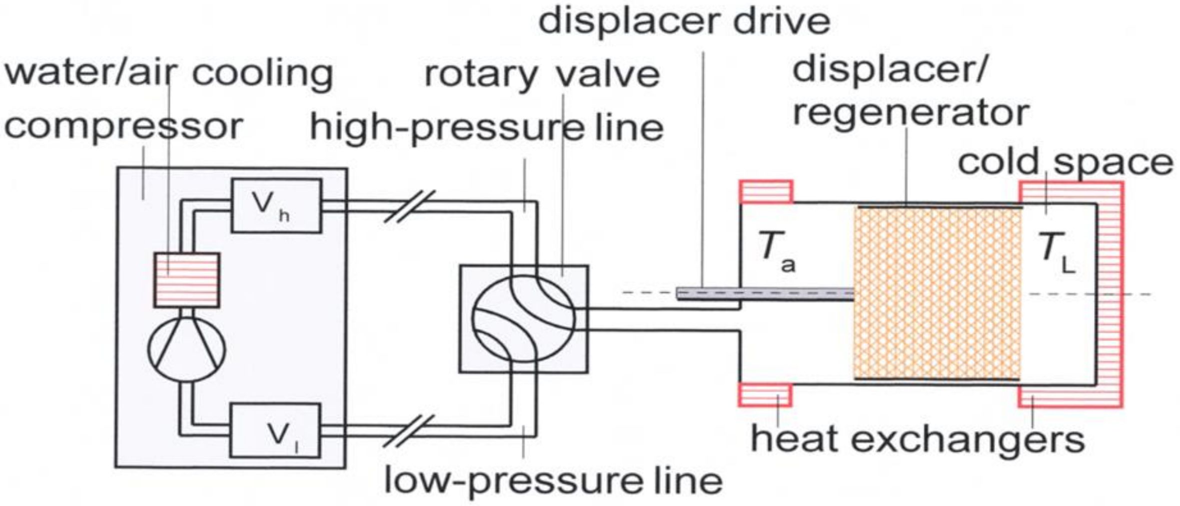


Fig.3 Sketch of a GM-cooler. Vh and Vl are buffer compressor volumes. The compressor cooling water has eliminated the compression heating thru a heating exchanger. The rotary valve alternative connects the cooler with the low and great-pressures compressor sides and runs synchronously with the displacer.

4-Basic Pulse-Tubes-Refrigerator

In 1964, the basic kind of refrigerator tube was designed, a simple cylindrical hollow tube. One end is open, and the other is closed. The open end is cold, while the closed end is S to ambient temp via a heating exchanger demonstrated in Fig.4

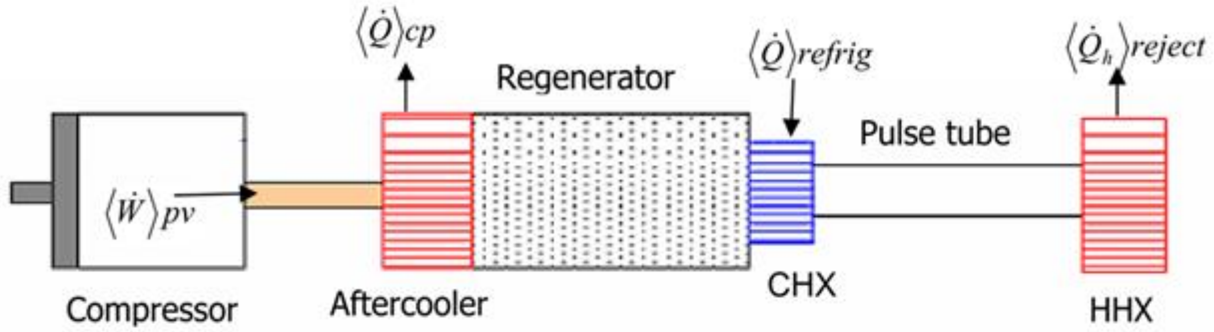


Fig.4 Sketch of fundamental PTR [6]

5-Orifice Pulse-Tubes-Refrigerator (OPTR)

Mikulin et al. improved the pulse tube design by adding an opening near the tube's warm end in 1984 [6][21] [22] [23][24]. Because of the problem, the PTR affects cooling performance and cold end temps because of the problem. As a result, a new kind of PTR was developed to solve the flow problem by adding it to the secondary compressor's hot end, which resulted in significant nozzle cooling benefits[25]. The PTR's cold end structure was simplified in 2005, and a single-stage refrigerator tube pulse valve was developed with an L-kind pulse tube and two slot valves at the hot end. Compared to the valve construction from the single orifice, it was discovered that this structure modifies the gas flow rate at the hot end[26][27]. The goals were to demonstrate that CFD simulation of PTRs could be done and to test the OPTR performance at various frequencies. All of the projected trends were correctly predicted by the CFD models. as demonstrated in fig.5-6. As a result, two main ideas for reaching the needed cooling power are (1) increasing the inlet valve's size and running it at greater frequencies and (2) enhancing throttling.[28]

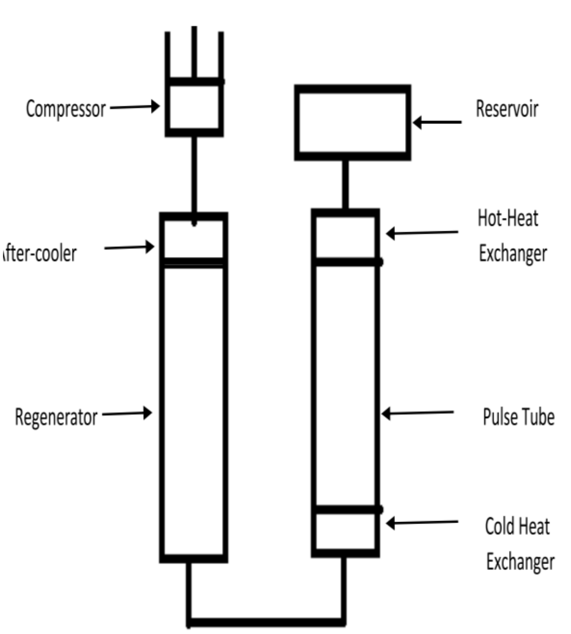


Fig.5 Sketch for Stirling Kind OPTR [8]

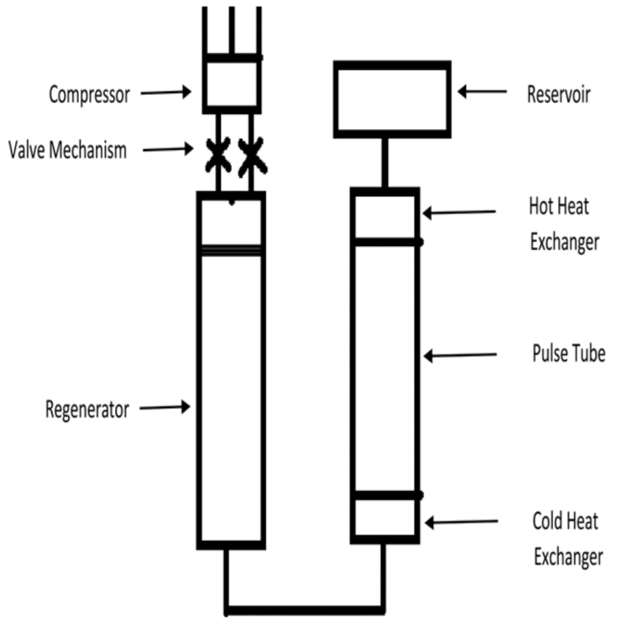


Fig.6 Sketch for GM Kind OPTR [8]

6-Double-Inlet Pulse-Tubes-Refrigerator

Refrigerators with orifice pulse tubes operate at substantially lower temps and have significantly more cooling capacity. Better efficacy could now be obtained by introducing a phase shift between pressure oscillations and the mass flow inside the PTR system demonstrated in Fig.5 [6][29] by Muhammad Arslan et al., Note that the DIPTR model provides greater versatility to obtain better cooling performance and efficacy, as it utilized a di-valve orifice with a percentage of 20% and a valve opening by 30% ℃ when restarting temps from 150 K, the load is 3.7 watts where the CFD model proved an improvement in the experimental results where it proved these Trials are important in the field of industrial application of gas liquefaction and control[30] Y.P. Banjara et al., implemented a dynamic computational three-dimensional simulation of a GM vertical DIPTR Pulse-Tubes-Refrigerator, which operates under various thermal boundary situations [1]. The numerical analysis presented in this work demonstrates the DPT's performance in great detail. According to predictions, opening the bypass valve in a DPT creates a larger pressure proportion in the pulse tube and delays the compressor's pressure phase. As a result, a DPT could produce more cooling power with less compressor P- V effort than a traditional OPT. A larger degree of bypass valve opening results in a greater mass flow rate thru the bypass tube, which lowers the mass flow rate at the pulse tube cold end and raises the mass flow rate non-harmoniousness at the hot end [29]

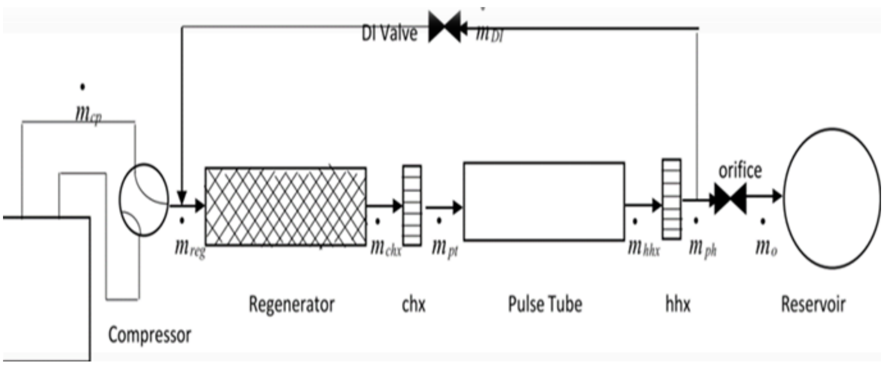


Fig. 5 Sketch of a (DIPTR) [8]

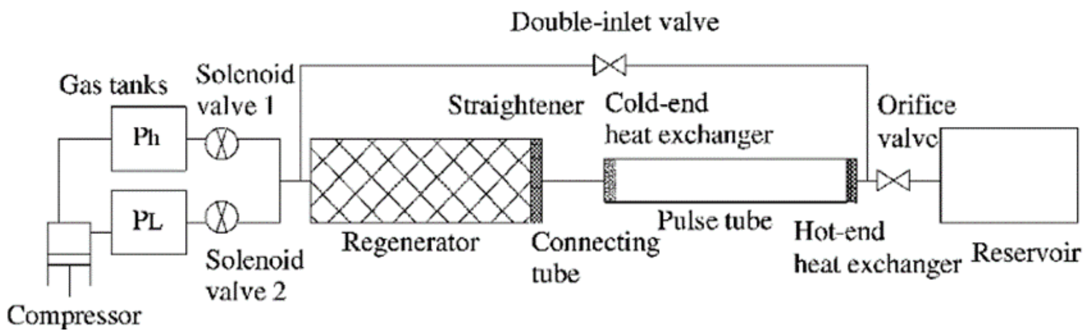


Fig. 1 Sketch of a G–M-kind DIPTR [2]

8-Inertance Pulse-Tubes-Refrigerator

PTR is considered one of the most recent kinds of the inertance pulse tube. It was discovered when the orifice valve was substituted with a long inertance tube with a very small internal diameter, as indicated in the diagram Fig(6), which boosted cooling capacity by adding reactive resistance to the system and increased cooling capacity[31]. In the simplified situation of infinite reservoir capacity and without dead volume of the regenerator, de Boer [32] determined the inertance Pulse-Tubes-Refrigerator (IPTR) refrigeration rate as a functional for necessary factors. The IPTR's performance is superior to that of the orifice Pulse-Tubes-Refrigerator (OPTR) over a restricted frequency range. Wei et al.[33] Theoretical calculations demonstrate that an inertance tube without a reservoir has a large phase-leading impact. A phasor plan is utilized to investigate the association between pulse tube geometry and phase-leading need. They discovered that a greater void volume in the pulse tube needed a stronger phase-leading impact. M. Lewis et al. [34] demonstrated how a basic inertial tube transmission line model could be utilized to get the best diameter and inertial tube length for a given acoustic power that agrees well with experiments to find the largest phase shift. Xi Chen et al., [35] While Sajjad discovered that the inertial tube is the best for large cooling power applications since the inertial tube's great temps cause it to dissipate much photoelectric energy

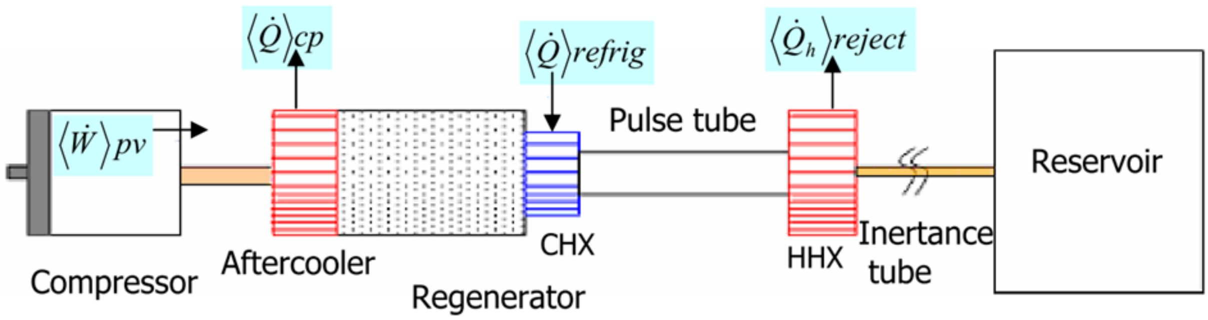


Fig6. Sketch of the IPTR [5]

9- Based On Frequency

In recent years, the scarcity of liquid helium and its expensive cost have prompted the quick improvement of liquid helium mechanical cryocoolers and their widespread use in the aerospace industry. Amongst the several mechanical cryocoolers, great-frequency pulse tube cryocoolers working at liquid helium temp (LHT-PTC) constitute one of the finest candidates for cooling systems for deep space studies because of their long life, excellent dependability, and compact structure. However, for space applications, increasing their efficacy is a major concern. LHT-PTC performance is greatly influenced by operating frequency, and regenerative materials with a large volumetric heating capacity at temps below 15 K could significantly increase LHT-PTC performance. Great surface area/volume proportion activated carbon and charcoal nanomaterials with outstanding adsorption ability at low temps are particularly promising great-performance regenerative materials. The LHT-PTCs performance was considerably improved. Great surface area/volume proportion activated carbon and charcoal nanomaterials with outstanding adsorption ability at low temps are particularly promising great-performance regenerative materials[36].

10-Conclusion

- Stirling-kind coolers have a greater frequency range (10-120)Hz than GM-kind coolers, which have a lower frequency range (1-5)Hz.

- Stirling coolers are now preferred over GM coolers because GM-kind coolers use rotary valves or solenoid valves, which cause great or low pressure during rotary valve opening and closing operations, resulting in pressure restrictions that make GM unsuitable for great-frequency coolants that require great cooling capacity.
- Stirling-kind coolers can achieve temps of 20K in two phases, while pulsing tube coolers of the kind GM coolers can only reach temps of less than 2K.

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