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# Investigation of Multi Bypass Pulse Tube Cryocooler

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**Abstract.** To meet the growing demands of vibration free and compact cooling devices for various space and military based application, Pulse tube cryocoolers (PTC) are in focus. Several modifications have been attempted in recent past to increase the performance of the PTC. These includes different geometric configurations, phase shift mechanism, multi-staging, multi-bypass etc. Multi bypass PTCs (MBTC) are capable of achieving temperatures below 18 K, which could otherwise be achieved only by multi-stage configuration. The present work focuses on investigation of single bypass pulse tube cryocooler. Sage model is developed for single stage inline PTC without and with the bypass to study the influence of design parameters on cold end temperature. Experiments are carried out on new MBPTC and the results are compared with the predictions.

## 1. Introduction

Pulse tube cryocoolers are widely used to serve low temperature requirement in various fields like space, gas industries, medical, superconducting applications etc. due to their compactness, reliability and cost-effectiveness. Principle of Pulse Tube Cryocooler (PTC) was initially presented by Gifford and Longworth [1]. A basic PTC consists of pressure wave generator, regenerator, heat exchangers and the pulse tube. Pressurization and depressurization in the pulse tube sets up a temperature gradient across it and provides cooling effect at one end, while the other end of the pulse tube is kept at ambient temperature.

Further developments of PTC were based on various phase shift mechanisms (PSM) in order to minimize cooling temperature. Watanabe and Yoshimura et al. [2] introduced a long neck tube at the hot end of PTC, now known as inertance tube, to decrease phase shift. A research group led by Zhou and Han [3] suggested the idea of multi bypass in which some amount of gas is bypassed from a point in the regenerator to another in the pulse tube. Cai and Wang et al. [4] experimentally verified the concept of multi bypass and achieved lower cooling temperature than the conventional PTC.

PTCs are classified on the basis of geometry, PSM used, operating frequency etc. Based on geometric configuration they can be of inline, U-type, coaxial or annular type. Present work focuses on Inline PTC with inertance tube as PSM. Inline PTC is fabricated and the effect of introduction of bypass is discussed based on theoretical and experimental results.

## 2. Multi bypass pulse tube cooler (MBPTC)

Introduction of multi bypass in conventional PTC was suggested in order to improve the performance of the cooler. Thin bypass tube is used to divert a fraction of gas from a bleeding point at the regenerator to the feeding point in the pulse tube. Figure 1 shows the schematic of the MBPTC with bleeding and



feeding points. The objective of multi bypass is to reduce the phase shift between the pressure pulse and mass flow rate in order to increase cooling capacity.

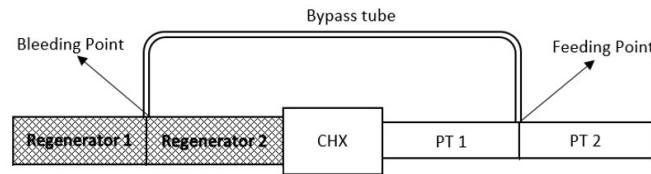


Figure 1. Schematic of MBPTC.

In addition, due to the bypass, mass flow rate from the Regenerator 2, as shown in Figure 1, gets reduced resulting in lesser pressure drop across it. This eventually increases the overall pressure ratio in the system and attains a lower temperature.

**3. Numerical analysis**

To understand the complex phenomenon in PTCs, Sage software, which is based on numerical methods, is used. Sage is particularly suited to model, optimize and design Stirling coolers, PTCs, and other cryocoolers used in research labs and industries. With Sage, users can build simulation model, specify components dimension and solve for the objective function in ordered to predict the performance of the cooler. The equations used in Sage considers one dimensional flow.

Typical numerical modelling using Sage software is better understood by the following mentioned sequence of operation.

- Modelling of all components and sub components of the PTC.
- Defining flow connection (mass and/or heat) among all components.
- Specifying all the design parameters as per problem physics.
- Specifying objective function and constraints if any.
- Solve for objective function.

Inline PTC without and with bypass is modelled in Sage as shown in Figure 2 with the objective to minimize cooling temperature.

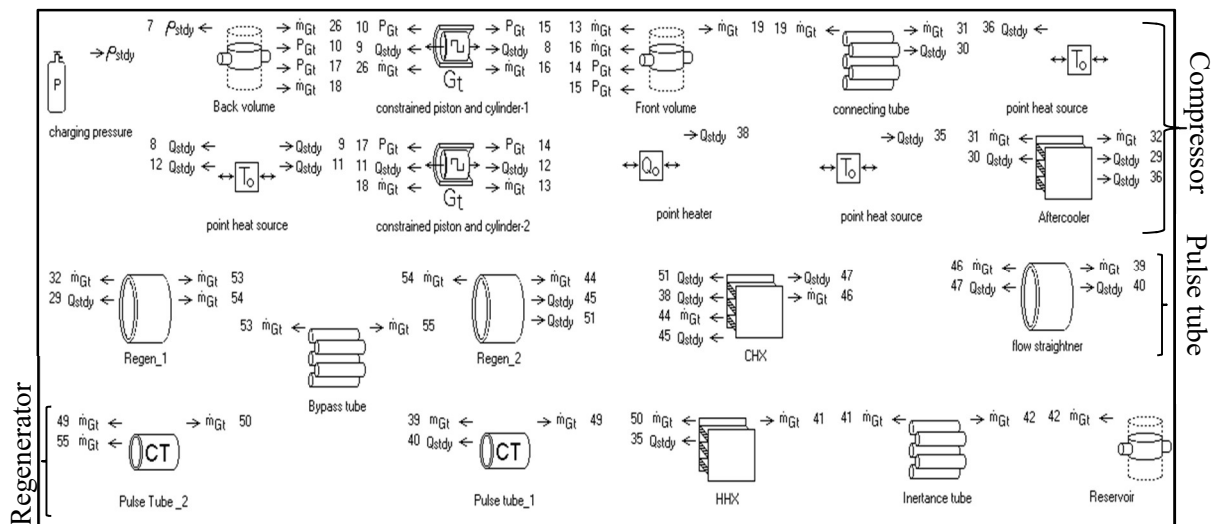


Figure 2. Sage model of Inline MBPTC.

Optimised design parameters of regenerator, pulse tube and inertance tube are selected for the fabrication of PTC set-up using the software. Bypass location is very important as it influences the performance of the PTC. Thus, positions of bypass on the regenerator and the pulse tube need to be

optimised. Table 1 shows the dimensions of the components obtained using Sage model. The predicted performance of MBPTC is expected to reach a no load temperature of 37 K for a power input of 300 W.

Table 1. Design parameters of the components of MBPTC.

Sr. no.	Component	Dimensions (mm)	Material
1	Aftercooler gas side	D = 16, L = 22	Copper
2	Regenerator mesh no.	400	SS316
3	Regenerator_1	D = 28, L = 27, t = 0.15	SS304
4	Regenerator_2	D = 28, L = 27, t = 0.15	SS304
5	Pulse tube_1	D = 12.2, L = 39, t = 0.15	SS304
6	Pulse tube_2	D = 12.2, L = 39, t = 0.15	SS304
7	Cold end heat exchanger (CHX)	D = 28, L = 15	Copper
8	Hot end heat exchanger (HHX)	D = 11, L = 19.2	Copper
9	Bypass tube	D = 2, L = 102, t = 1	SS304
10	Inertance tube	D = 2.3, L = 2000	Copper
11	Reservoir	Volume = 500 cm <sup>3</sup>	SS304

D = Diameter, L = Length, t = Thickness

Figure 3 and Figure 4 show the phase difference between the pressure pulse and mass flow rate in both PTCs without and with bypass as obtained using Sage model. Phase shift in simple PTC is more than that in PTC with bypass.

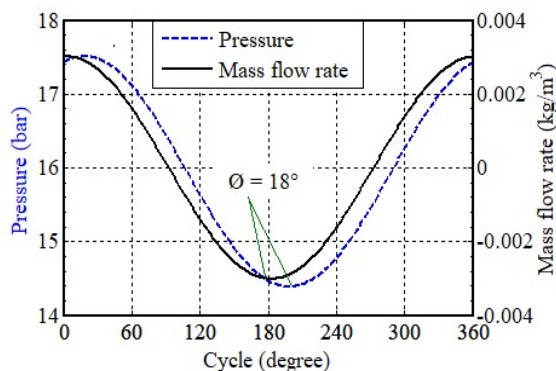


Figure 3. Phase difference in PTC without bypass.

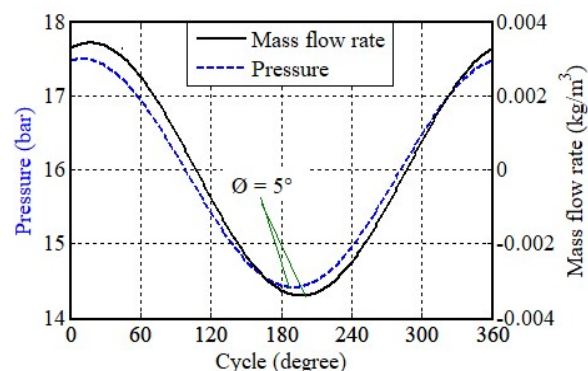


Figure 4. Phase difference in PTC with bypass.

#### 4. Experimental set-up

Experimental set-up consists of pressure wave generator (PWG), cold head assembly, inertance tube PSM, vacuum jacket, vacuum pump and instruments for recording process parameters. Figure 5 shows the schematic of the experimental set-up.

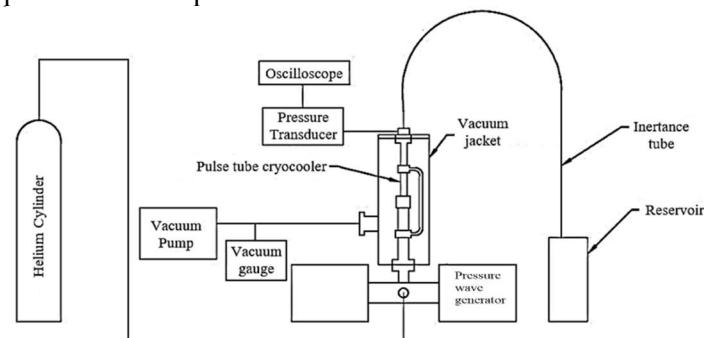


Figure 5. Schematic of experimental set-up.

Cold head assembly includes aftercooler, regenerator, CHX, pulse tube and HHX. PWG is connected to the cold head assembly through the connecting tube. Aftercooler, cold end and hot end heat exchangers are fabricated using copper material. Regenerator and pulse tube are stainless steel seamless tubes with wall thickness of 0.15 mm. Thin tube ensures that there is minimal axial conduction between the hot and the cold end. SS316 stainless steel meshes are used as regenerator matrix with mesh size of 400. Figure 6 and Figure 7 show complete experimental set up and cold head assembly of MBPTC fabricated for experimentation respectively.

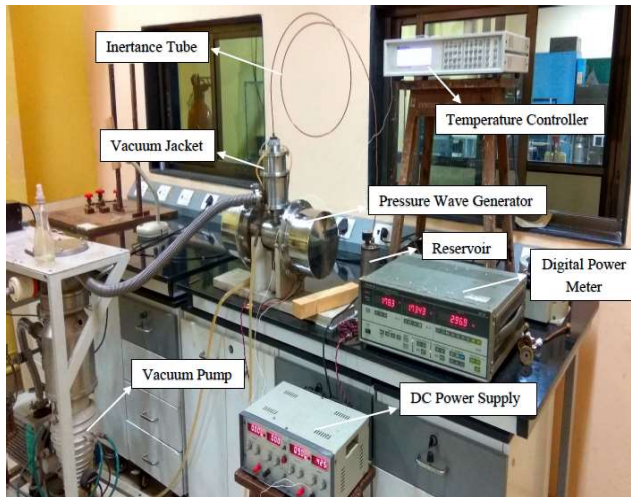


Figure 6. Experimental set up.

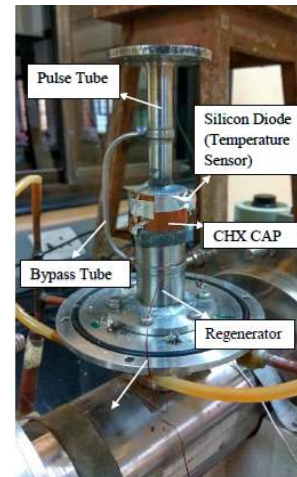


Figure 7. Cold head assembly of MBPTC.

## 5. Results and Discussion

Inline PTC, fabricated without and with bypass, is tested for the input power of 300 W and for operating frequency of 50 Hz. A comparison is made between them based on no load temperature and refrigeration effect. Figure 8 and Figure 9 show cool down curve and refrigeration effect (RE) for MBPTC respectively.

### 5.1. Cool down curve

Cool down curve depicts the time taken to achieve no load temperature with maximum deviation of  $\pm 0.05$  K. As seen from Figure 8, it takes around 35 min to attain lowest cooling temperature.

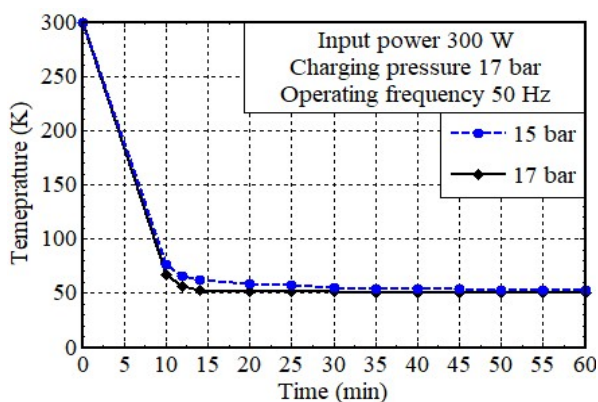


Figure 8. Cool down curve for MBPTC.

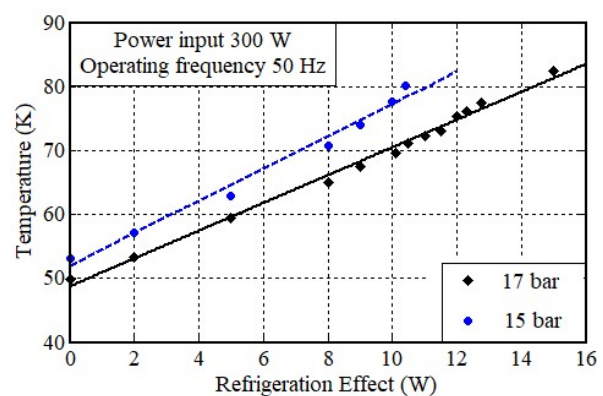


Figure 9. Refrigeration effect at different charging pressure for MBPTC.

### 5.2. Refrigeration effect

To measure refrigeration effect (RE) a resistive heater powered by DC power supply, is mounted at CHX to maintain constant cooling load. Temperature is recorded corresponding to heat load after the steady state is reached. Figure 9 shows refrigeration effect at different temperatures and charging pressure for inline MBPTC. As the charging pressure is increased refrigeration effect increases and no load temperature gets reduced due to higher pressure ratio in the pulse tube. Refrigeration effect of 14 W at 80 K is obtained for charging pressure of 17 bar while 10.4 W at 80 K is obtained at 15 bar charging pressure.

### 5.3. Comparison of inline PTC without and with bypass

Several experiments are carried out on PTCs without and with bypass and the experimental results are plotted along with the predictions obtained in Sage. Figure 10 shows the comparison of inline PTC without and with bypass for compressor power of 300 W and charging pressure of 17 bar.

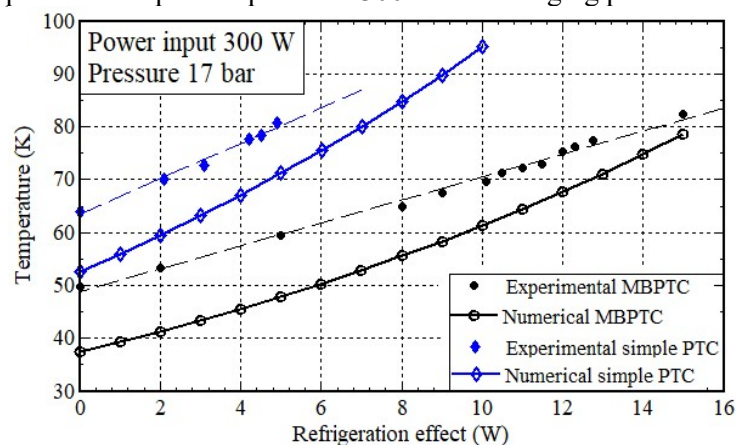


Figure 10. Comparison of simple PTC and MBPTC with numerical results.

No load temperature of 64.3 K is obtained by PTC without bypass whereas MBPTC attained 49.9 K is for similar operating conditions. As seen from Figure 10, with the introduction of bypass in the PTC, RE is increased from 4.6 W to 14 W at 80 K whereas Sage predicted RE to be increased from 6.5 W to 15.2 W at 80 K. Coefficient of performance for PTC with bypass is 0.046, while for PTC without bypass, it is 0.022. Experimental study confirms that introduction of bypass tube is effective to increase the performance of PTC.

## 6. Conclusions

Numerical and experimental investigation are carried out on inline PTC without and with bypass. Introduction of bypass in conventional PTC improves the performance of cooler by decreasing pressure drop across regenerator and changing the phase angle favourably. A lowest temperature of 49.9 K is attained at charging pressure of 17 bar using the bypass configuration.

## 7. References

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