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DESIGN & REFRIGERATION POWER LOSSES OF TWO STAGE PTR

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Abstract: ***The pulse tube refrigerator (PTR) is a Cryocooler which is capable of reaching temperature of a few tens of Kelvin in a single stage and a few Kelvin in two stages. Unlike ordinary refrigeration cycles which utilize the vapor compression cycle, a PTR implements the oscillatory compression and expansion of gas within a closed volume to achieve the desired refrigeration. Pulse tube refrigerator has the advantages of long life operation, high reliability and low vibration over the conventional Cryocooler, such as G-M and Stirling coolers because of the absence of moving parts at their low temperature end. Due to its associated advantages, pulse tube refrigerators have several applications such as cooling of infrared sensors, night vision equipment, SQUID, cryopumping etc.***
Keywords: Regenerator, Cryocooler,

I. INTRODUCTION

The application research on high Tc superconducting (HTS) devices and equipment such as superconducting motor, generator, fault current limiter, power cable has become more and more practical. The HTS material can be classified into two types, BSCCO (1stgeneration) and YBCO (2nd generation), which should be operated at temperature ranges of 30–40 K and 50–60 K, respectively. So the Cryocooler technology for cooling such HTS devices becomes more and more important. For the merit of light weight, small size and high efficiency, Stirling-type pulse-tube Cryocooler is one of the promising candidates. According to the required refrigerating temperature near 30 K, staged pulse-tube Cryocoolers are recommended for those applications. So far, some experimental results of staged Stirling-type pulse-tube cryocoolers have been reported. Sun power Inc. developed a two-stage pulse-tube cryocooler, which can achieve a lowest tem-perature of 24.4 K and 80 K at the first and second stages, respectively, and provide 260 mW at 30 K [1]. A two-stage pulse tube cryocooler developed by Sierra Lobo Inc. can provide 1.4 W at18.3 K at the second stage and 5 W at 67 K at the first stage with an input PV work of 600 W[2]. A two-stage pulse-tube cryocooler developed by University of Giessen achieved a lowest stationary temperature of 19.6 K at the second stage, while the first stage reached 73 K, with an operating frequency of 35 Hz [3]. Finally, the thermal linked two-stage pulse-tube cryocooler developed by University of Giessen and Zhejiang University reached a lowest temperature of 12.96 K with a total input electrical power of 400 W, when each stage was driven by one independent linear compressor [4]. The above researches mostly are concentrated on the pulse-tube cold head, however, the compressor also plays and import role in a cryocooler.

II. SELECTION OF GEOMETRICAL DIMENSION

Table 1.1 shows the detail of several pulse tube configurations experimentally studies along with lowest temperature achieved in their first and second stages.

Table1.1Details of experimental pulse tube configuration

Sl No	1st stage				2nd stage				Regenerator materials		No load temperature (K)	
	PT		Reg		PT		Reg					
	D	L	D	L	D	L	D	L	1st stage	2nd stage	1st stage	2nd stage
1	14	200	25	163	14	350	19	190	SS + Lead (85% + 15%)	Lead + SS (85% + 15%)	118.4	13.5
2	19	200	25	163	14	350	19	190	SS + Lead (85% + 15%)	Er_3Ni + Lead + SS (31% + 57% + 12%)	86.3	7.8
3	19	200	38	140	14	350	19	190	SS (100%)	Er_3Ni + Lead + SS (31% + 57% + 12%)	80.0	7.2
4	19	200	25	200	14	390	19	190	SS + Lead (85% + 15%)	Er_3Ni + SS (85% + 15%)	73.8	5.1
5	19	270	25	200	14	390	19	190	SS + Lead (85% + 15%)	Er_3Ni + Lead + SS (31.5% + 57% + 11.5%)	59.9	3.5
6	19	270	25	200	14	390	19	190	SS + Lead (85% + 15%)	$HoCu_2$ + Lead + SS (30% + 40% + 30%)	65.0	3.3
7	19	270	25	200	14	390	19	190	SS + Lead (85% + 15%)	$HoCu_2$ + Er_3Ni + Lead + SS (27% + 27% + 27% + 19%)	66.7	3.0
8	14	200	25	163	14	350	25	190	SS + Lead (85% + 15%)	Er_3Ni + Lead + SS (37% + 27% + 36%)	118.7	14.0
9	25	150	38	140	14	350	19	190	SS (100%)	Er_3Ni + Lead + SS (31% + 57% + 12%)	176.5	24.4
10	25	150	38	140	10	350	19	190	SS (100%)	Er_3Ni + Lead + SS (31% + 57% + 12%)	188.9	59.5
11	19	270	25	163	14	390	19	190	SS + Lead (85% + 15%)	Er_3Ni + Lead + SS (31% + 57% + 12%)	76.4	6.5
12	19	270	25	200	14	390	19	190	SS + Lead (85% + 15%)	Er_3Ni + Lead + SS (31% + 57% + 12%)	72.0	4.5
13	19	270	25	163	14	350	19	190	SS + Lead (85% + 15%)	Er_3Ni + Lead + SS (31% + 57% + 12%)	77.0	4.5
14	19	270	25	200	14	390	19	230	SS + Lead (85% + 15%)	Er_3Ni + Lead + SS (31% + 57% + 12%)	70.0	4.7
15	19	270	19	200	14	390	19	190	SS + Lead (85% + 15%)	Er_3Ni + Lead + SS (31% + 57% + 12%)	76.0	4.6

PT = Pulse tube, Reg = Regenerator, D = Diameter, L = Length, SS = Stainless Steel meshes (size 200). All dimensions are in mm.

Effect of dimensions of pulse tube and regenerators on the cold end temperatures [5]

a) First stage pulse tube. The effect of first stage pulse tube length on its cold end temperature appears to be significant. This can be seen by comparing the configurations 4and 5. Increasing the pulse tube length by 70 mm leads to a decrease in the first stage temperature from 73.8 K to 59.9 K. Comparison of the configurations 1 and 2 shows that the diameter of the first stage pulse tube also has a significant effect on its cold end temperature. A change in the pulse tube diameter from 14 mm to 19 mm has led to the decrease of first stage cold end temperature from 118.4 K to 86.3 K.

(b) First stage regenerator. The effect of the first stage regenerator length on its cold end temperature appears to be less. This can be seen by comparing the configurations 11 and 12. Although the length of the regenerator is increased by 37 mm the first stage cold end temperature drops only by 4.4 K. Comparison of configurations 12 and 15 shows that the effect of diameter of the first stage regenerator is less on its cold end temperature. A change in the regenerator diameter from 25 mm to 19 mm leads to an increase of the first stage temperature by 4 K.

(c) Second stage pulse tube. The effect of second stage pulse tube length on its cold end temperature is significant, which can be seen by comparing the configurations 11 and 13.Decrease in the pulse tube length from 390 mm to 350 mm leads to a decrease in the second stage cold end temperature from 6.5 K to 4.5 K. Similarly, the comparison of the configurations 9 and 10 shows that the diameter of the second stage pulse tube has a significant effect on its cold end temperature. Decrease of the second stage pulse tube diameter from 14 mm to 10 mm causes an increase in the second stage cold end temperature from 24.4 K to 59.5 K.

(d) Second stage regenerator. The effect of second stage regenerator length on its cold end temperature appears to be less. A comparison of the configurations 12 and 14 shows that increasing the regenerator length by 40 mm leads to a marginal increase of the cold end temperature from 4.5 K to 4.7 K. Similarly a comparison of the configurations 1 and 8 shows that the diameter of the second stage regenerator has less effect on its cold end temperature. A change in the regenerator diameter from 19 mm to 25 mm leads to an increase in the second stage cold end temperature from 13.5 K to 14 K.

III. DESIGN OF PULSE TUBES

The pulse tube is simply a thin walled, hollow cylindrical tube made up of stainless steel. The main objective of the pulse tube is to carry the heat from the cold end to the warm end by an enthalpy flow. By imposing a correct phase difference between pressure and mass flow in the pulse tube by phase shifting mechanisms, heat load is carried away from the CHX to the WHX.The dimensions of the pulse tubes have been selected from table 1.1 and standard seamless stainless tubes available in the market as per the dimensions mentioned in table1.2

Table1.2 Dimensions of Pulse tubes

Dimension	First stage	Second stage
Outer diameter	21 mm	16 mm
Inner diameter	19 mm	14 mm
Length	270 mm	390 mm
Internal volume	76.5 cm^3	17.14 cm^3
Aspect ratio*	14.2	27.8

IV. DESIGN OF REGENERATORS

The regenerator is the most important component of the apparatus. Ideally, PTC regenerators with no pressure drop and a heat exchanger effectiveness of 1 are desired, in order to achieve the maximum enthalpy flow in the pulse tube. Wire mesh screens are usually selected as the regenerator packing material, since they offer high heat transfer surface areas, low pressure drop, high heat capacity, low thermal conductivity and it is readily available in useful mesh sizes from #50 meshes (50 x 50 openings per inch) to over #250 meshes. The system uses 1000 phosphorus bronze wire meshes (#150 mesh size) and 1100 stainless steel wire meshes (#150 mesh size) as the first and second stage regenerator materials respectively.

Table1.3 Dimensions of Regenerators

Dimension	First stage	Second stage
Outer diameter	26 mm	21 mm
Inner diameter	24 mm	19 mm
Length	130 mm	150 mm
No of Screens	1000	1100
Aspect ratio*	5.4	7.8

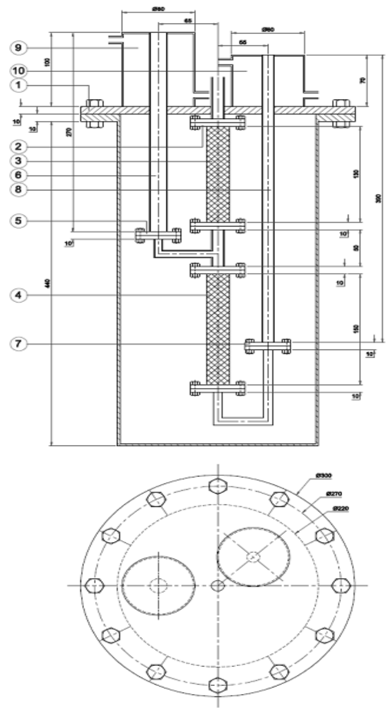

Fig.1 Assembly drawing of apparatus 1-Top Cover Plate,2-Regenerator Flange,3- First stage Regenerator,4-second stage Regenerator,5-First stage Pulse tube flange,6-First stage Pulse tube,7-Second stage Pulse tube flange,8-Second stage Pulse tube flange,9-Water jacket First stage,10-Water jacket second stage

V. REFRIGERATION POWER LOSSES

The losses of refrigeration power [6-9] result by several mechanisms such as (a) Axial conduction, (b) Regenerator ineffectiveness, (c) Pressure drop in the regenerator, (d) Radiation to Pulse tube Cold end from ambient, (e) Gas conduction in the vacuum jacket etc. Of these, the loss due to gas conduction is quite small, because of cryopumping effects at very low temperatures and can be neglected. Hence, in our analysis, only the other losses have been evaluated and taken into account. They are described briefly below. Axial conduction: The heat transfer by axial conduction is an important mechanism for the loss of refrigeration power. In a pulse tube, the axial heat conduction takes place through its walls and helium gas, while in a regenerator, this occurs through the wall, helium gas in the void volume and the matrix material filled within. Ju [7] has shown that the sinusoidal oscillations of gas flow at high pressure in the pulse tube and regenerator lead to enhanced heat conduction at a rate an order of magnitude greater than the pure gas conduction. Thus the effective heat conduction losses due to helium gas, solid wall and regenerator matrix may be of the same order of magnitude.

The conduction heat flow Q_{AC} across a small section of length dx in a medium is given by

$$Q_{AC} = k_m A_m (dT/dx) \qquad (1)$$

Here, km refers to the thermal conductivity of specific medium ,A_m is the cross section area of the medium and dT/dx is the temperature gradient across the length,dx. Knowing the experimental parameters of a given medium, the above equation is integrated to obtain the total axial conduction heat flow through the medium, incorporating the thermal conductivity integrals over the appropriate temperature range

Regenerator ineffectiveness: The function of a regenerator is to cool the incoming gas to the refrigeration temperature by periodically transferring heat from the incoming gas to the exhausting gas through an intermediate heat exchange with the regenerator matrix. Due to the non-ideal nature, in reality, the regenerator is not 100% efficient and so, the incoming gas is not cooled to the refrigeration temperature but to a temperature slightly above it and thus a loss is introduced. The loss due to ineffectiveness of the regenerator is given as[9],

$$Q_{RG}= m_{RG}\, C_P\, I_{RG}\, (T_h-T_c) \quad (2)$$

In the above equation,T_h and$T_c$are the temperatures of the hot and cold boundaries of the regenerator. Here I_{RG} refers to the regenerator inefficiency. Pressure drop in regenerator: One of the important refrigeration loss mechanisms in a cryocooler is that due to the pressure drop across the regenerators. The refrigeration loss Qpd due to pressure drop is given by Thirumaleshwar et al.[28]as,

$$Q_{pd}= (\Delta P/P_{avg})\, [(PR+1)/(PR - 1)]Qi \quad (3)$$

Here, ΔP is the average pressure drop across the regenerator and P_{avg} is the average pressure in the system, PR is the pressure ratio. For a randomly stacked spherical particle matrix, the friction factor f and ΔP are given by [9],

$$f = [(1-\Phi) / \Phi][570(1- \Phi^2)/ (\Phi Re)+3.5] \quad (4)$$ and

$$\Delta P= f\, (l_{RG}/d_s)(\, G^2/2\rho) \quad (5)$$

Here,d_s represents the average diameter of the spherical particle in the regenerator matrix and G is the mass flow rate per unit area and is given by $G =(m_c/A_{flow})$

VI. CONCLUSION

From this paper we conclude that the performance of the pulse tube wholly depends upon the geometrical parameters such as length, thickness and diameter of the pulse tube and specific heat of working fliud.also the regenerator material which is stacked inside the regenerator housing. as we increase the stage of the pulse tube we got more refrigerating power.

REFERENCES

[1] Wilson KB, Gedeon DR. Status of pulse tube cryocooler development atSun power Inc. Proceeding of the 13th international cryocooler conference. Cryocoolers 2004; 13:31–40.
[2] guyen C, Yeckley A, Culler A, et al. Hydrogen oxygen propellant densifierusing a two-stage pulse tube cryocooler. Adv Cryo Eng 2004;49(B):1703–9.U
[3] Yang LW, Thummes G. High frequency two-stage pulse tube cryocooler with base temperature below 20 K. Cryogenics 2005;45:155–9
[4] Tang K, Chen GB, Thummes G. 13 K thermal linked two stage Stirling type pulse tube cryocooler. Chinese Sci Bull 2005; 18:2046–8.
[5] S S. Kasthurirengan et al. / International Journal of Heat and Mass Transfer 52 (2009) 986–995
[6] J. Yuyama, M. Kasuya, Experimental study on refrigeration losses in pulse tube refrigerators, Cryogenics 33 (1993) 947–950.
[7] Y.L. Ju, On the heat conduction losses of Pulse tube and Regenerator at temperature range of 300–4 K, Adv. Cryog. Eng. 47 (2002) 942–949.
[8] M. Thirumaleshwar, S.V. Subramanyam, Gifford McMahon cycle – a theoretical analysis, Cryogenics 26 (1986) 177–188.
[9] P.K. Kush, M. Thirumaleshwar, Design of regenerators for a GM cycle refrigerator, Cryogenics 29 (1989) 1084–1091

