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EFFECT OF COLD CHAMBER TEMPERATURE, HOT CHAMBER TEMPERATURE AND SUPPLY VOLTAGE OF STIRLING CRYOCOOLER ON REFRIGERATION EFFECT

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Abstract: *Now a day cryocoolers of miniature and micro miniature capacity are very famous in defence as used for missile infrared night vision equipment and heat seeking infrared missile guidance systems. These infrared devices are developed with optical characteristics with very low temperature. Very low temperature as 120 K can be produced by cryocoolers. A cryocooler generally consist of a compression unit, an expansion unit and heat exchanger.In this paper analysis is made for effect of cold temperature of chamber, hot temperature chamber and supply voltage on cooling capacity of stirling cryocooler.*

Keywords: *Stirling cycle; Cryocoolers; Regenerator; Inertia force; Magnetic force; Electromagnetic force; Piston; Cooling capacity.*

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1 INTRODUCTION

Stirling cryoccoler is getting a great attention all over the world. In stirling cryocooler gas such as helium or hydrogen is used. In stirling cycle gas performs a closed cycle, during which it is, alternately compressed at ambient temperature in an expansion space. An ideal Stirling cycle consisting of two isotherms and two isochors produces refrigeration at the Carnot coefficient of performance.

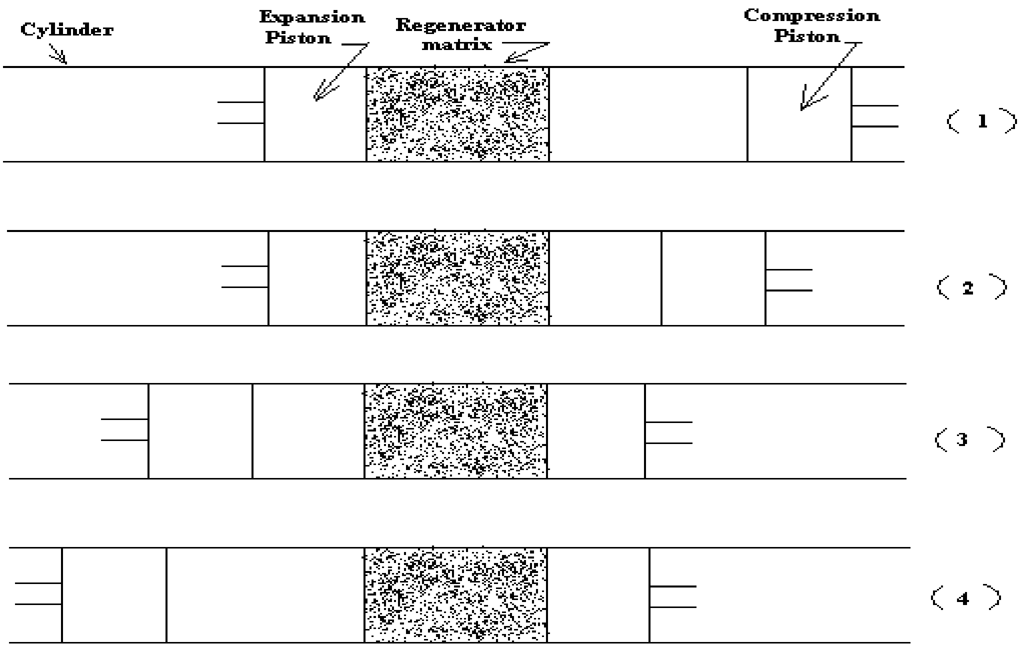

Figure 1- concept of stirling cryocooler

To understand stirling cryocoolers consider a cylinder containing two opposed pistons, with a refrigerator between them. The regenerator may be thought of as a thermodynamic sponge, alternatively absorbing heat and releasing heat. This is accomplished with a matrix of finely divided metal in the form of wires or strips. One of the two spaces between the regenerator and the pistons is called the expansion space, and is maintained at low temperature T_E. The other space is called the compression space, and is maintained at ambient temperature T_C. It is assumed that there is no thermal conduction in the longitudinal direction, then temperature gradient (T_C-T_E) across the transverse faces of the regenerator exist. The pistons are assumed to move without friction or leakage of the working fluid enclosed between them. Consider the fig: 1. [1]. In small free piston stirling cryocoolers Helium is the typical working fluid and the pressure waves that are generated by the dual- opposed pistons of the linear compressor are the driving force of the displacer in the expander. The dynamic characteristics of the linear compressor are determined not only by the forces caused by the pressure differences between the compression space and the buffer space, but also by forces of the mechanical springs and masses of the moving parts of the compressor like piston etc.[2]

2 ANALYSIS AND EQUATION

With the help of Fourier *hv/hg* can be written as:

$$hv/hg = [a_0 + a_1\text{Cos}\,\beta + a_2\text{Cos}\,2\beta + \_\_\_\_\_ a_n\text{Cos}\,n\beta] + [b_0 + b_1\text{Sin}\,\beta + b_2\text{Cos}\,2\beta + \_\_\_\_ + b_n\text{Cos}\,n\beta]$$

Normalized active height, $$\frac{hv}{hg} = a_0 + a_2\text{Cos}\,2\beta + a_4\text{Cos}\,4\beta + \_\_\_\_\_ a_{2n}\text{Cos}\,2n\beta \qquad (1)$$

$$i = [A_1\cos\beta + A_3\cos 3\beta + \ldots + A_{2n-1}\cos(2n-1)\beta] + [B_1\text{Sin}\,\beta + B_3\text{Sin}\,3\beta + \ldots + B_{2n-1}\text{Sin}(2n-1)\beta] \qquad (2)$$

$$\text{so, Pi} = \frac{E_0}{2R_T(1+R_L^{\,2})}\left[E_0 - \frac{E_S(2a_0 - a_2)}{2(hs/hg)}(\sin\phi + R_L\cos\phi)\right] \qquad (3)$$

$$\text{Po} = \frac{1}{2\pi}\int_0^{2\pi} E_M\, i\, d\beta \qquad (4)$$

$$\text{Po} = -\frac{1}{2\pi}\int_0^{2\pi} Es\frac{(hv/hg)}{(hs/hg)}\, i\,\text{Sin}\beta\, d\beta \qquad \textit{(from eq 4)}$$

$$= -\frac{1}{2\pi}\int_0^{2\pi} \text{Es}\frac{(hv/hg)}{(hs/hg)}\, i\,\text{Sin}\beta\, d\beta \qquad (5)$$

$$\text{We get, Po} = -\frac{E_S}{2\pi(hs/hg)}\left[a_0B_1 + \sum_{n=1}^{\infty}\frac{a_{2n}}{2}(B_{2n+1} - B_{2n-1})\right] \qquad (6)$$

Refrigeration effect Q_{co} is given by $Q_{co} = n\int_0^{2\pi} P_e\, dV_d$

$$Qco = -n\pi A_d.X_d\,[Z_pX_p\,\text{Sin}\theta - F_{pe}X_p\omega\cos\theta - F_{de}X_d\omega] \qquad (7)$$

The expression for work done or power input to cryocooler is given by:

$$\text{Pci} = \text{n}\int P_c dV_p = \text{n}\int(\overline{\text{P}} + Z_P x_P + Z_d x_d + F_{pc}x'_p + F_{dc}x'_d)\,dV_P$$

$$\text{Pci} = n\,\pi\,Ap\,X_p\,[Z_d\,X_d\,\text{Sin}\,\theta + F_{pc}X_p\,\omega + F_{dc}X_d\,\omega\,\cos\theta] \qquad (8)$$

$$\text{COP} = -\frac{A_dX_d[Z_pX_p\sin\theta - F_{pc}X_p\omega\cos\theta - F_{de}X_d\omega]}{A_pX_p[Z_dX_d\sin\theta + F_{pc}X_p\omega + F_{dc}X_d\omega\cos\theta]} \qquad (9)$$

Various force acting on the piston are.

Pressure force = $(Pc - \overline{P})\ Ap = Z_p\ X_p\ A_p\ \text{Cos}(\beta) + Z_d\ X_d\ A_p\ (\text{Cos}(\beta)\text{Cos}(\theta) - Z_d\ X_d\ A_p\ \text{Sin}(\beta)\text{Sin}(\theta)) - \omega F_{pc}\ X_p A_p sin\ \beta - \omega F_{dc}\ X_d A_p\ [\text{Sin}\beta Cos\theta + Cos\beta Sin\theta]$ (10)

Spring force = $K_p\ x_p = K_p\ X_p\ \text{Cos}\beta$ (11)

Electromagnetic force, $Emf = B_u E_0(\text{Cos}\,\phi + R_L \text{Sin}\,\phi)\text{Cos}\beta - B_C R_L X_p \omega \text{Cos}\beta + B_C X_p \omega \text{Sin}\,\beta + B_u E_0(R_L \text{Cos}\,\phi - \text{Sin}\,\phi)\text{Sin}\beta + B_S\ X_p \omega(\frac{S_A}{E_S}\text{Cos}\beta + \frac{S_B}{E_S}\text{Sin}\,\beta)$ (12)

now substituting these values in the balance force

$$-M_p\omega^2\ X_p\ \text{Cos}\ \beta + A_P[Z_p\ X_p\ \text{Cos}\ \beta + Z_d\ X_d \text{Cos}\ \beta \text{Cos}\ \theta - Z_d X_d \text{Sin}\ \beta \text{Sin}\theta - \omega F_{pc}\ X_p sin\ \beta - \omega F_{dc}\ X_d\ \text{Sin}\beta Cos\theta - \omega F_{dc}\ X_d\ Cos\beta Sin\theta] + K_P X_p \text{Cos}\ \beta = B_U E_0(\text{Cos}\ \phi + R_L\ \text{Sin}\ \phi)\text{Cos}\ \beta - B_C R_L X_p \omega \text{Cos}\ \beta + B_S X_p \omega(\frac{S_A}{E_S}\text{Cos}\ \beta + \frac{S_B}{E_S}\text{Sin}\beta) + B_C X_p \omega sin\beta + B_u E_o(-\text{Sin}\phi + R_L\ \text{Cos}\ \phi)\ sin\beta$$

$$X_p = \frac{B_U E_0(\sin\phi - R_L\cos\phi)}{A_p Z_d \frac{X_d}{X_P}\sin\theta + \frac{S_B}{E_S}B_S\omega + B_C\omega + F_{pc}\omega A_p + F_{dc}\omega\frac{X_d}{X_p}A_p Cos\theta} \quad (13)$$

3 RESULT AND DISSCUSSION

To study the effect of temperature of hot chamber, temperature of cold chamber and supply voltage on cooling capacity of a stirling cryocoolers a computer programme is develop. From this computer program results are taken in form of tables and then by using these tables graphs are plotted for refrigeration capacity.

Table 1 Supply voltage to linear motor

S.No.	e0	qe0
1	18	0.93771
2	19	1.03712
3	20	1.14055
4	21	1.24785
5	22	1.35887
6	23	1.47342
7	24	1.59139
8	25	1.71261
9	26	1.83692
10	27	1.96417
11	28	2.0942
12	29	2.22687
13	30	2.36203

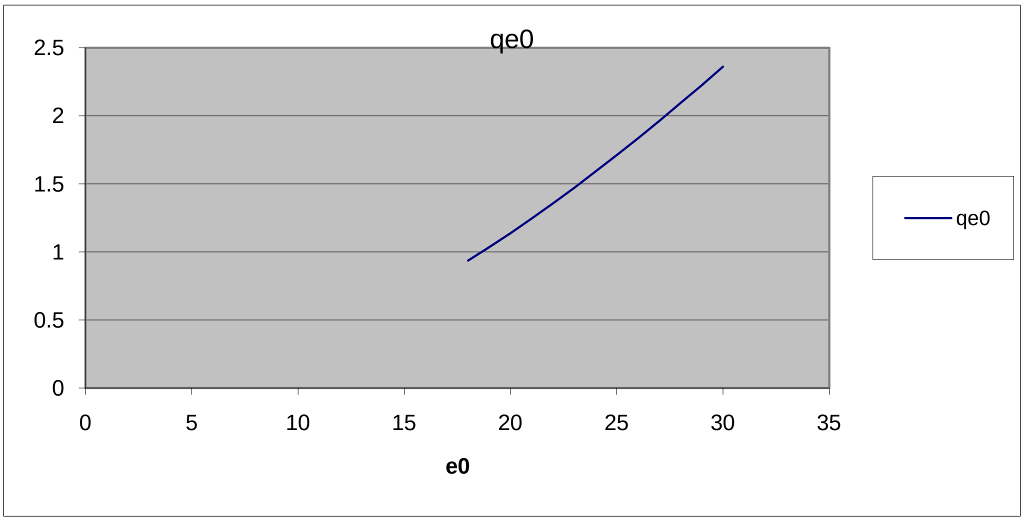

Figure 2- Refrigeration vs Supply Voltage

As clear in the plot between refrigeration (qe0) and supply voltage.(e0), if one want to increase the refrigeration effect of stirling cryocoolers the supply voltage must increases.

Table 2 cold space temperature

S.No.	**tc**	**qe0**
1	40	0.84301
2	42	0.90656
3	44	0.97141
4	46	1.03751
5	48	1.10482
6	50	1.17329
7	52	1.2429
8	54	1.3136
9	56	1.38536
10	60	1.53199
11	70	1.91557
12	80	2.32193
13	82	2.40582

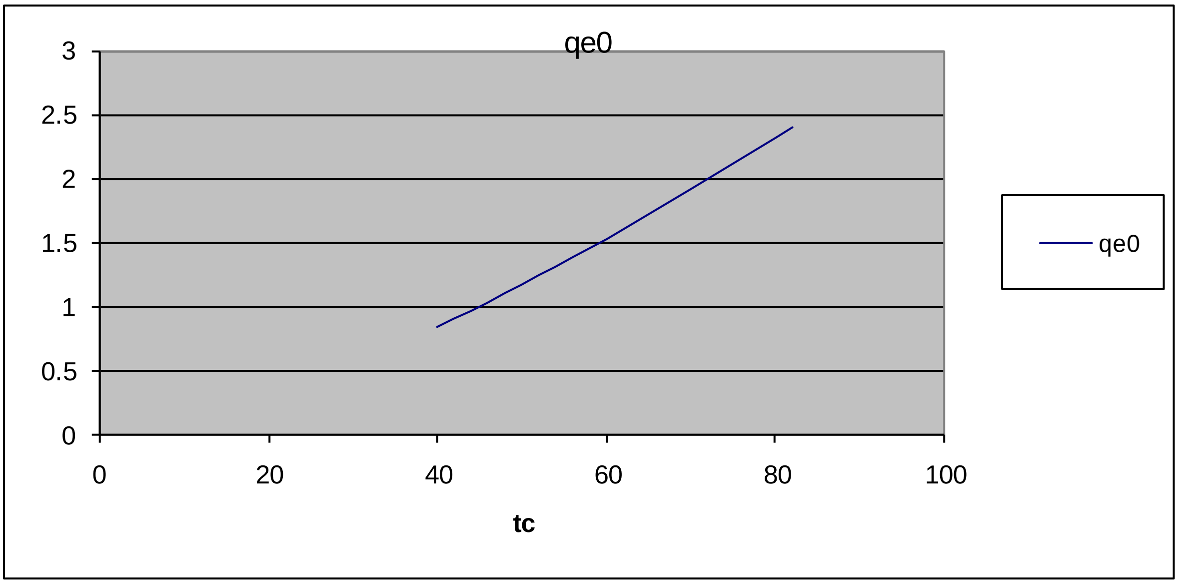

Figure 3- Refrigeration vs Cold Chamber Temperature

In plot refrigeration effect Vs cold space temperature, we can observe that with increase in temperature of cold chamber refrigeratiom effect increases and with decrese in cold chamber temperature refrigeration effect decreases.

Table 3 hot chamber temperature

S.No.	**th**	**qe0**
1	250	2.28862
2	260	2.16304
3	270	2.04857
4	280	1.94386
5	290	1.84777
6	300	1.75931
7	310	1.67766
8	315	1.63916
9	320	1.60209
10	325	1.56639
11	330	1.53199

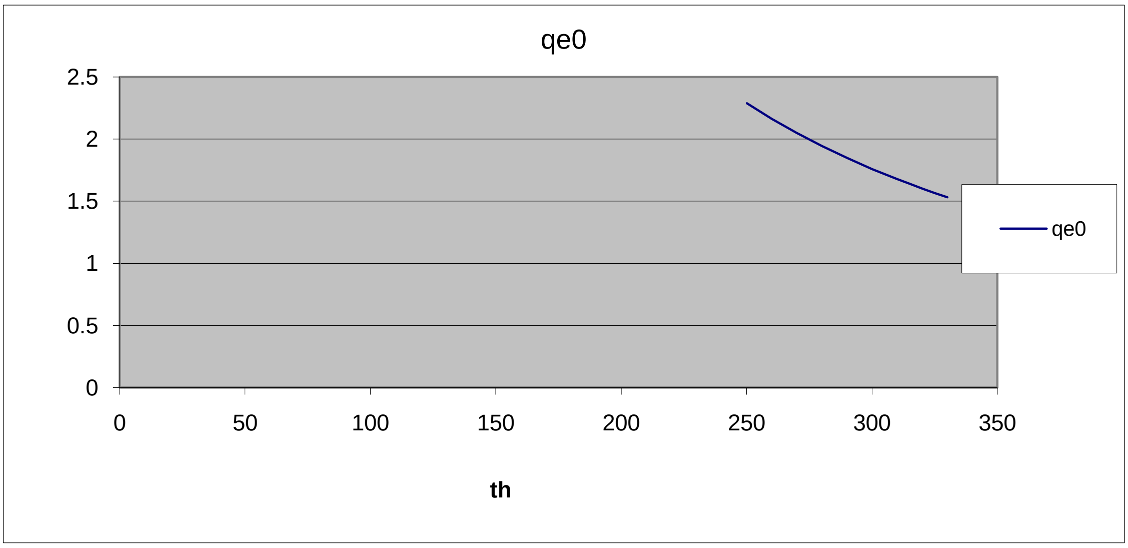

Figure 4- Refrigeration vs Hot Chamber Temperature

In plot Refrigeration effect Vs hot space temperature with increase in hot chamber temperature curves come downward. Hence we can say with increase in hot chamber temperature refrigeration effect decreses.

4 CONCLUSION

The results give a clear illustration of the effect of supply voltage, cold chamber temperature and hot chamber temperature on the refrigeration effect. It is concluded that with increase in cold space temperature refrigeration effect increases, and decreases when cold space temperature decreases. When we increase the supply voltage, the refrigeration effect of stirling cryocoolers increases, and decreses and vice versa. When one increases the hot chamber temperature the refrigeration effect decreses.They also show how much significant supply voltage, cold chamber temperature and hot chamber temperature becomes when we require cooling effect.

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