EFFECT OF MASS OF PISTON AND STIFFNESS OF SPRING ON REFRIGERATION AND COEFFICIENT OF PERFORMANCE OF STIRLING CRYOCOOLER

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ABSTRACT

With very fast change in science and technology the low temperature environment become very famous in defenses and night vision. To make these applications possible Stirling cryocoolers is used. These are smaller machines of miniature and micro miniature capacity and developed in field applications required of miniature electrical or thermal power input to obviate the need for liquid cryogens. The analysis is done to study the effect of mass of piston and stiffness of spring on refrigeration and coefficient of performance of Stirling cryocoolers.

Keywords: Crycooler, Displacer, Expansion, Spring Stiffness, Stirling.

I. INTRODUCTION

From last several decades the rapidly extending use of very low temperatures in research and high technology and the concurrent high degree of activity in cryogenic engineering have mutually supported each other, each improvement in refrigeration technique makes possible wider opportunities for research and each new scientific discovery creating a need for a refrigerator with special features. The science and technology of producing a low temperate environment is generally known as cryogenics. The word cryogenics is made up of two Greek words “cryo” means frost or cold and “gen’ means to generate. Strictly speaking cryogenics means to produce cold but today the word cryogenics is associated with production and study of low temperature environment. Over the years the word cryogenics has developed many common usages. A cryogenic fluid is one used in the production of the cold and cryogenic machinery is the hardware used in achieving the low temperature environment. A cryocooler is a device or producing refrigeration at temperatures less than 120. The cryocooler was intended for the cooling of the detectors, lasers and electronic equipments with a special feature that compression and expansion take place in separate chamber but in same engine cylinder. Both the compartments are connected with a thin tube. The machine is hermetically sealed. The piston is driven by a linear motor and free displacer is driven by pressure wave produced in bounce space. The quality or worth of a unit of such refrigeration depends on the temperature at which the refrigeration is available [1]. This paper is organized as follows. The working principle of stirling cryocooler is explained in the Section II. In section III, the analysis based on equation is done and the discussion based on the result is presented in the Section IV. Conclusion is done in Section V.

II. WORKING PRINCIPLE

The Stirling cycle cooler is a free piston, linear motor driven device. The internal running surfaces are supported by gas bearing, so no contact wear takes place. The entire unit is hermetically sealed. It is capable of continuous modulation and of maintaining high efficiencies down to very low lifts. This means that it adapts easily to cooling needs and keeps performing with high efficiency even at low demand. The Stirling cycle has been utilized for cryocoolers with notable success. A gas such as hydrogen or helium is used in this type of Stirling cryogenic range. The gas performs a closed cycle, during which it is, alternately compressed at ambient temperature in an expansion space[8].An ideal Stirling cycle consisting of two isotherms and two isochors produces refrigeration at the Carnot coefficient of performance. Despite this high ideal performance, actual refrigerators, which approximate the Stirling cycle, must be carefully designed to obtain satisfactory performance in a cryocooler of reasonable size per unit capacity.

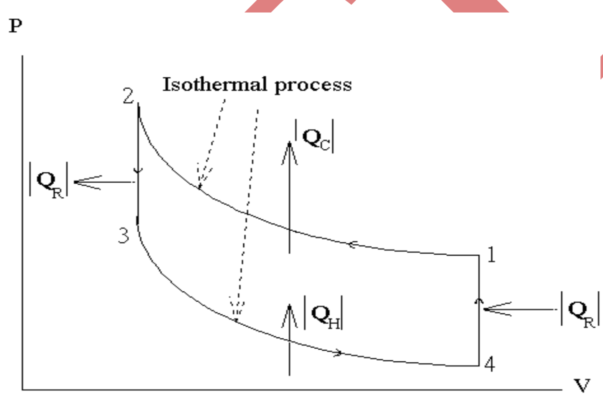

Fig 1 Stirling cycle

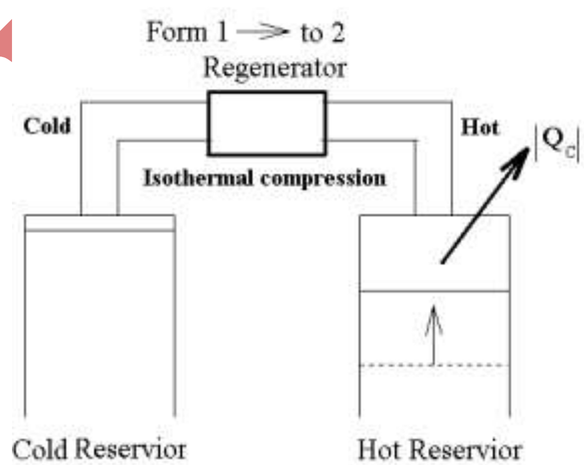

Fig 2 Isothermal Compression

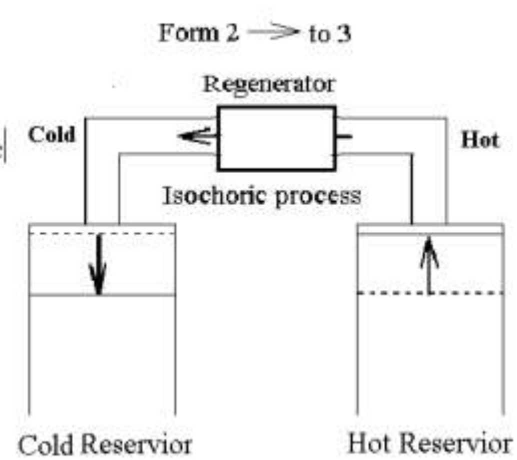

Fig 3 Isochoric Process

Process 1→2 is an isothermal process, the piston in contact with hot reservoir is compressed isothermally, hence heat |*Q*C| has been rejected, and (isothermal compression → d*U* = 0, W is positive and *Q*C is negative) the heat rejected is

$$Q_h = \int_{V_1}^{V_2} PdV = nRT_h \ \ln\frac{V_2}{V_1}$$

2 → 3 It is an isochoric process, the left piston moves down while the right piston moves up. The volume of system is kept constant, thus no work has been done by the system, but heat *Q*R has been output to regenerator which causes temperature to decrease to Tc.

3 → 4 It is an isothermal expansion process, the left piston in contact with cold reservoir expanded isothermally at temperature Tc. Therefore

$$Q_C = \int_{V_3}^{V_4} PdV = nR\ T_C \ \ln\frac{V_4}{V_3}$$

4 → 1 It is an isochoric process which is a reversed process of 2 → 3, but temperature changes from T_c to T_h.

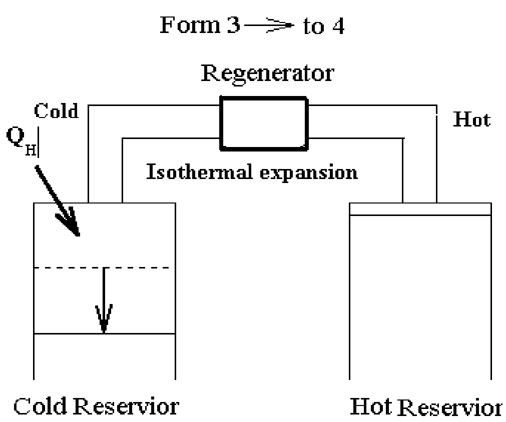

Fig 4 Isothermal Expansion

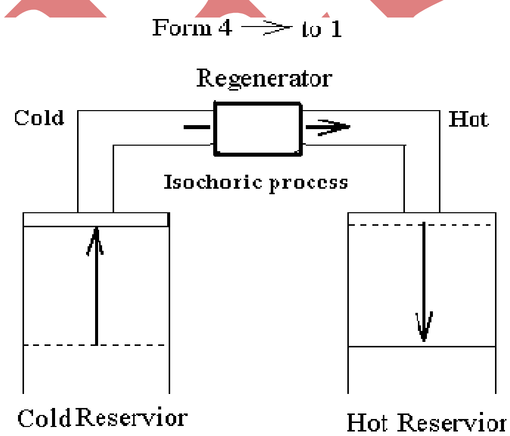

Fig 5 Isochoric Process

Assume that the compression space piston is at the outer dead point, and the expansion space piston is at the inner dead point, close to the face of the regenerator. All the working fluid is then in the compression space at ambient temperature. The volume is a maximum, and the pressure and temperature are represented by (1) on the P-V and T-S diagram as shown by the following Fig: 2

III. ANALYSIS AND EQUATIONS

The analysis for the following parameters will be carried out for the in–series double coil linear motor [12]:

1 Active wire length ad active coil height

2 Normalised active height of the coil (*hv*/*hg*)

3 Current

4 Power expressions

i) Input power

ii) Output power

iii) Efficiency

These parameters have been derived with the help of following expressions [10],[11]:

With the help of Fourier Series Normalised coil height can be written as:

$h_v/h_g = a_0 + a_2 \text{ Cos } 2\beta + a_4 \text{ Cos } 4\beta + \_\_\ \_\_ a_{2n} \text{ Cos } 2n\beta$

Current:; $i = [A1\cos\beta + A3\cos 3\beta + \ldots\ldots + A2n{-}1\cos(2n-1)\beta] + [B1\text{Sin}\,\beta + B3\text{Sin}\,3\beta + \ldots\ldots + B2n{-}1\ \text{Sin}(2n-1)\,\beta]$

Normalized active height of the coil is $\frac{hv}{hg} = a_0 + a_2 \text{ Cos } 2\beta + a_4 \text{ Cos } 4\beta + \_\_\_\_\_ a_{2n} \text{ Cos } 2n\beta$

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

Output power $Po = -\frac{E_S}{2\pi(hs/hg)}\left[a_0 B_1 + \sum_{n=1}^{\infty}\frac{a_{2n}}{2}(B_{2n+1} - B_{2n-1})\right]$

Work done on cryocoolers, $Pci = n\pi Ap\, X_p\, [Z_d\, X_d \text{ Sin } \theta + F_{pc} X_p\, \omega + F_{dc} X_d\, \omega \cos\theta]$

Coeffficient of performance, $COP = -\frac{A_d X_d[Z_p X_p \sin\theta - F_{pc} X_p \omega\cos\theta - F_{de} X_d \omega]}{A_p X_p[Z_d X_d \sin\theta + F_{pc} X_p \omega + F_{dc} X_d \omega\cos\theta]}$

IV. RESULTS AND DISCUSSIONS

After analysis of free piston free displacer stirling cryocooler with flow losses, a computer program is develop. From computer program results are taken in form of tables. With help of these table graphs are plotted for refrigeration capacity and COP.

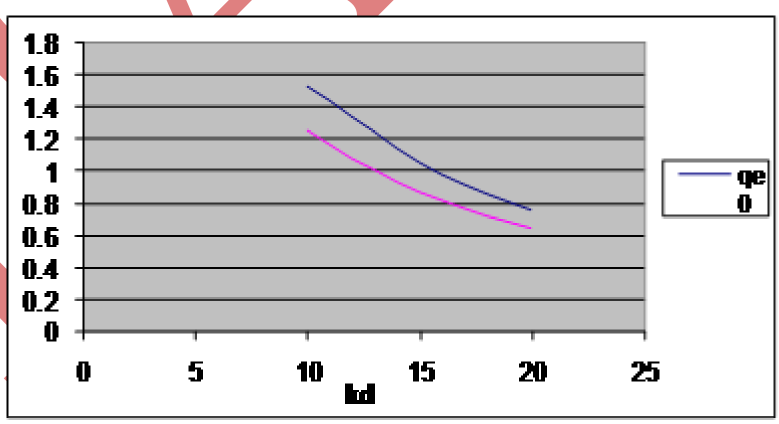

Fig 6 Refrigeration Effect Vs Siffness of Spring on Displacer Side

In the plot between refrigeration effect and stiffness of spring on displacer side, we observe that increasing stiffness of spring two curves come close to each other i.e. flow losses decreases and in the plot COP Vs Stiffness of spring on displacer side with increase in spring stiffness flow losses decreases. Hence we can say with increase in spring stiffness flow losses decreases.

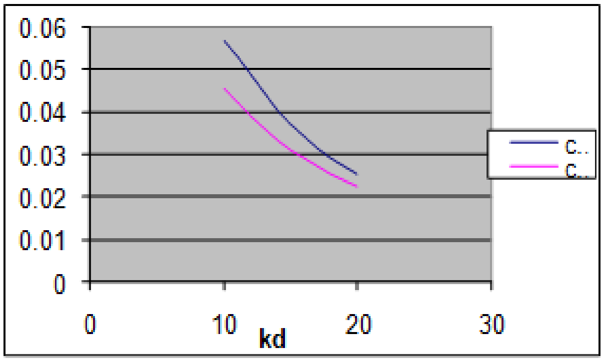

Fig 7 Coefficient of Performance Vs Stiffness of Spring On Displacer Side

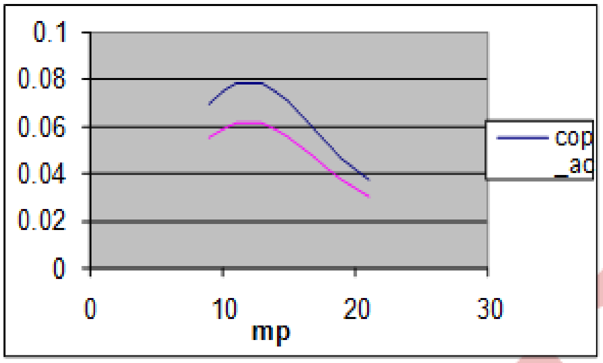

Fig 8 Coefficient of Performance Vs Mass Of Piston

In plot Coefficient of performance Vs mass of piston, when the mass of piston increases curves go away from each other. For the value of mass of piston 13 the diversion of curves are maximum and after that curves come closer to each other. Hence we can say with the increase in mass of piston flow losses increases for some value and then goes on decreases. In plot Refrigeration effect Vs mass of piston, when the mass of piston increases curves go away for some value of mass of piston and then come closer to each other. Hence we can say with increase in mass of piston flow losses first increases for some value and then decreases.

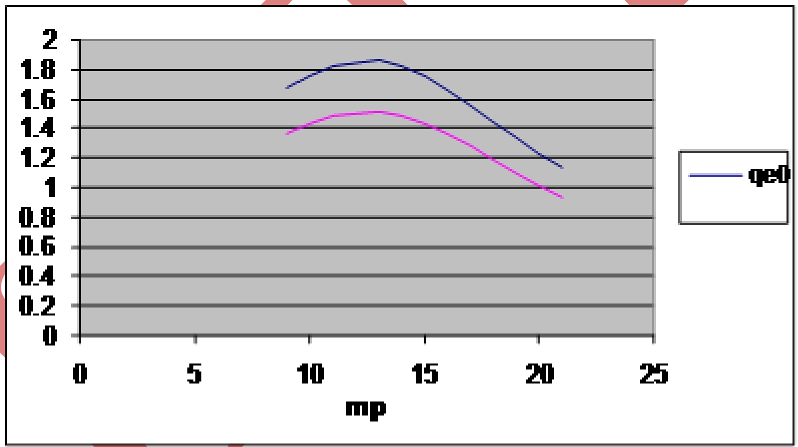

Fig 9 Refrigeration effect Vs mass of piston

V. CONCLUSION

From the above discussed graphs in result and discussion, we can conclude that with increase in stiffness of spring on displacer side flow losses decreases in graph COP and Refrigeration Vs stiffness of spring displacer side. Flow losses first increases then decreases in graph COP and Refrigeration Vs mass of piston mp when mass of piston increases. With increase in stiffness of spring on piston side flow losses increases in graph COP and Refrigeration Vs stiffness of spring on piston side.

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