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# LOW FREQUENCY SPLIT CYCLE CRYOCOOLER

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A split cycle Stirling cryocooler with two different drive motors and operating at a low drive frequency can have high thermodynamic efficiency. The temperature of the cold end of the cryocooler varies with drive frequency, voltage of the input electrical power and initial charge pressure values. The cryocooler operating at 8 Hz can provide 7 watts of refrigeration at 77 K for 230 watts of electrical input power.

Key Words: High efficiency; low power; Stirling cryocooler.

## 1. Introduction

Cryocoolers for infrared detectors must have high efficiency, small size and weight, low vibrational levels, high reliability, rapid cool-down and simple operation. If they are to be used in satellites, long unattended lifetime is also of great importance [1]. These requirements, generally speaking, can be satisfied by the Stirling cycle, and improvements in the operation of Stirling coolers have been reported in recent years [2]. In the case of direct crankshaft drive, it is not always possible to obtain ideal dynamic balance and the resulting vibrations may effect the performance of the infrared elements. For this reason, the split cycle was developed. However, the net refrigeration of the split cycle, either driven pneumatically or by a linear motor, is small. In order to get more refrigeration without sacrificing efficiency, we have tested a low frequency split cycle cryocooler which give 7 watts of refrigeration at 77 K for an input power of 230 watts.

## 2. Description

The prototype cryocooler consisted of two parts, a compressor unit and a displacer unit, which are connected by a small diameter tube 30 cm long. Figure 1 shows a sketch of the cryocooler. The compressor unit is a modified Stirling refrigerator driven by a small DC motor so that its speed can be easily controlled. The displacer unit is driven by a separate DC linear motor. The cold displacer is made of stainless steel. The case of the displacer is made of epoxy glass fibre in which a stainless steel net matrix is embedded. The phase angle between the compressor piston and the displacer is controlled by an electronic system. The consumption of power for the DC linear motor is less than 10 watts. Using two DC motors with respective voltage, control devices and the electronic system, it is possible to conveniently and individually control and adjust the speed of the compressor, the stroke of the displacer and the phase angle between the compressor piston and the displacer.

## 3. Results

It is well known that the performance of the cryocooler is dependent on the charge pressure, the speed of the motor, displacer stroke and compressor stroke, when the diameters of the compressor and displacer are given. Because the compressor and displacer are separated and driven by different DC motors, the speed of the compressor and the displacer stroke can be individually adjusted and controlled [3]. Hence there is an extra parameter - input voltage - added to the performance of the cryocooler [4].

### 3.1 Influence of Input Voltage to Linear Motor

During operation when the input voltage to the linear motor is varied, the stroke of the displacer is changed, and the performance of the cryocooler is varied. Figure 2 shows the variation in the performance of the cryocooler. As the input voltage increases, the stroke of the displacer increases rapidly. For input voltages greater than 18 V, the stroke is almost constant (curve Z). The temperature of the cold end is almost constant until the input voltage is over 27 V, when the temperature of the cold end slightly increases (curve $T_c - V_d$). The curve $N_d$ shows variation of input power of the linear motor with $V_d$.

### 3.2 Influence of the Speed of the Cryocooler

It is well known that the performance of the cryocooler is dependent on speed for a constant charge pressure. Figure 3 shows the variation of the temperature of the cold end and of the stroke of the displacer with the speed of the cryocooler. The $T_{min}$ of the cold end is obtained at a speed of 480 RPM. The stroke of the displacer also varies with speed. The curve illustrates that if the operation of the cryocooler deviates from optimum, the losses increase rapidly.

### 3.3 Influence of Charge Pressure

The cryocooler was operated with charge pressures ranging from 3.92 bar to 7.84 bar. Figure 4 shows that the temperature of the cold end varied with charge pressure which can be explained by the change in the stroke of the displacer as the charge pressure is varied.

### 3.4 Exergy Efficiency

This cryocooler has been tested at about 8 Hz. With the input voltage to the linear motor of 18 V and charge pressure is 7.84 bar, the minimum temperature of cold end is about 34 K. The cooling time from ambient temperature to $T_{min}$ is about 20 minutes. The exergy efficiency of the cryocooler $\eta_e$ is computed as follows [5]:

$$\eta_e = \frac{Q_c}{N_{tot}} \left( \frac{T_a}{T_c} - 1 \right). \tag{1}$$

where $Q_c$ - - net refrigeration (W), $T_a$ - - ambient temperature (K),
$N_{tot}$ - - total consumed power (W), and $T_c$ - - temperature of cold end (K).

It is rather satisfactory that a small cryocooler showed an exergy efficiency of 8.8%. Table 1 shows the exergy efficiency of different Stirling cycle cryocoolers.

Table 1. Exergy Efficiency of Different Stirling Cryocooler

| Type | Refrigeration (Watt) | Consumed Power (Watt) | Exergy Efficiency (%) |
|---|---|---|---|
| Rhombic driven | 0.3 (64 K - 70 K)<br>1.5 (135 K - 150 K) | 30 | 3.68 - 3.26%<br>6.11 - 5.0% |
| Pneumatically driven | 0.87 (73 K) | 48 | 5.6% |
| Entirely electromagnetically driven[6] | 0.5 (80 K) | 30 | 4.6% |
| Prototype | 7 (77 K) | 230 | 8.8% |

## 4. Conclusions

The prototype cryocooler showed that a single stage Stirling cooler with a two drive system and phase angle control can be operated with satisfactory results. It is possible to develop this drive system for larger systems and to minimize size and height.

## 5. Acknowledgment

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## 6. References

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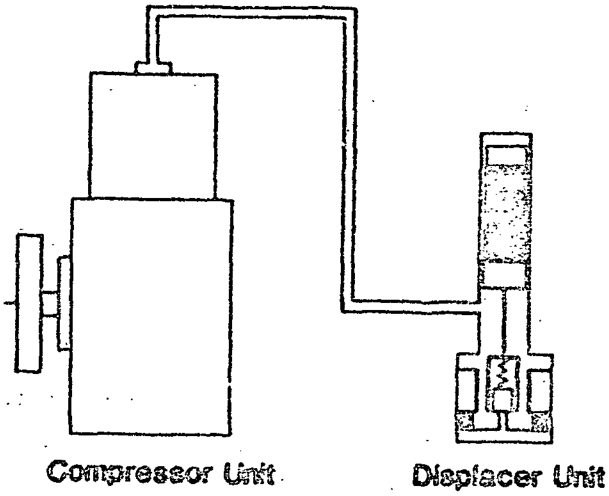

Figure 1. Sketch of the cryocooler.

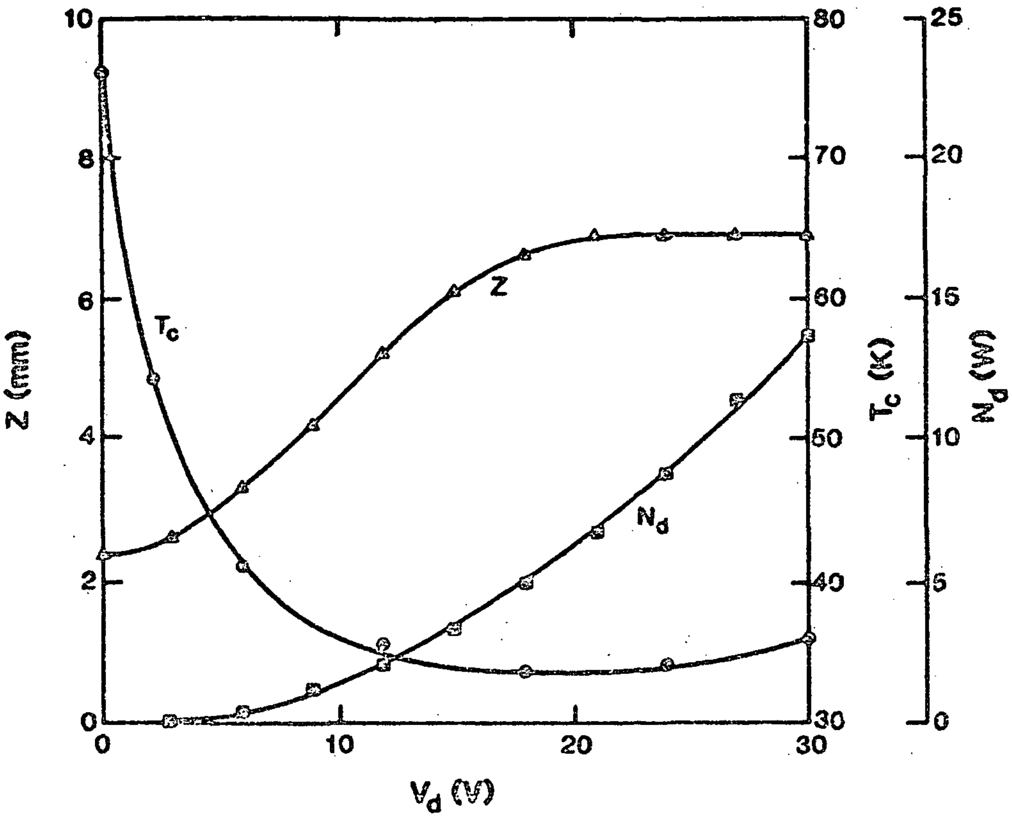

Figure 2. The performance of the crycooler as a function of voltage of linear motor (n = 420 rpm, $p_{av}$ = 8 kg/cm$^2$).

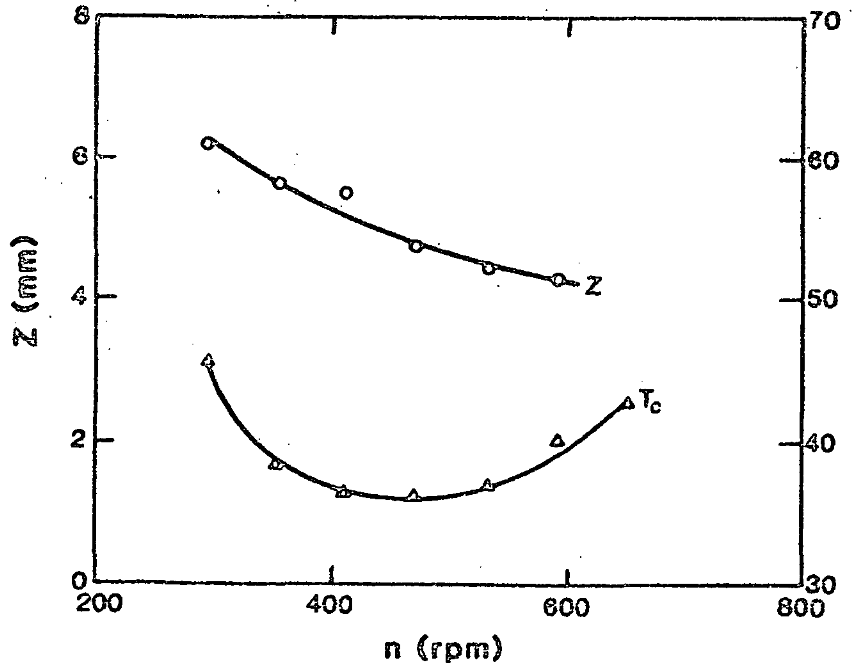

Figure 3. Temperature of the cold end $T_c$ and stroke of the displacer Z as function of speed, ($p_{av}$ = 8 kg/cm$^2$, $V_d$ = 12 V).

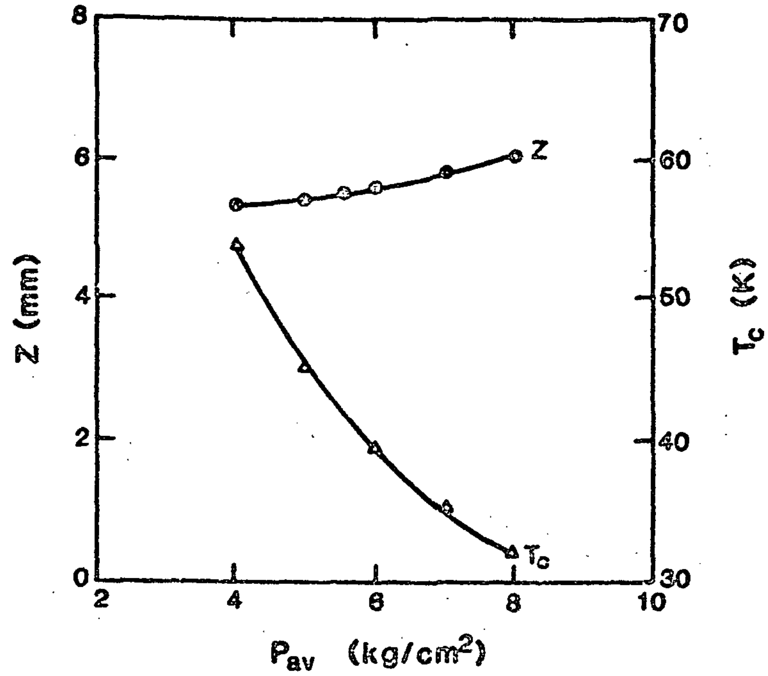

Figure 4. Temperature of the cold end $T_c$ and stroke of the displacer Z as function of charge pressure $P_{av}$ (n = 540 rpm, $V_d$ = 27 V).