CONSIDERATIONS IN SELECTING A THERMOELECTRIC HEAT PUMP

Depending on the direction and amount of current, thermoelectric heat pumps have the ability to cool, heat, or stabilize the temperature of devices. The most publicized operating condition is the cooling mode; however, heating mode and temperature stabilization capabilities should not be overlooked when considering the use of heat pumps.

By applying the correct amount of current at the desired polarity, the temperature of a device can be stabilized as the ambient temperature oscillates. "Fine tuning" temperature stability depends on the quality of the temperature controller. The more sophisticated the temperature controller the more constant the temperature. Tolerances of ± 0.1 to ± 0.3°C at a stabilized temperature are reasonable. A major feature of a thermoelectric heat pump is the ability to stabilize device temperatures when the ambient temperature is within approximately + 5°C of the desired control temperature. A conventional heater has the ability to heat a device above the ambient temperature but does not have positive action capability when the ambient exceeds the control capability. Separate heating and cooling systems are eliminated by using a thermoelectric heat pump.

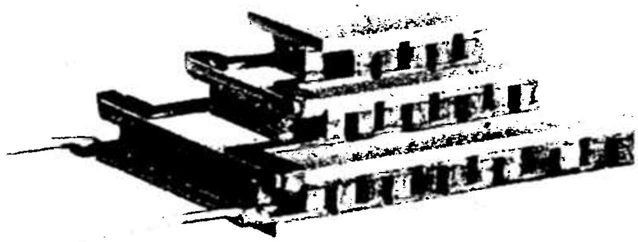
Thermoelectric heat pumps have a fast thermal response. The single- or multi-stage heat pumps will achieve the maximum cold side temperature within 60 seconds after power is applied. This response time occurs when there is no added mass on the cold side and the hot side is attached to a good heat sink. As the mass of a device is added to the cold surface the time to reach maximum temperature will be increased. The amount of increase will depend on the mass of the device.

For heating, less current is required to achieve a given temperature differential than when cooling. Due to the fast response time, care should be taken not to reverse current to the heat pumps until the amount of current necessary to achieve a specified temperature differential in the heating mode is defined. When the required amount of current has been defined, the current can be switched from cooling to heating as desired.

The basic operating characteristics of a thermoelectric heat pump include the cold and hot side temperature, heat pumping capacity at the cold side, heat dissipated at the hot side, input current, and voltage. The acceptable range of each of these characteristics are usually known before selecting a specific heat pump. Generally there are several heat pumps that have characteristics in the desired range. The best suited heat pump will depend on the application. Considerations in the final selection are cost, reliability, maximum heat pumping or maximum COP.

The first consideration is to determine the number of stages required to obtain the desired temperature differential. A single-stage heat pump is defined as a group of n- and p-type semiconductor materials connected electrically in series and thermally in parallel as shown in Figure 2a. The heat load generally determines the lowest cold side temperature that a heat pump will attain. However, even with zero heat load regardless of the amount of power applied, every heat pump has a theoretical maximum cold temperature. For example, the coldest temperature that can be reached from a hot side temperature of 27°C (300°K) is approximately −47°C (226°K) for a single-stage heat pump. This is determined by the basic parameters of the thermoelectric material. For colder temperatures multi-stage heat pumps must be used. A multi-stage heat pump as shown in Figure 2b is essentially several single-stage heat pumps stacked in a vertical array. Typically a multi-stage heat pump is pyramid shaped because the lower stage must pump the heat dissipated by the upper stages in addition to the active heat load. Therefore there are usually more thermoelements in the lower stage than the upper stage.

(a) Single-Stage

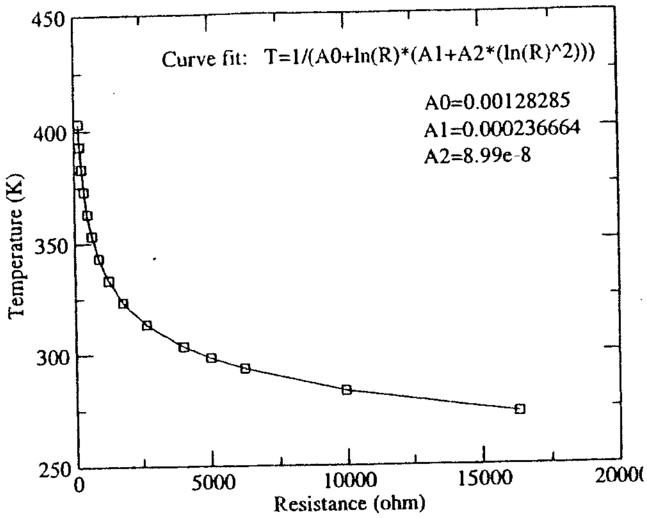


(b) Multi-Stage

FIGURE 2 Single- and Multi-Stage Heat Pumps

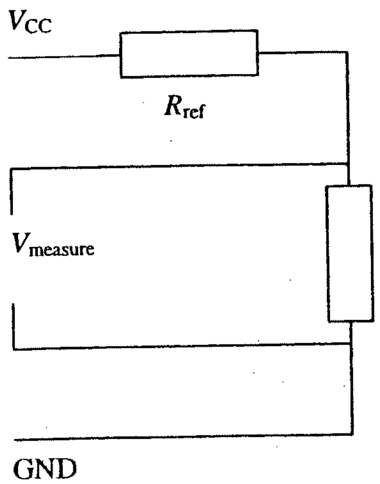
Temperature sensor:

Thermistor, Type ACC-003 (ELFA)..



Temperature (°C)	Temperature (K)	Resistance (Ω)
0	273.15	16325
10	283.15	9950
20	293.15	6245
25	298.15	5000
30	303.15	4028.5
40	313.15	2663.3
50	323.15	1801.5
60	333.15	1244
70	343.15	876
80	353.15	627.5
90	363.15	457.7
100	373.15	339.2
110	383.15	255.2
120	393.15	194.7
130	403.15	150.5

4-wire temperature measurement: The exitation current is passed through separate wires to avoid voltage drop in the wires used for measuring the signal. Voltage across thermistor measured using a 16 bit DAQ card (NI 6036E) in differential mode. Excitation current provided by external voltage source ($V_{CC} \approx 5$ V) with large resistor in series ($R_{ref} = 1.5984$ MΩ).



$V_{CC} = 5.0717$ V
$R_{ref} = 1.598400$ MΩ

$$I = \frac{V_{CC} - V_{measure}}{R_{ref}}$$

$$R_{thermistor} = \frac{V_{measure}}{I}$$

$$T = \frac{1}{A0 + \ln R_{thermistor}\left(A1 + A2\left(\ln R_{thermistor}{}^{2}\right)\right)}$$

$(\ln R_{thermistor})^2$

THEORY OF THERMOELECTRIC HEAT PUMPS

Figure 1 is a diagram of a thermoelectric heat pump consisting of an n- and p-type semiconductor material. In the cooling mode, dc current passes from the n- to the p-type semiconductor material. The temperature T_c, of the interconnecting tab decreases and heat is absorbed from the surroundings. This heat absorption (cooling) occurs because electrons pass from a low energy level in the p-type material thru the tab to a higher energy level in the n-type material. This heat is conducted through the semiconductor materials by electron transport to the other end of the junction, T_h, and liberated as the electrons return to a lower energy level in the p-type material. The product of the thermoelectric power, S, and the absolute temperature, T_c, is the Peltier coefficient, ST_c. The Peltier coefficient relates to a cooling effect as current passes from the n-type material to the p-type material, and a heating effect when passing from the p-type material to an n-type material as shown in Figure 1 a & b.

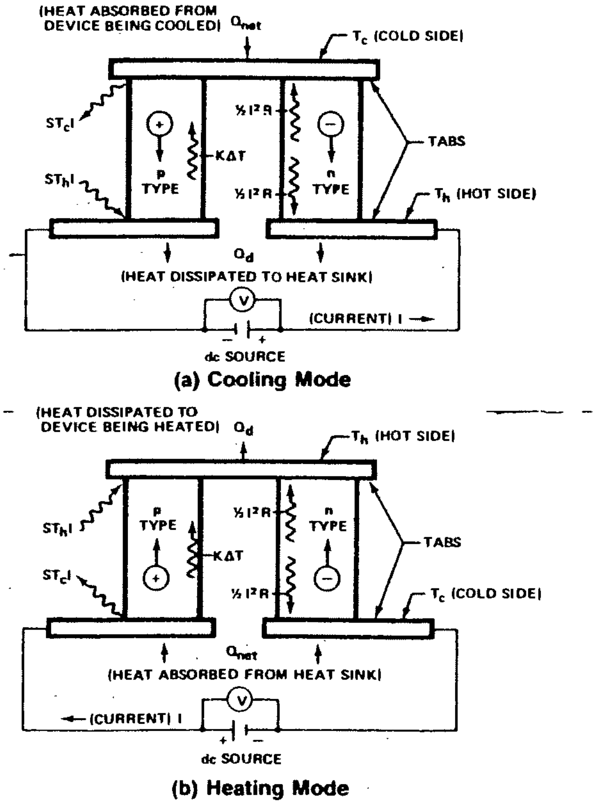


FIGURE 1 Diagram of a Thermoelectric Heat Pump

Ideally, the amount of heat absorbed at the cold side is dependent on the product of the Peltier coefficient, ST_c, and the current, I. This product, Q_p, is the first term in equation (1). Practically, the heat absorbed at T_c, from the surroundings is reduced by two sources. One is Joule heat, Q_j, and the other is conducted heat, Q_c. Joule heat is generated internally in the thermoelements as current passes through the semiconductor materials. One-half of this heat is transmitted to the cold end and one-half to the hot end. Conducted heat is transmitted from the hot end to the cold end by thermal conduction.

The net amount of heat, Q_{net}, that can be absorbed at the cold side, T_c, in Figure 1a, is shown in equation (1).

(1) $$Q_{net} = Q_p - Q_j - Q_c = ST_cI - \tfrac{1}{2}I^2R - K(T_h - T_c)$$

In the above equation, S is the sum of the thermoelectric power of each semiconductor material, R is the total electrical resistance of the heat pump, and K is the total thermal conductance.

The net heat dissipated at the hot side, T_h, is the sum of the Peltier heat, plus one-half of the Joule heat, minus the thermally conducted heat. The resulting steady-state equation at the hot side, T_h, is given by:

(2) $$Q_d = ST_hI + \tfrac{1}{2} I^2R - K(T_h - T_c)$$

The required input electrical power, P, is the difference between the amount of heat dissipated at the hot side and the net amount of heat absorbed at the cold side. Effectively, this is the sum of the emf's or Seebeck effects from the temperature difference between the hot and cold sides, and the total Joule heating as shown in equation (3)

(3) $$P = Q_d - Q_{net} = S(T_h - T_c)\,I + I^2R$$

Two basic designs for thermoelectric heat pumps are (a) operation at maximum heat pumping, and (b) operation at maximum Coefficient of Performance (COP).

The current for maximum heat pumping is obtained by using the differential operator $dQ_{net}/dI = O$ and then determining algebraically that:

(4) $$I_{max} = \frac{ST_c}{R}$$

The maximum temperature differential that can be achieved for a single-stage heat pump can be determined by inserting I_{max} of equation (4) into equation (1) and solving for ΔT_{max} when $Q_{net} = 0$.

(5) $$\Delta T_{max} = (T_h - T_c)_{max} = \tfrac{1}{2} ZT_c^2$$

The Z term in equation (5) is called the Figure of Merit and is the result of combining the S, R, and K terms.

(6) $$Z = \frac{S^2}{RK} = \text{Figure of Merit}$$

The Figure of Merit is important because it is dependent upon the properties of the thermoelectric material.

The voltage for the heat pump is the sum of the Seebeck voltage and the voltage from the resistance of the semiconductor materials. It is obtained by solving for $V = P/I$, where P is defined in equation (3).

(7) $$V = S(T_h - T_c) + IR$$

The COP for the heat pump is equal to the net heat pumped divided by the input electrical power, P.

(8) $$COP = \frac{Q_{net}}{P} = \frac{ST_cI - \tfrac{1}{2}I^2R - K(T_h - T_c)}{S(T_h - T_c)\,I + I^2R}$$

By differentiating the COP with respect to the current, the current for maximum COP is defined to be:

(9) $$I_{COP} = \frac{K(T_h - T_c)}{\tfrac{1}{2} S(T_h + T_c)}\left[\sqrt{1 + \tfrac{1}{2} Z (T_h + T_c)} + 1\right]$$

Inserting the current for maximum COP of equation (9) into equation (8), the maximum COP obtainable is:

(10) $$COP_{max} = \frac{T_c}{T_h - T_c} \cdot \frac{\sqrt{1 + \tfrac{1}{2} Z (T_h + T_c)} - T_h/T_c}{\sqrt{1 + \tfrac{1}{2} Z (T_h + T_c)} + 1}$$

These equations may be used for the preliminary design of a thermoelectric heat pump.