International Journal of Scientific Research & Engineering Trends
Volume 7, Issue 5, Sept-Oct-2021, ISSN (Online): 2395-566X

Performance and Selection of Thermoelectric Module for Given Temperature Range

Prajyot Chavan, Azeem Peerjade, Shahid Jamadar, Sushant Sutar, Asst. Prof. Dipak Patil
Department of Mechanical Engineering,
Savitribai Phule Pune University, Pune, India.
prajyot.chavan.me@ghrcem.raisoni.net, azeempasha,peerjade.me@ghrcem.raisoni.net, shahid.jamadar.me@ghrcem.raisoni.net, sushant.sutar.me@ghrcem.raisoni.net, dipak.patil@raisoni.net

***Abstract*-Experimental investigations on several commercially available TEC and TEG are conducted in industries to evaluate performance trends. Experimental setups are analyzed and the parameters determining the performance and working of thermoelectric modules. It is found that how we use thermoelectric modules with different application in industrial sector with different works. Finally, the thermoelectric module has much more applications and in the paper work also shows analysis for easily used in engineering sector.**

***Keywords*-Thermoelectric Module, Performance, Efiiciency, Selection**

I. INTRODUCTION

Refrigeration is defined as the process of heat-removal from an area so as to bring it to a lower temperature than surrounding temperature. during this context, my seminar topic, "Peltier cooling module" which works on thermoelectric refrigeration, aims to supply cooling by using thermoelectric effects instead of the more prevalent conventional methods such as 'vapour compression cycle' or the 'vapour absorption cycle'.

There are three sorts of thermoelectric effect:
- The Seebeck effect,
- The Peltier effect,
- The Thomson effect.

Among these three effects, TE cooler works on the Peltier effect; which states that when voltage is applied across two junctions of dissimilar electrical conductors, absorption of heat takes place at one junction and rejection of heat at the other junction. Peltier coolers are usually used as a cooling element in laser diodes, CCD cameras (charge coupled device), blood analyzers, portable picnic coolers laser diodes, microprocessors etc.

1. Thermoelectric Effect:

The thermoelectric effect applies to the direct conversion of temperature differences to electric voltage and the other way around. A thermoelectric device creates voltage when there's a special temperature on each side. Conversely, when a voltage is applied thereto, it creates a temperature difference. As observed at atomic scale, an applied gradient is responsible for charge carriers within the material to diffuse from the recent side to the cold side. The phenonmenon "thermoelectric effect" is further categorized into three separately identified effects: the Seebeck effect, Peltier effect, and Thomson effect.

2. The Peltier Effect:

Peltier discovered that there was a diverse phenomenon to the Seebeck Effect, whereby thermal energy might be absorbed at one dissimilar metal junction and rejected at the opposite junction when an electrical current flowed within the loop.

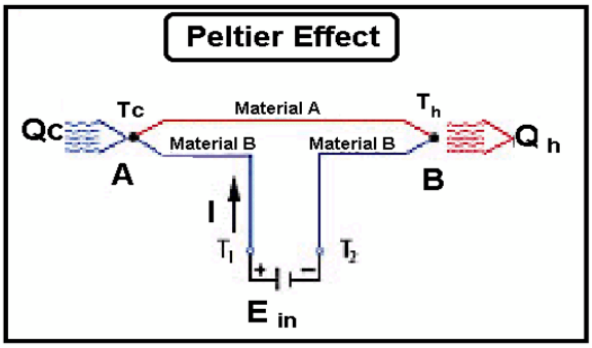

Fig 1. Peltier Effect.

In Figure above, the circuit is constructed such that a special configuration is achieved that illustrates the Peltier Effect, a phenomenon opposite that of the Seebeck Effect. With application of a voltage (Ein) to terminals T1 and T2, an electrical current (I) will flow within the circuit. As effect of these 3 the present flow, a small cooling effect (QC) will occur at thermocouple A (where heat is absorbed), and a heating effect (QH) will occur at junction B (where heat is expelled). Remember that this effect could also be reversed by changing the direction of electrical current flow which will reverse the direction of heat flow.

3. The Seebeck Effect:

The Seebeck effect is that the conversion of warmth directly into electricity at the junction of dissimilar electrical conductors. It is named in the memory of Baltic German physicist Thomas Johann Seedbeck.

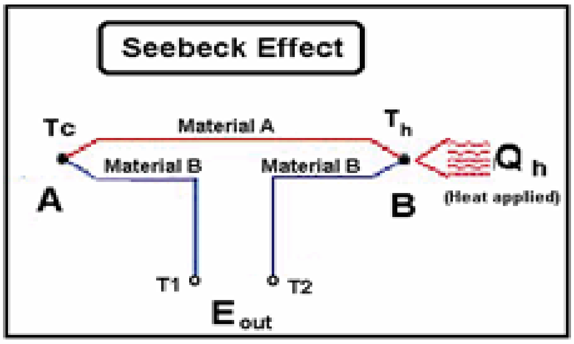

Fig 2. Seedbeck Effect.

As observed in Figure, the conductors are two dissimilar metals named as material A and material B. The junction temperature at A is considered as a reference and is maintained at a comparatively cool temperature (TC).

The junction temperature at B is employed as temperature above temperature TC. With heat applied to junction B, a voltage (Eout) will appear across terminals T1 and T2 and hence an electrical current would flow continuously during this loop. This voltage is understood because the Seebeck EMF, are often expressed as Eout = α (TH-TC).

4. The Thomson Effect:
According to the Thomson effect, when an electrical current is skilled a conductor having a gradient over its length, heat is going to be either absorbed by or expelled from the conductor. The absorption or rejection of heat depends on the direction of both, the electrical current and gradient .This phenomenon is understood because of the Thomson Effect.

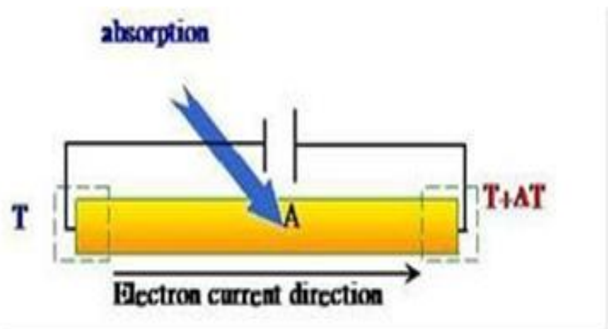

Fig 3. Thomson Effect.

II. WORKING OF PELTIER CO OLER

The Peltier effect is the result of electrical current flowing through two dissimilar conductors; counting on the direction of current flow, the junction of the 2 conductors will either absorb or release heat.

In the world of thermoelectric technology, semiconductors (usually Bismuth Telluride) are the fabric of preference for producing the Peltier effect because they will be more easily optimized for pumping heat. Using this sort of fabric, a Peltier device (i.e., thermoelectric module) is often constructed in its simplest form around one semiconductor "pellet" which is soldered to electrically-conductive material on each end (usually plated copper).As a result of this configuration, the second dissimilar material required for the Peltier effect, is none other than the copper connection paths to the power supply.

III. PELTIER COOLING WITH N-TYPE SEMICONDUCTOR

In Figure below, "N-type" semiconductor material is employed to fabricate the pellet in order that electrons (with a negative charge) are going to be the charge carrier employed to make the majority of the Peltier effect. N-type semi-conductor features a extra electron in its Fermi level (higher energy level).

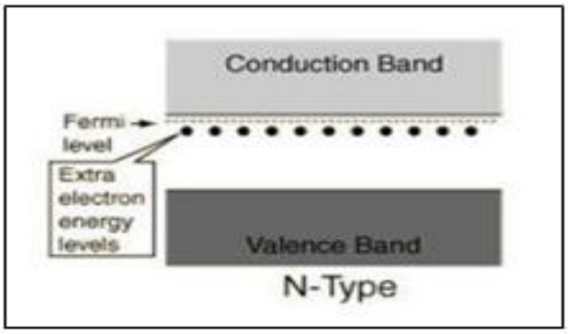

Fig 4.N Type Conduction.

With a DC voltage source connected as shown, electrons are going to be repelled by the negative pole and attracted by the positive pole of the supply; thanks to this attraction, electrons at Fermi level move towards positive terminal by releasing heat and creating the holes within the Fermi level.

Now, thanks to continuous supply of current, electrons move from valance band (lower energy band) to Fermi level by absorbing energy from the junction. With the electrons flowing through the N-type material from bottom to top, heat is absorbed at rock bottom junction and actively transferred to the highest junction.

IV. PELTIER COOLING WITH P & N TYPE OF SEMICONDUCTORS

By constructing N and P-type pellets during a "couple" (see Figure) and forming a junction between them with a plated copper tab, it's possible to configure a circuit which will allow all of the heat to move in similar direction.

As depicted in the illustration, with the free 8 (bottom) end of the P-type pellet connected to the positive voltage potential and the free (bottom) end of the N-type pellet respectively connected to the negative side of the voltage.

As seen in previous section, for N- type of semiconductor, absorption of heat from the junction takes place at the negative terminal and heat releases at the junction proximal to the positive terminal. For P-type of semiconductor, absorption of heat takes place at the junction near the positive terminal and exemption of heat at the junction near the negative terminal.

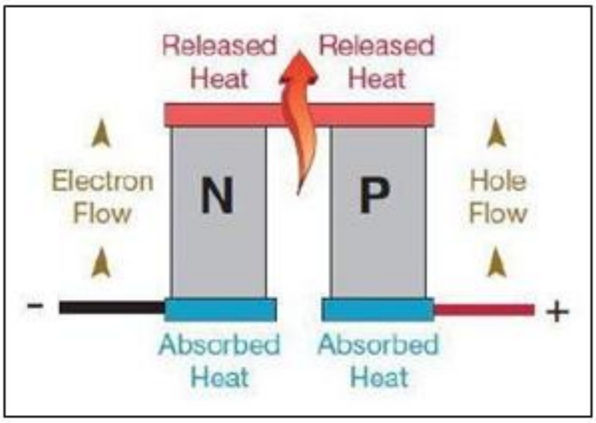

Fig 5. Thermoelectric cooler.

V. FABRICATION OF PELTIER COOLER

As we've seen in previous section, for getting thermoelectric effect, couples of P and N type semiconductors are connected in serial by metal plates. By following this it absorbs the heat from one end and releases the heat to a different end. So, when solid state P-N materials are connected electrically serial and thermally in parallel it makes one thermoelectric unit as shown in Figure 6.

A typical TEC module comprises of two highly thermally conductive substrates (A12O3, AlN, BeO) that function Hot/Cold plates. An array of p-type and semiconductor device (Bi2Te3, Sb2Te3, Bi2Se3, PbTe, Si-Ge) pellets are connected electrically serial sandwiched between the substrates. The device is generally attached to the cold side of the TEC module, and a conductor which is required for enhanced cooling is attached to the recent side. Solder is generally wont to connect the TEC elements onto the conducting pads of the substrates. The development of one stage thermoelectric module is shown in Figure.

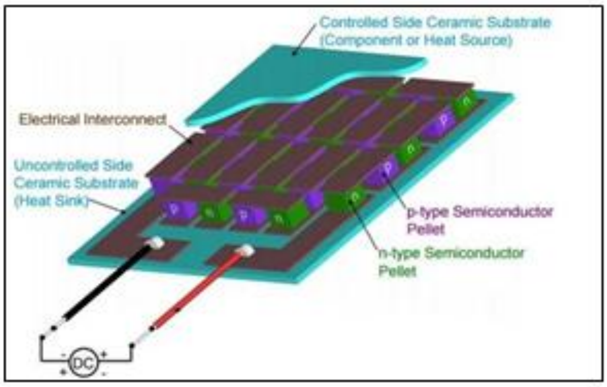

Fig 6.Thermoelectric cooler Module.

VI. GOVERNING EQUATIONS

1. Cooling power

$$Q_1 = (\alpha_p - \alpha_n) I T_1 - (T_2 - T_1)*(K_p + K_n) - I^2 (R_p + R_n)/2$$

2. Power consumed

$$W = (\alpha_p - \alpha_n).I.(T_2 - T_1) + I^2.(R_p + R_n)$$

3. Coefficient of performance

$$\therefore COP = \frac{\left((\alpha_p - \alpha_n) I T_1 - (T_2 - T_1) * (K_p + K_n) - \frac{I^2 (R_p + R_n)}{2}\right)}{\left((\alpha_p - \alpha_n).I.(T_2 - T_1) + I^2.(R_p + R_n)\right)}$$

4. Maximum cooling power

$$Q_1 = (\alpha_p - \alpha_n) I T_1 - (T_2 - T_1) * (K_p + K_n) - \frac{I^2 (R_p + R_n)}{2}$$

VII. THERMOELECTRIC MODULE SELECTION

Selection of the right TE Cooler for a selected application requires an evaluation of the entire system during which the cooler are going to be used. for many applications it should be possible to use one of the standard module configurations while in certain cases a special design could even be needed to satisfy stringent electrical, mechanical, or other requirements. The general cooling system is dynamic in nature and system performance could also be a function of several interrelated parameters. As a result, it always is vital to make a series of iterative calculations to “zero-in” on the proper operating parameters.

If there's any uncertainty about which TE device would be best fitted to a selected application, we highly recommend

International Journal of Scientific Research & Engineering Trends
Volume 7, Issue 5, Sept-Oct-2021, ISSN (Online): 2395-566X

that you simply simply contact our engineering staff for assistance. Before beginning the actual process of TE module selection, the designer should be prepared to acknowledge the next questions:

- At what temperature must the cooled object be maintained?
- What proportion heat must be far away from the cooled object?
- What is the significance of thermal response time? If yes, how quickly should the cooled object show variation in temperature after DC power has been applied?
- What's the expected ambient temperature? Will the ambient natural action significantly during system operation?
- What's the extraneous heat input (heat leak) to the thing as results of conduction, convection, and/or radiation?
- What proportion space is out there for the module and warmth sink?
- What power is available?
- Does the temperature of the cooled object need to be controlled? If yes, to what precision?
- What's the expected approximate temperature of the heat sink during operation? Is it possible that the warmth sink temperature will change significantly because of ambient fluctuations, etc.?

Every application obviously will have its own set of requirements that likely will vary in level of importance. Based upon any critical requirements that cannot be altered, the designer’s job are getting to be to select compatible components and operating parameters that ultimately will form an efficient and reliable cooling system. A design example is presented in section 9.5 as an example the concepts involved within the standard engineering process.

Before beginning any thermoelectric design activity it's necessary to possess an understanding of basic module performance characteristics. Performance data is presented graphically and is referenced to a specific conductor base temperature. Most performance graphs are standardized at a conductor temperature (Th) of +50°C and therefore the resultant data is usable over a variety of roughly 40°C to 60°C with only a small error. Upon request, we'll supply module performance graphs referenced to any temperature within a spread of -80°C to +200°C.

To demonstrate the utilization of those performance curves allow us to present an easy example. Suppose we've alittle electronic “black box” that's dissipating 15 watts of heat. For the electronic unit to function properly its temperature won't exceed 20°C. The space ambient temperature often rises well above the 20°C level thereby dictating the use of a thermoelectric cooler to reduce the unit’s temperature.

For the aim of this instance we'll neglect the heat sink (we cannot do this in practice) apart from to state that its temperature are often maintained at 50°C under worst-case conditions. We’ll investigate the use of a 71-couple, 6-ampere module to provide the required cooling.

1. GRAPH: Qc vs. I:
This graph, shown in Figure below, relates a module’s heat pumping capacity (Qc) and temperature difference (DT) as a function of input current (I). During thisexample, established operating parameters for the TE module include Th = 50°C, Tc = 20°C, and Qc = 15 watts. The specified DT = Th-Tc = 30°C.

It is necessary first to figure out whether one 71-couple, 6-ampere module is capable of providing sufficient heat removal to satisfy application requirements. We locate the DT=30 line and find that the utmost Qc value occurs at point A and with an input current of 6 amperes. By extending a line from point A to the left y-axis, we'll see that the module is capable of pumping approximately 18 watts while maintaining a Tc of 20°C.

Since this Qc is slightly above necessary, we follow the DT=30 line downward until we reach a foothold (point B) that corresponds to a Qc of 15 watts. Point B is that the operating point that satisfies our thermal requirements. By extending a line downward from point B to the x-axis, we discover that the proper input current is 4.0 amperes.

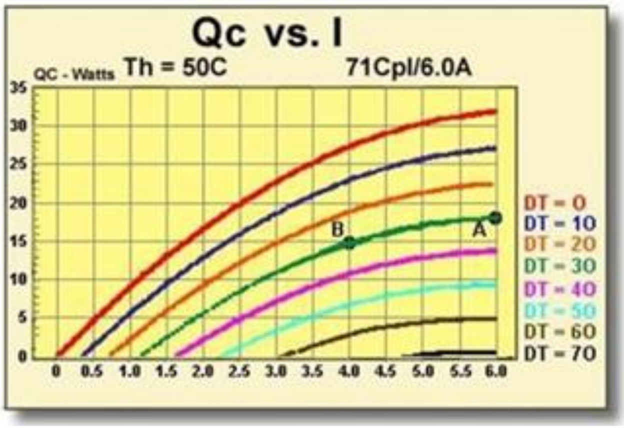

Fig 7.Heat Pumping Capacity Related to Temperature Differential as a Function of Input Current

2. GRAPH: Vin vs. I :
This graph, shown in Figure below, relates to a module’s input voltage (Vin) and temperature difference (DT) as a function of input current (I). In given example, parameters for the TE module include Th = 50 deg C, DT = 31 deg C, and I = 4 amperes. We locate the DT=31 line and, at the 4.0 ampere intersection, mark point C.

By extension of line from point C towards the left y-axis, we will observe that the specified module input voltage (Vin) is nearly 6.75 volts.

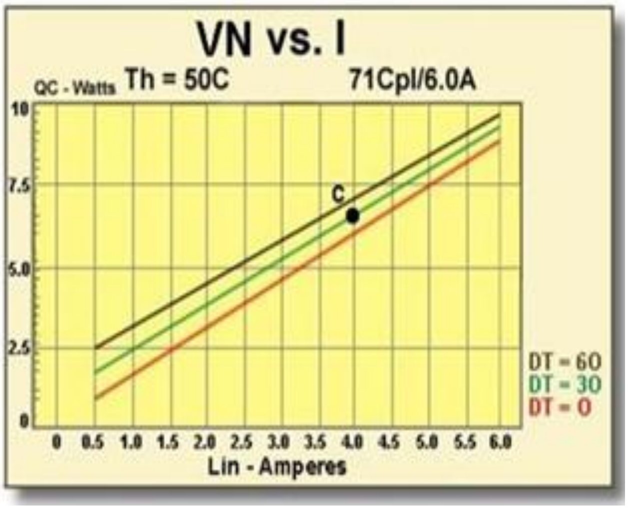

Fig 8.Input Voltage Related to Temperature Differential as a Function of Input Cuurent

3. GRAPH: COP vs. I:
The following graph, shown in Figure below, shows a module's coefficient of performance (COP) and temperature differential (DT) as a function of input current (I). In this example, parameters for the TE module include Th = 50 deg C, DT = 31 deg C, and I = 4.0 amperes.

We locate the DT=31 line and, at the 4.0 ampere intersection, mark point D. By extending a line from point D to the left y- axis, we will see that the module's coefficient of performance has a value of approximately 0.59.

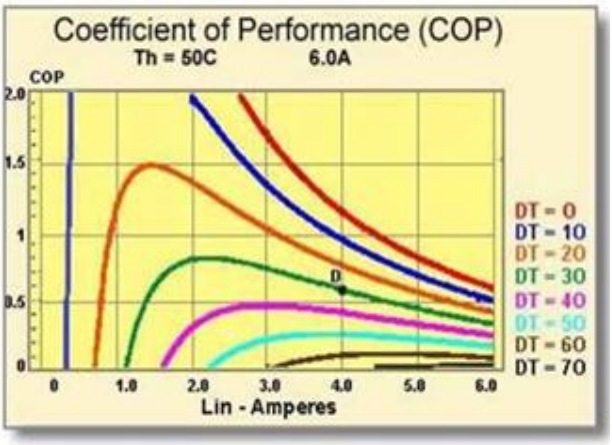

Fig 9.COP Related to Temperature Differential as a Function of Input Current

Note that COP is a measure of a module's efficiency and it is always desirable to maximize COP whenever possible. COP may be calculated by:

$$COP = \frac{\text{Heat Pumped}}{\text{Input Power}} = \frac{Q_c}{P_{in}}$$

4. An additional graph of Vin vs.:
Th, of the type shown in Figure below, relates a module's input voltage (Vin) and input current (I) as a function of module hot side temperature (Th). Beacuse of Seebeck effect, input voltage at given value of I and Th is least when DT=0 and highest when DT is at maximum point. Consequently, the graph of Vin vs. Th usually is presented for a DT=31 condition so as to give the typical value of Vin.

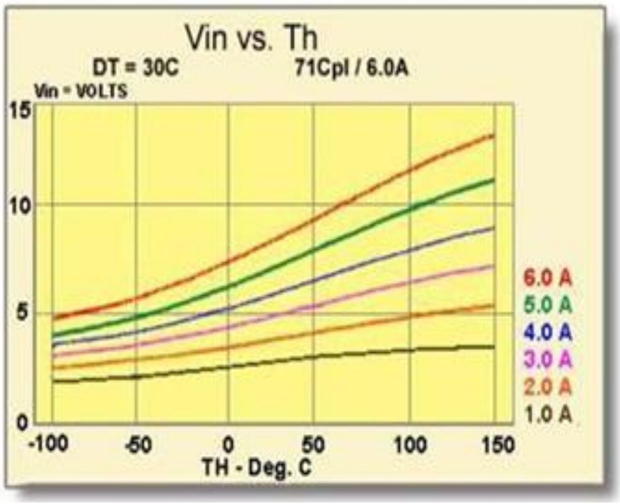

Fig 10.Input Voltage Related to Input Current as a Function of Hot side Temperature

5. Design Example:
To illustrate the typical design process, let us present an example of a TE cooler application involving the temperature stabilization of a laser diode. The diode, along side related electronics, is to be mounted during DIPKovar housing and must be maintained at a temperature of 25 deg C.

With the housing mounted on the system circuit card, tests show that the housing features a thermal resistance of 6°C/watt. The laser electronics dissipates a complete of 0.5 watts and therefore the design maximum ambient temperature is 35°C.

It is essential to pick a TE cooling module that not only will have sufficient cooling capacity to take care of the right temperature, but also will meet the dimensional requirements required by the housing. A 18 -couple, 1.25 ampere TE cooler is chosen initially because it does have compatible dimensions and also appears to possess appropriate performance characteristics. Performance graphs for this module are going to be wont to derive relevant parameters for creating mathematical calculations. To begin the planning process we must first evaluate the warmth sink and make an estimate of the worst- case module hot side temperature (Th). For the specified TE cooler, the maximum input power (Pin) can be found from Figure below at point A.

- Max. Module Input Power (Pin) = 1.25 amps x 2.4 volts = 3.0 watts
- Max. Heat Input to the Housing =3.0 watts + 0.5 watts = 3.5 watts
- Housing Temperature Rise = 3.5 watts x 6°C/watt = 21.0°C
- Max. Housing Temperature (T,) = 35°C ambient + 21.0 °C rise = 56°C Since the hot side temperature (Th) of 56.0°C is reasonably close to the available Tin = 50°C performance graphs, these graphs could also be wont to determine thermal performance with little or no error.

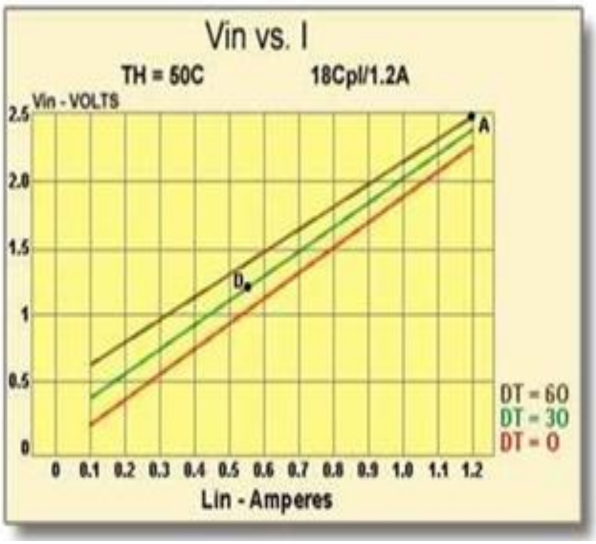

Fig 11.Vin vs I. Graph

Now that we've established the worst-case Th value it's possible to assess module performance.Module Temperature Differential (DT) = Th – Tc = 56 – 25 = 31°CFrom above Figure 12 it can be seen that the maximum heat pumping rate (Qc) for DT=31 occurs at point B and is approximately 0.9 watts. Since a Qc of only 0.5 watts is needed, we can follow the DT=31 line down until it intersects the 0.5 watt line marked as point C.

By extending a line downward from point C to the x-axis, we will see that an input current (I) of roughly 0.55 amperes will provide the specified cooling performance. Referring back to the Vin vs. I graph in Figure, a current of 0.55 amperes, marked as point D, requires a voltage (Vin) of about 1.2 volts. We will need to repeat our calculations because the required input power is comparatively lower than the value used for our initial calculation.

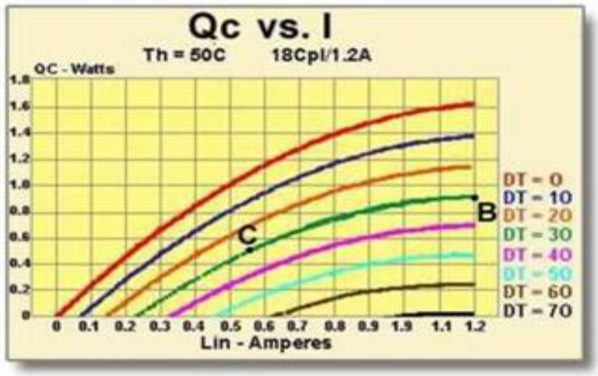

Fig 12.Qc vs I. Graph

8The new power and temperature values will be:

- Max. Module Input Power (Pin) = 0.55 amps x 1.2 volts =0.67 watts
- Max. Heat Input to the Housing = 0.67 watts + 0.50 watts = 1.17 watts
- Housing Temperature Rise = 1.17 watts x 6 deg C/watt = 7.02°C
- Max. Housing Temperature (Th) = 35°C ambient + 7.02°C rise = 42.02°C
- Module Temperature Differential (DT) = Th-Tc = 42.02°C- 25°C = 17.02°C

It has often been seen that because we now have another new value for Th it'll be necessary to continue repeating steps outlined above until a stable condition is acquired. Note that calculations usually are repeated until the difference within the Th values from successive calculations is small.

There is no reason to present the repetitive calculations here but we will conclude that the chosen 18-couple TE module will function alright during this application. The performed analysis clarifies the importance of the warmth sink in any TE cooling application.

6. Use of Multiple Modules:

Relatively large TE cooling applications may require the use of multiple individual modules in order to obtain the desired rate of heat removal. For these applications, TE modules are mounted thermally in parallel and connected electrically in serial.

An electrical series-parallel connection arrangement can also be used advantageously for certain instances. Because conductor performance becomes increasingly vital as power levels rise, make certain that chosen conductor is adequate for the appliance.

VIII. CALCULATION OF THERMOELECTRIC MODULE PERFORMANCE

There are five variable parameters applicable to a thermoelectric module that affects its operation. These parameters include:

- I – The input current supplied to the module expressed in amperes
- Vin – The input voltage supplied to the module expressed in volts
- Th – The temperature at the hot side of the module expressed in °K
- Tc – The temperature at the cold side of the module expressed in °K
- Qc – The heat supplied to the module expressed in watts

For calculating the module performance it is needed to set at least three of these variables to specific values. Two common calculation methods involve either (a) Setting the values of Th,

I, and Qc or, (b) Setting the values of Th, I and Tc. For the computer-oriented person, a relatively direct calculation routine can be developed to relentlessly step through a series of fixed values to produce an output result of module performance over a range of operating conditions.

1. Single-Stage Module Calculations:
These equations mathematically describe the performance of a single- stage thermoelectric module as illustrated in Figure below. While making entries of numerical data, do not forget that temperature values must be corresponded in degrees Kelvin (°K).

Calculations of the various parameters should be performed in the following manner shown.

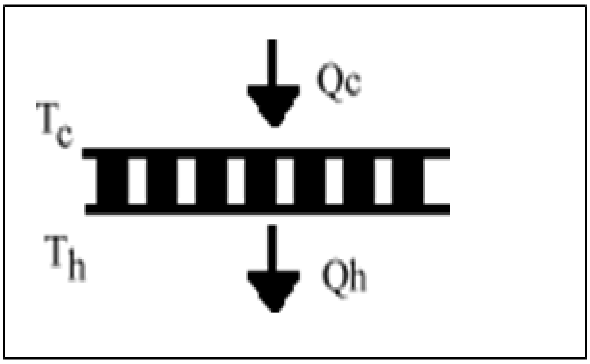

Fig 13.Single stage module.

The temperature variance (DT) across the module in °K or °C is:

$$DT = Th - Tc$$

Value of Heat pumped (Qc) by the module in watts is:

$$Qc = (SM \times Tc \times I) - (0.5 \times I2 \times RM) - (KM \times DT)$$

The input voltage (Vin) to the module in volts is:

$$Vin = (SM \times DT) + (I \times RM)$$

The electrical input power (Pin) to the module in watts is:

$$Pin = Vin \times I$$

The heat expelled by the module (Qh) in watts is:

$$Qh = Pin + Qc$$

The coefficient of performance (COP) of a refrigerator is:

$$COP = Qc / Pin$$

2. Heating Mode Operation:
Thermoelectric modules may be operated in the heating mode by reversing the polarity of the applied DC power. When applied in this manner, the TE module acts as a “heat pump” and heating efficiencies close to 100 percent may be realized under certain conditions.

A quick increase in temperature occurs when heating an object with smaller mass; ensure to avoid overheating of either the module or object. In the heating mode, shown in Figure below, the heat sink and object effectively are in opposite positions whereby the object is now at temperature (Th) and the heat sink is at temperature (Tc).

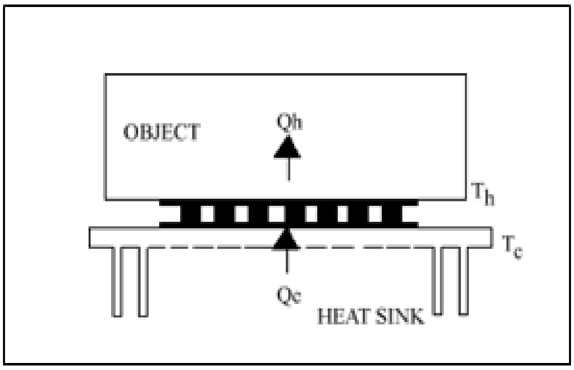

Fig 14.Heat sink and object.

Heat flow to the object (Qh) is given by the expression:

$$Qh = (SM \times Th \times I) + (0.5 \times I2 \times RM) - (KM \times (Th - Tc))$$

The coefficient of performance of a heater (COPH) is:

$$COPH = Qh / Pin$$

IX. CONCLUSION

Thermoelectric devices will be used extensively for personal electronic applications. These applications extend from wearable items, such as watches or cloths, to biomedical applications such as drug delivery and vital signs monitoring. Current technology can provide devices for micro- thermoelectric applications, such as cooling of integrated circuit. But, to reach the full potential of these applications, a cost effective mass production techniques need to be developed, and the performance needs to be optimized. In general, mass production will extend the use of these devices to many industrial applications.

As indicated, a good thermoelectric material should have high electrical conductivity but low thermal conductivity. Electrical conductivity increases with the increase of the carrier concentration and and/or the carrier mobility. Therefore, improvement can be achieved by developing material structure or fabrication process that increases the mobility or the carrier concentration, or both. One way to achieve this goal is to use super-lattice, quantum well structures, where the mobility can be enhanced and consequently Seebeck effect can be increased.

These structures benefit from quantum confinement which enhances the figure of merit and this can be extended to nanowire and quantum dots. Another way of increasing the carrier concentration is by bombarding a multilayer thermoelectric material with Si ions at different doses.

In conclusion, thermoelectric devices have a great potential in both personal and industrial electronics. However, a more efficient materials need to be developed and mass production techniques need to be adopted to reach this potential. Morever the need of precise selection of the peltier module with all its functional constituents intact play a vital role in the performance it exhibits in different operating conditions.

In such cases even a minimal variation in performance can reflect to a bigger change in the expected output results. This study enables us in figuring out the different parameters to look upon while the selection of peltier module for our needs based on the performance factor. It also highlights the different techniques to be used in order to modify the system functioning according to our applications and verify values of unknown variables by setting the values of other known variables.

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