DESIGN AND FABRICATION OF SOLAR REFRIGERATION USING PELTIER MODULE

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Abstract

In the recent years, energy crisis and environment degradation due to the increase in CO_2 *emission. So we designed her that "Solar Refrigeration using Peltier Module, it does not need any kind of refrigerant and mechanical device like compressor, prime mover etc. for its operation. Our project utilizes the solar energy for its operation. This project is one of the most cost effective, clean and environment friendly. The main purpose of this method is to provide refrigeration system to remote areas where power supply is not possible.*

Thermoelectric devices (TED's) continue to be an area of high interest in both thermal management and energy harvesting applications. Due to their compact size, reliable performance, and their ability to accomplish sub-ambient cooling, much effort is being focused on optimized methods for characterization and integration of TED's for future applications. Predictive modelling methods can only achieve accurate results with robust input physical parameters, therefore TED characterization methods are critical for future development of the field. Often times, physical properties of TED sub-components are very well known, however the "effective" properties of a TED module can be difficult to measure with certainty. The module-lsured parameters, the metrology output from an offthe - shelf TED is used in a system-level thermal model to predict and validate observed metrology temperatures.

Introduction

A thermoelectric (TE) cooler, sometimes called a thermoelectric module or Peltier cooler, is a semiconductor-based electronic component that functions as a small heat pump. By applying a low voltage DC power source to a TE module, heat will be moved through the module from one side to the other. One module face, therefore, will be cooled while the opposite face simultaneously is heated. It is important to note that this phenomenon may be reversed whereby a change in the polarity (plus and minus) of the applied DC voltage will cause heat to be moved in the opposite direction. Consequently, a thermoelectric module may be used for both heating and cooling thereby making it highly suitable for precise temperature control applications.

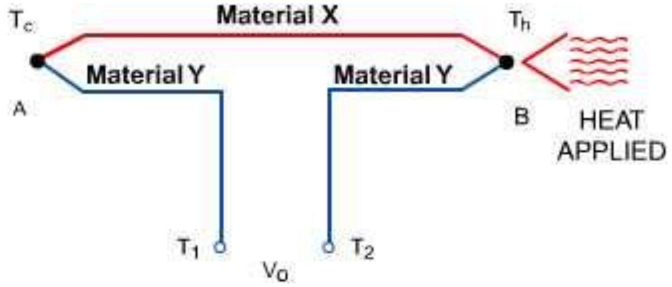
To provide the new user with a general idea of a thermoelectric cooler’s capabilities, it might be helpful to offer this example. If a typical single-stage thermoelectric module was placed on a heat sink that was maintained at room temperature and the module was then connected to a suitable battery or other DC power source, the “cold” side of the module would cool down to approximately -40°C. At this point, the module would be pumping almost no heat and would have reached its maximum rated “DeltaT (DT).” If heat was gradually added to the module’s cold side, the cold side temperature would increase progressively until it eventually equaled the heat sink temperature. At this point the TE cooler would have attained its maximum rated “heat pumping capacity” (Qmax).

Both thermoelectric coolers and mechanical refrigerators are governed by the same fundamental laws of thermodynamics and both refrigeration systems, although considerably different in form, function in accordance with the same principles.

In a mechanical refrigeration unit, a compressor raises the pressure of a liquid and circulates the refrigerant through the system. In the evaporator or “freezer” area the refrigerant boils and, in the process of changing to a vapor, the refrigerant absorbs heat causing the freezer to become cold. The heat absorbed in the freezer area is moved to the condenser where it is transferred to the environment from the condensing refrigerant. In a thermoelectric cooling system, a doped semiconductor material essentially takes the place of the liquid refrigerant, the condenser is replaced by a finned heat sink, and the compressor is replaced by a DC power source. The application of DC power to the thermoelectric module causes electrons to move through the semiconductor material. At the cold end (or “freezer side”) of the semiconductor material, heat is absorbed by the electron movement, moved through the material, and expelled at the hot end. Since the hot end today’s thermoelectric coolers make use of modern semiconductor technology whereby doped semiconductor material takes the place of dissimilar metals used in early thermoelectric experiments.

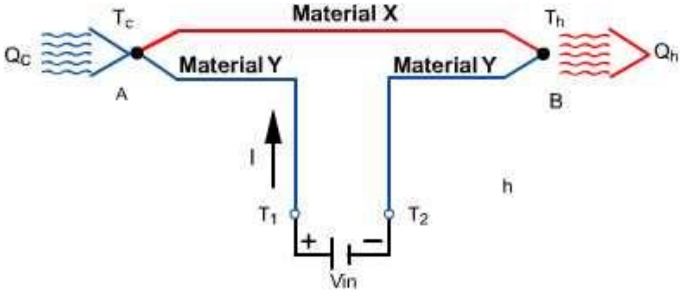
The Seebeck, Peltier, and Thomson Effects, together with several other phenomena, form the basis of functional thermoelectric modules. Without going into too much detail, we will examine some of these fundamental thermoelectric effects.

1.1. SEEBECK EFFECT: To illustrate the Seebeck Effect let us look at a simple thermocouple circuit as shown in Figure (1.1). The thermocouple conductors are two dissimilar metals denoted as Material x and Material y.



In a typical temperature measurement application, thermocouple A is used as a “reference” and is maintained at a relatively cool temperature of Tc. Thermocouple B is used to measure the temperature of interest (Th) which, in this example, is higher than temperature Tc. With heat applied to thermocouple B, a voltage will appear across terminals Tl and T2. This voltage (Vo), known as the Seebeck emf, can be expressed as:

1.2. PELTIER EFFECT: If we modify our thermocouple circuit to obtain the configuration it will be possible to observe an opposite phenomenon known as the Peltier Effect.



If a voltage (Vin) is applied to terminals Tl and T2 an electrical current (I) will flow in the circuit. As a result of the current flow, a slight cooling effect (Qc) will occur at thermocouple junction A where heat is absorbed and a heating effect (Qh) will occur at junction B where heat is expelled. Note that this effect may be reversed whereby a change in the direction of electric current flow will reverse the direction of heat flow. The Peltier effect can be expressed mathematically as:

Qc or Qh=pxy x I

where:

pxy is the differential Peltier coefficient between the two materials, x and y, in volts I is the electric current flow in amperes Qc, Qh is the rate of cooling and heating, respectively, in watts.

Joule heating, having a magnitude of I x R (where R is the electrical resistance), also occurs in the conductors as a result of current flow. This Joule heating effect acts in opposition to the Peltier effect and causes a net reduction of the available cooling.

1.3. THOMSON EFFECT: When an electric current is passed through a conductor having a temperature gradient over its length, heat will be either absorbed by or expelled from the conductor. Whether heat is absorbed or expelled depends upon the direction of both the electric current and temperature gradient. This phenomenon, known as the Thomson Effect, is of interest in respect to the principals involved but plays a negligible role in the operation of practical thermoelectric modules. For this reason, it is ignored.

1.4. THERMOELECTRIC MATERIALS: The thermoelectric semiconductor material most often used in today’s TE coolers is an alloy of Bismuth Telluride that has been suitably doped to provide individual blocks or elements having distinct “N” and “P” characteristics.

Thermoelectric materials most often are fabricated by either directional crystallization from a melt or pressed powder metallurgy. Each manufacturing method has its own particular advantage, but directionally grown materials are most common. In addition to Bismuth Telluride (Bi_2Te_3), there are other thermoelectric materials including Lead Telluride (PbTe), Silicon Germanium (SiGe), and Bismuth-Antimony (Bi-Sb) alloys that may be used in specific situations. Illustrates the relative performance or Figure-of-Merit of various materials over a range of temperatures. It can be seen from this graph that the performance of Bismuth Telluride peaks within a temperature range that is best suited for most cooling applications.

APPROXIMATE FIGURE-OF-MERIT (Z) FOR VARIOUS TE MATERIALS

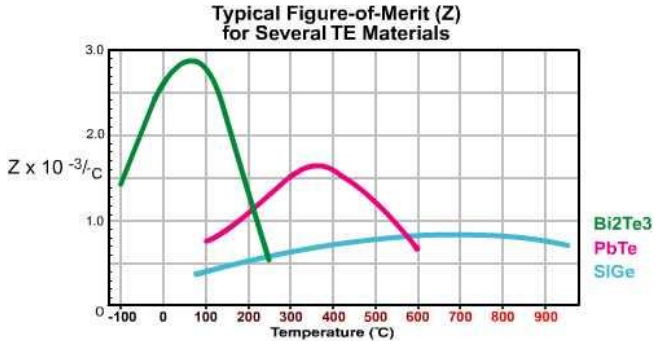


Figure (1.1) Performance of Thermoelectric Materials at Various Temperatures

1.5. BISMUTH TELLURIDE MATERIAL: Crystalline Bismuth Telluride material has several characteristics that merit discussion. Due to the crystal structure, Bi_2Te_3 is highly anisotropic in nature. This results in the material's electrical resistivity being approximately four times greater parallel to the axis of crystal growth (C-axis) than in the perpendicular orientation. In addition, thermal conductivity is about two time's greater parallel to the C-axis than in the perpendicular direction. Since the anisotropic behavior of resistivity is greater than that of thermal conductivity, the maximum performance or Figure-of-Merit occurs in the parallel orientation. Because of this anisotropy, thermoelectric elements must be assembled into a cooling module so that the crystal growth axis is parallel to the length or height of each element and, therefore, perpendicular to the ceramic substrates.

There is one other interesting characteristic of Bismuth Telluride that also is related to the material's crystal structure. Bi_2Te_3 crystals are made up of hexagonal layers of similar atoms.

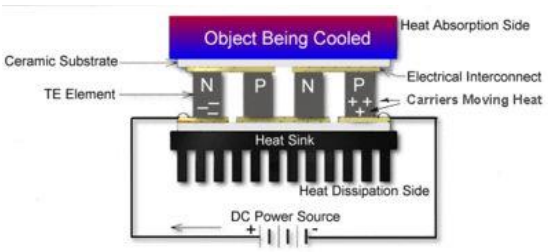


Figure (1.2) Schematic Diagram of a Typical Thermoelectric Cooler

Both N-type and P-type Bismuth Telluride thermoelectric materials are used in a thermoelectric cooler. This arrangement causes heat to move through the cooler in one direction only while the electrical current moves back and forth alternately between the top and bottom substrates through each N and P element. N-type material is doped so that it will have an excess of electrons (more electrons than needed to complete a perfect molecular lattice structure) and P-type material is doped so that it will have a deficiency of electrons (fewer electrons than are necessary to complete a perfect lattice structure). The extra electrons in the N material and the “holes” resulting from the deficiency of electrons in the P material are the carriers which move the heat energy through the thermoelectric material. Figure (1.2) shows a typical thermoelectric cooler with heat being moved as a result of an applied electrical current (I). Most thermoelectric cooling modules are fabricated with an equal number of N-type and P-type elements where one N and P element pair form a thermoelectric “couple.” The module illustrated in Figure (1.2) has two pairs of N and P elements and is termed a “two-couple module”.

Heat flux (heat actively pumped through the thermoelectric module) is proportional to the magnitude of the applied DC electric current.

Typical applications for thermoelectric modules include:

- Avionics
- Black box cooling
- Calorimeters
- CCD (Charged Couple Devices)
- CID (Charge Induced Devices)
- Cold chambers
- Cold plates
- Compact heat exchangers
- Constant temperature baths
- Dehumidifiers
- Dew point hygrometers
- Electronics package cooling
- Electrophoresis cell coolers
- Environmental analyzers
- Heat density measurement
- Ice point references
- Immersion coolers
- Integrated circuit cooling
- Inertial guidance systems
- Infrared calibration sources and black body references

- Infrared detectors
- Infrared seeking missiles
- Laser collimators
- Laser diode coolers
- Long lasting cooling devices
- Low noise amplifier

The use of thermoelectric modules often provides solutions, and in some cases the ONLY solution, to many difficult thermal management problems where a low to moderate amount of heat must be handled. While no one cooling method is ideal in all respects and the use of thermoelectric modules will not be suitable for every application, TE coolers will often provide substantial advantages over alternative technologies. Some of the more significant features of thermoelectric modules include:

No Moving Parts: A TE module works electrically without any moving parts so they are virtually maintenance free.

Small Size and Weight: The overall thermoelectric cooling system is much smaller and lighter than a comparable mechanical system. In addition, a variety of standard and special sizes and configurations are available to meet strict application requirements.

Ability to Cool Below Ambient: Unlike a conventional heat sink whose temperature necessarily must rise above ambient, a TE cooler attached to that same heat sink has the ability to reduce the temperature below the ambient value.

Ability to Heat and Cool with the Same module: Thermoelectric coolers will either heat or cool depending upon the polarity of the applied DC power. This feature eliminates the necessity of providing separate heating and cooling functions within a given system.

Precise Temperature Control: With an appropriate closed-loop temperature control circuit, TE coolers can control temperatures to better than +/- 0.1°C.

High Reliability: Thermoelectric modules exhibit very high reliability due to their solid state construction. Although reliability is somewhat application dependent, the life of typical TE coolers is greater than 200,000 hours.

Electrically “Quiet” Operation: Unlike a mechanical refrigeration system, TE modules generate virtually no electrical noise and can be used in conjunction with sensitive electronic sensors. They are also acoustically silent.

Operation in any Orientation: TEs can be used in any orientation and in zero gravity environments. Thus they are popular in many aerospace applications.

Convenient Power Supply: TE modules operate directly from a DC power source. Modules having a wide range of input voltages and currents are available. Pulse Width Modulation (PWM) may be used in many applications

Spot Cooling: With a TE cooler it is possible to cool one specific component or area only, thereby often making it unnecessary to cool an entire package or enclosure.

Ability to Generate Electrical Power: When used "in reverse" by applying a temperature differential across the faces of a TE cooler, it is possible to generate a small amount of DC power.

Environmentally Friendly: Conventional refrigeration systems can not be fabricated without using chlorofluorocarbons or other chemicals that may be

- When cooling below the dew point, moisture or frost will tend to form on exposed cooled surfaces. To prevent moisture from entering a TE module and severely reducing its thermal performance, an effective moisture seal should be installed. This seal should be formed between the heat sink and cooled object in the area surrounding the TE module(s). Flexible foam insulating tape or sheet material and/or silicone rubber RTV are relatively easy to install and make an effective moisture seal. Several methods for mounting thermoelectric modules are available and the specific product application often dictates the method to be used. Possible mounting techniques are outlined in the following paragraphs.

HEIGHT TOLERANCE: Most thermoelectric cooling modules are available with two height tolerance values, +/-0.3mm (+/-0.010″) and +/-0.03mm (0.001″). When only one module is used in a thermoelectric subassembly, a +/-0.3mm tolerance module generally is preferable since it provides a slight cost advantage over a comparable tight-tolerance module. For applications where more than one module is to be mounted between the heat sink and cooled object, however, it is necessary to closely match the thickness of all modules in the group to ensure good heat transfer. For this reason, +/-0.03mm (+/-0.001″) tolerance modules should be used in all multiple-module configurations.

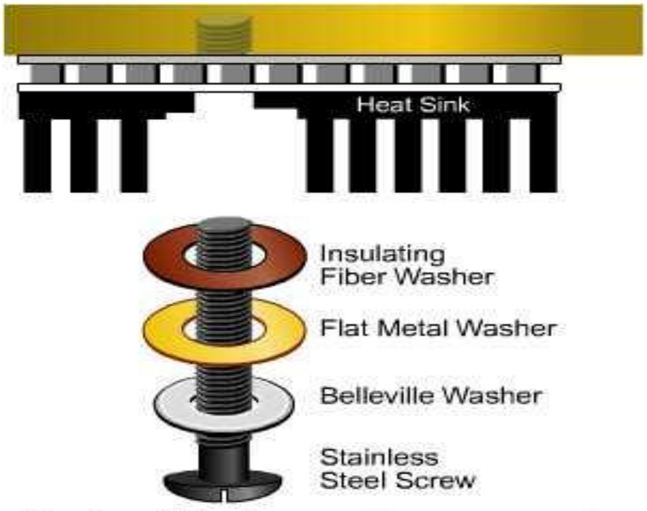
2.1. Clamping:

The most common mounting method involves clamping the thermoelectric module(s) between a heat sink and flat surface of the article to be cooled. This approach, as illustrated in Figure (6.1), usually is recommended for most applications and may be applied as follows:

a) Machine or grind flat the mounting surfaces between which the TE module(s) will be located. To achieve optimum thermal performance mounting surfaces should be flat to within 1mm/m (0.001 in/in).

b) If several TE modules are mounted between a given pair of mounting surfaces, all modules within the group must be matched in height/thickness so that the overall thickness variation does not exceed 0.06mm (0.002″). Module P/N with a "B" ending should be specified.

c) Mounting screws should be arranged in a symmetrical pattern relative to the module(s) so as to provide uniform pressure on the module(s) when the assembly is clamped together. To minimize heat loss through the mounting screws, it is desirable to use the smallest size screw that is practical for the mechanical system. For most applications, M3 or M3.5 (4-40 or 6-32) stainless steel screws will prove satisfactory. Alternately, non-metallic fasteners can be used, e.g., nylon. Smaller screws may be used in conjunction with very small mechanical assemblies. Belleville spring washers or split lock-washers should be used under the head of each screw to maintain even pressure during the normal thermal expansion or contraction of system components.



Typical Fastener Components

d) Clean the module(s) and mounting surfaces to ensure that all burrs, dirt, etc., have been removed.

e) Coat the "hot" side of the module(s) with a thin layer (typically 0.02mm / 0.001″ or less thickness) of thermally conductive grease and place the module, hot side down, on the heat sink in the desired location. Gently push down on the module and apply a back and forth turning motion to squeeze out excess thermal grease. Continue the combined downward pressure and turning motion until a slight resistance is detected. Ferrotec America recommends and stocks American Oil and Supply (AOS) type 400 product code 52032.

f) Coat the "cold" side of the module(s) with thermal grease as specified in step (e) above. Position and place the object to be cooled in contact with the cold side of the module(s). Squeeze out the excess thermal grease as previously described.

g) Bolt the heat sink and cooled object together using the stainless steel screws and spring washers. It is important to apply uniform pressure across the mounting surfaces so that good parallelism is maintained. If significantly uneven pressure is applied, thermal performance may be reduced, or worse, the TE module(s) may be damaged. To ensure that pressure is applied uniformly, first tighten all mounting screws finger tight starting with the center screw (if any). Using a torque screwdriver, gradually tighten each screw by moving from screw to screw in a crosswise pattern and increase torque in small increments. Continue the tightening procedure until the proper torque value is reached. Typical mounting pressure ranges from 25 – 100 psi depending on the application. If a torque screwdriver is not available, the correct torque value may be approximated by using the following procedure:

In a crosswise pattern, tighten the screws until they are "snug" but not actually tight. In the same crosswise pattern, tighten each screw approximately one quarter turn until the spring action of the washer can be felt.

h) A small additional amount of thermal grease normally is squeezed out soon after the assembly is first clamped together. In order to insure that the proper screw torque is maintained, wait a minimum of one hour and recheck the torque by repeating step (g) above.

2.2. CAUTION: Over-tightening of the clamping screws may result in bending or bowing of either the heat sink or cold object surface especially if these components are constructed of relatively thin material. Such bowing will, at best, reduce thermal performance and in severe cases may cause physical damage to system components. Bowing may be minimized by positioning the clamping screws close to the thermoelectric module(s) and by using moderately thick materials. However, if hot and/or cold surfaces are constructed of aluminum which is less than 6mm (0.25″) thick or copper which is less than 3.3mm (0.13″) thick, it may be necessary to apply screw torque of a lower value than specified in step (g) above.

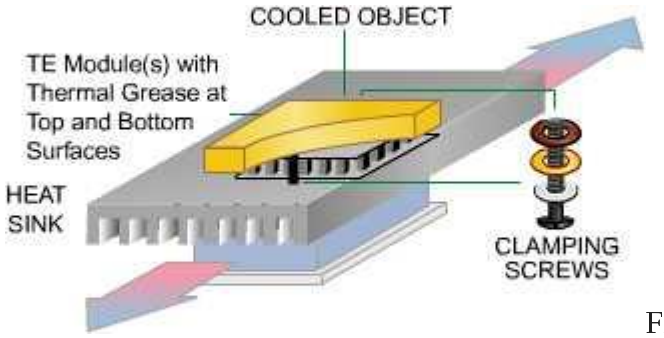


Figure (2.1)

TE Module Installation Using the Clamping Method

The proper bolt torque for TE module assemblies can be determined by the following relationship:

$T=((S_a \text{ x } A)/N) \text{ x } K \text{ x } d$

Where:

T = torque on each bolt
S_a = cycling 25-50 psi, static 50-75 psi.
A = total surface area of module(s)
N = number of bolts used in assembly
K = torque coefficient (use K=0.2 for steel, K=0.15 for nylon)
d = nominal bolt diameter

For steel fasteners, we typically recommend either:

6-32 d=.138 in (.350 cm)
4-40 d=.112 in (.284 cm)

The following recommended torque is calculated for nine 9500/065/018 modules held by four 4-40 steel fasteners:

$T=((75\ \text{lbs/in.}^2 \times (.44'' \times .48'') \times 9)/4) \times 0.2 \times .112\ \text{in.} = 0.8\ \text{in-lbs.}$

2.3. Bonding with Epoxy

A second module mounting method that is useful for certain applications involves bonding the module(s) to one or both mounting surfaces using a special high thermal-conductivity epoxy adhesive. Since the coefficients of expansion of the module's ceramics, heat sink and cooled object vary, we do not recommend bonding with epoxy for larger modules. Please consult your applications engineer for guidance. Note: Unless suitable procedures are used to prevent outgassing, epoxy bonding is not recommended if the TE cooling system is to be used in a vacuum. For module mounting with epoxy:

a) Machine or grind flat the mounting surfaces between which the TE module(s) will be located. Although surface flatness is less critical when using epoxy, it is always desirable for mounting surfaces to be as flat as possible.

b) Clean and degrease the module(s) and mounting surfaces to insure that all burrs, oil, dirt, etc., have been removed. Follow the epoxy manufacturer's recommendations regarding proper surface preparation.

c) Coat the hot side of the module with a thin layer of the thermally conductive epoxy and place the module, hot side down, on the heat sink in the desired location. Gently push down on the module and apply a back and forth turning motion to squeeze out excess epoxy. Continue the combined downward pressure and turning motion until a slight resistance is detected.

d) Weight or clamp the module in position until the epoxy has properly cured. Consult the epoxy manufacturer's data sheet for specific curing information. If an oven cure is specified, be sure that the maximum operating temperature of the TE module is not exceeded during the heating procedure. Note that most TE cooling modules manufactured by Ferrotec have maximum operating temperatures of 200 °C for the 95-Series.

2.4. Soldering

Thermoelectric modules that have metallized external faces may be soldered into an assembly provided that reasonable care is taken to prevent module overheating. Soldering to a rigid structural member of an assembly should be performed on one side of the module only (normally the hot side) in order to avoid excessive mechanical stress on the module. Note that with a module's hot side soldered to a rigid body, however, a component or small electronic circuit may be soldered to the module's cold side provided that the component or circuit is not rigidly coupled to the external structure. Good temperature control must be maintained within the soldering system in order to prevent damage to the TE module due to overheating. Our thermoelectric modules are rated for continuous operation at relatively high temperatures (150 or 200 °C) so they are suitable in most applications where soldering is desirable. Naturally these relative temperatures should not be exceeded in the process. Since the coefficients of expansion of the module ceramics, heat sink and cooled object vary, we do not recommend soldering modules larger than 15 x 15 millimeters. Soldering should not be considered in any thermal cycling application. For module mounting with solder, the following steps should be observed:

a) Machine or grind flat the mounting surface on which the module(s) will be located. Although surface flatness is not highly critical with the soldering method, it is always desirable for mounting surfaces to be as flat as possible. Obviously, the heat sink surface must be a solderable material such as copper or copper plated material.

b) Clean and degrease the heat sink surface and remove any heavy oxidation. Make sure that there are no burrs, chips, or other foreign material in the module mounting area.

c) Pre tin the heat sink surface in the module mounting area with the appropriate solder. The selected solder must have a melting point that is less than or equal to the rated maximum operating temperature of the TE device being installed. When tinning the heat sink with solder, the heat sink's temperature should be just high enough so that the solder will melt but in no case should the temperature be raised more than the maximum value specified for the TE device.

d) Apply soldering flux to the TE module's hot side and place the module on the pre tinned area of the heat sink. Allow the module to "float" in the solder pool and apply a back and forth turning motion on the module to facilitate solder tinning of the module surface. A tendency for the module to drag on the solder surface rather than to float is an indication that there is an insufficient amount of solder. In this event, remove the module and add more solder to the heat sink.

e) After several seconds the module surface should be tinned satisfactorily. Clamp or weight the module in the desired position, remove the heat sink from the heat source, and allow the assembly to cool. When sufficiently cooled, degrease the assembly to remove flux residue.

2.5. Mounting Pads And Other Material

There are a wide variety of products available designed to replace thermally conductive grease as an interface material. Perhaps the most common are silicon-based mounting pads. Originally for use in mounting semiconductor devices, these pads often exhibit excessive thermal resistance in thermoelectric applications. Since the pads allow for rapid production and eliminate cleanup time, they are popular in less demanding applications. Leading manufacturers in this area include The Bergquist Company and the Chomerics Division of Parker Hannifin Corporation.

2.6. Thermal System Design Considerations

The first step in the design of a thermoelectric cooling system involves making an analysis of the system’s overall thermal characteristics. This analysis, which may be quite simple for some applications or highly complex in other cases, must never be neglected if a satisfactory and efficient design is to be realized. Some of the more important factors to be considered are discussed in the following paragraphs. Although we have made certain simplifications that may horrify the pure thermodynamicist, the results obtained have been found to satisfy all but those few applications that approach state-of-the-art limits.

Please note that design information contained in this manual is presented for the purpose of assisting those engineers and scientists who wish either to estimate cooling requirements or to actually develop their own cooling systems. For the many individuals who prefer not to become involved in the details of the thermoelectric design process, however, we encourage you to contact us for assistance. Ferrotec is committed to providing strong customer technical support and our engineering staff is available to assist in complex thermoelectric-related design activities.

ACTIVE HEAT LOAD: The active heat load is the actual heat generated by the component, “black box” or system to be cooled. For most applications, the active load will be equal to the electrical power input to the article being cooled (Watts = Volts x Amps) but in other situations the load may be more difficult to determine. Since the total electrical input power generally represents the worst case active heat load, we recommend that you use this value for design purposes.

PASSIVE HEAT LOAD: The passive heat load (sometimes called heat leak or parasitic heat load) is that heat energy which is lost or gained by the article being cooled due to conduction, convection, and/or radiation. Passive heat losses may occur through any heat-conductive path including air, insulation, and electrical wiring. In applications where there is no active heat generation, the passive heat leak will represent the entire heat load on the thermoelectric cooler.

Determination of the total heat leak within a cooling system is a relatively complicated issue but a reasonable estimate of these losses often can be made by means of some basic heat transfer calculations. If there is any uncertainty about heat losses in a given design, we highly recommend that you contact our engineering staff for assistance and suggestions.

HEAT TRANSFER EQUATIONS:

Several fundamental heat transfer equations are presented to assist the engineer in evaluating some of the thermal aspects of a design or system.

HEAT CONDUCTION THROUGH A SOLID MATERIAL: The relationship that describes the transfer of heat through a solid material was suggested by J.B. Fourier in the early 1800's. Thermal conduction is dependent upon the geometry and thermal conductivity of a given material plus the existing temperature gradient through the material. Although thermal conductivity varies with temperature, the actual variation is quite small and can be neglected for our purposes. Mathematically, heat transfer by conduction may be expressed as:

$$Q=\frac{(K)(DT)(A)}{X}$$

Where:

Symbol	Definition	English Units	Metric Units
Q	Heat Conducted Through the Material	BTU/hour	watts
K	Thermal conductivity of the material	BTU/hour-ft°F	watts/meter-ft°C
A	Cross-sectional area of the material	square feet	square meters
x	Thickness of length of the materials	feet	meters
DT	Temperature difference between cold and hot sides of the material	Degrees F	Degrees C

HEAT TRANSFER FROM AN EXPOSED SURFACE TO AMBIENT BY CONVECTION:

Heat leak to or from an uninsulated metal surface can constitute a significant heat load in a thermal system. Isaac Newton proposed the relationship describing the transfer of heat when a cooled (or heated) surface is exposed directly to the ambient air. To account for the degree of thermal coupling between the surface and surrounding air, a numerical value (h), called the Heat Transfer Coefficient, must be incorporated into the equation. Heat lost or gained in this manner may be expressed mathematically as: Q=(h)(A)(DT)

Q=(h)(A)(DT)

Where:

Symbo	Definition	English Units	Metric Units
Q	Heat transferred to or from ambient	BTU/hour	watts
h	Heat transfer coefficient. For still air use a value of: For turbulent air use a value of	BTU/hour-ft^2-ft°F 4 to 5 15 to 20	watts/meter^2-ft°C 23 to 28 85 to 113
A	Area of the exposed surface	square feet	square meters
DT	Temperature difference between the exposed surface and ambient	Degrees F	Degrees C

HEAT TRANSFER THROUGH THE WALLS OF AN INSULATED ENCLOSURE: Heat leak to or from an insulated container combines an element of thermal conduction through the insulating material with an element of convection loss at the external insulation surfaces. Heat lost from (or gained by) an insulated enclosure may be expressed mathematically as:

$$Q = (A)(DT)$$

$$\frac{x}{K} \qquad \frac{1}{h}$$

Where:

Symbol	Definition	English Units	Metric Units
Q	Heat conducted through the enclosure	BTU/hour	watts

Symbol	Definition	English Units	Metric Units
K	Thermal conductivity of the insulation	BTU/hour-ft°F	watts/meter-°C
A	External surface area of the enclosure	square feet	square meters
x	Thickness of the insulation	feet	meters
DT	Temperature difference between the inside and outside of the enclosure	Degrees F	Degrees C
h	Heat transfer coefficient For still air use a value of: For turbulent air use a value of:	BTU/hour-ft^2-°F 4 to 5 15 to 20	watts/meter^2-°C 23 to 28 85 to 113

TIME NEEDED TO CHANGE THE TEMPERATURE OF AN OBJECT: Determination of the time required to thermoelectrically cool or heat a given object is a moderately complicated matter. For good accuracy, it would be necessary to make a detailed analysis of the entire thermal system including all component parts and interfaces. By using the simplified method presented here, however, it is possible to make a reasonable estimate of a system's thermal transient response.

$$t = \frac{(m)(C_p)(DT)}{Q}$$

where:

Symbol	Definition
t	Time period for temperature change
m	Weight of material

Symbol	Definition
C_p	Specific heat of the material
DT	Temperature change of the material
Q	Heat transferred to or from material

Note (1): 1 Watt = 0.239 calories/second
Note (2): Thermoelectric modules pump heat at a rate that is proportional to the

temperature difference (DT) across the module. In order to approximate actual module performance,

the average heat removal rate should be used when determining the transient behavior of a thermal system.

The average heat removal rate is:

$$Q = 0.5\ (Q_c \text{ at } DT_{min} + Q_c \text{ at } DT_{max})$$

where:

Q_c at DT_{min} is the amount of heat a thermoelectric module is pumping at the initial object temperature when DC power is first applied to the module. The DT is zero at this time and the heat pumping rate is at the highest point.

Q_c at DT_{max} is the amount of heat a thermoelectric module is pumping when the object has cooled to the desired temperature. The DT is higher at this time and the heat pumping rate is lower.

HEAT TRANSFER FROM A BODY BY RADIATION: Most thermoelectric cooling applications involve relatively moderate temperatures and small surface areas where radiation heat losses usually are negligible. Probably the only situation where thermal radiation may be of concern is that of a multistage cooler operating at a very low temperature and close to its lower limit. For such applications, it sometimes is possible to attach a small radiation shield to one of the lower module stages. By fabricating this shield so that it surrounds the upper stage and cooled object, thermal radiation losses may be reduced substantially.

As an indication of the magnitude of heat leak due to thermal radiation, consider the following. A perfect black-body having a surface area of 1.0 cm^2 and operating at -100°C (173°K) will receive approximately 43 milliwatts of heat from its 30°C (303°K) surroundings. Be aware that the accurate determination of radiation loss is a highly complicated issue and a suitable heat transfer textbook should be consulted for detailed information. A very simplified estimation of such losses may be made, however, by using the equation given below.

Q_R=(s)(A) (e) (T_h^4 T_c^4)

where: **R-VALUE OF INSULATION:** The R-value of an insulating material is a measure of the insulation's overall effectiveness or resistance to heat flow. R-value is not a scientific term, per se, but the expression is used extensively within the building construction industry in the United States. The relationship between R-value, insulation thickness, and thermal conductivity may be expressed by the equation:

x = Thickness of the insulation in inches

k = Thermal conductivity of the insulation in BTU/hr-ft-°F

Note: Insulation R-value normally is based on insulation thickness in inches. Since thermal conductivity values in Appendix B are expressed in feet, the k value in the equation's denominator has been multiplied by 12.

THERMAL INSULATION CONSIDERATIONS: In order to maximize thermal performance and minimize condensation, all cooled objects should be properly insulated. Insulation type and thickness often is governed by the application and it may not be possible to achieve the optimum insulation arrangement in all cases. Every effort should be made, however, to prevent ambient air from blowing directly on the cooled object and/or thermoelectric device.

Figures (2.2) and (2.3) illustrate the relationship between the heat leak from an insulated surface and the insulation thickness. It can be seen that even a small amount of insulation will provide a significant reduction in heat loss but, beyond a certain point, greater thicknesses give little benefit. The two heat leak graphs show heat loss in watts per square unit of surface area for a one degree temperature difference (DT) through the insulation. Total heat leak (Qtot) in watts for other surface areas (SA) or DT's may be calculated by the expression:

$Q_{tot} = Q_{leak}$ x SA x DT

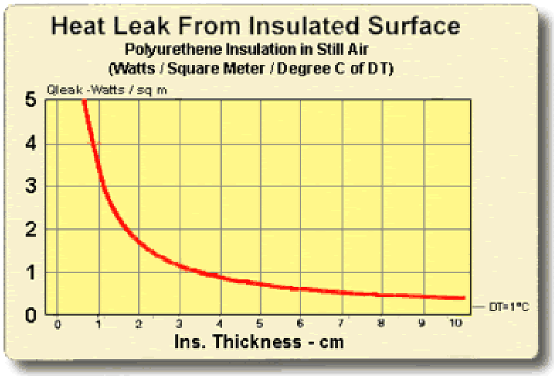


Figure (2.2)Heat Leak from an Insulated Surface in Metric Units

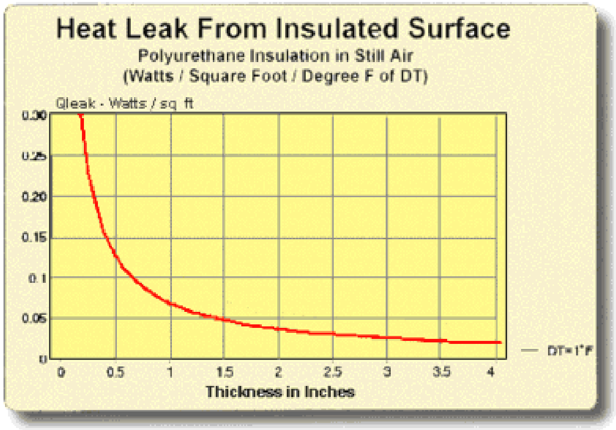


Figure (2.3)Heat Leak from an Insulated Surface in English

Thermoelectric Module Selection

Selection of the proper TE Cooler for a specific application requires an evaluation of the total system in which the cooler will be used. For most applications it should be possible to use one of the standard module configurations while in certain cases a special design may be needed to meet stringent electrical, mechanical, or other requirements. Although we encourage the use of a standard device whenever possible, Ferrotec America specializes in the development and manufacture of custom TE modules and we will be pleased to quote on unique devices that will exactly meet your requirements.

The overall cooling system is dynamic in nature and system performance is a function of several interrelated parameters. As a result, it usually is necessary to make a series of iterative calculations to “zero-in” on the correct operating parameters. If there is any uncertainty about which TE device would be most suitable for a particular application, we highly recommend that you contact our engineering staff for assistance.

Before starting the actual TE module selection process, the designer should be prepared to answer the following questions:

- At what temperature must the cooled object be maintained?
- How much heat must be removed from the cooled object?
- Is thermal response time important? If yes, how quickly must the cooled object change temperature after DC power has been applied?
- What is the expected ambient temperature? Will the ambient temperature change significantly during system operation?
- What is the extraneous heat input (heat leak) to the object as a result of conduction, convection, and/or radiation?
- How much space is available for the module and heat sink?
- What power is available?

- Does the temperature of the cooled object have to be controlled? If yes, to what precision?
- What is the expected approximate temperature of the heat sink during operation? Is it possible that the heat sink temperature will change significantly due to ambient fluctuations, etc.?

Each application obviously will have its own set of requirements that likely will vary in level of importance. Based upon any critical requirements that can not be altered, the designer's job will 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 to illustrate the concepts involved in the typical engineering process.

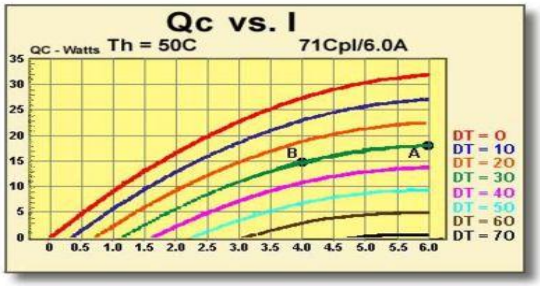
USE OF TE MODULE PERFORMANCE GRAPHS:

Before beginning any thermoelectric design activity it is necessary to have an understanding of basic module performance characteristics. Performance data is presented graphically and is referenced to a specific heat sink base temperature. Most performance graphs are standardized at a heat sink temperature (Th) of +50°C and the resultant data is usable over a range of approximately 40°C to 60°C with only a slight error. Upon request, we can supply module performance graphs referenced to any temperature within a range of -80°C to +200°C.

To demonstrate the use of these performance curves let us present a simple example. Suppose we have a small electronic "black box" that is dissipating 15 watts of heat. For the electronic unit to function properly its temperature may not exceed 20°C. The room 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 purpose of this example we will neglect the heat sink (we cannot do this in practice) other than to state that its temperature can be maintained at 50°C under worst-case conditions. We will investigate the use of a 71-couple, 6-ampere module to provide the required cooling.

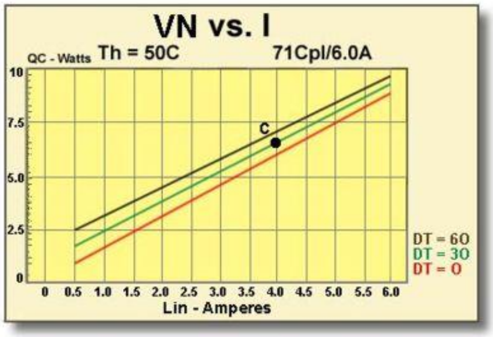
GRAPH: Qc vs. I This graph, shown in Figure (2.4), relates a module's heat pumping capacity (Qc) and temperature difference (DT) as a function of input current (I). In this example, established operating parameters for the TE module include Th = 50°C, Tc = 20°C, and Qc = 15 watts. The required DT = Th-Tc = 30°C.

It is necessary first to determine whether a single 71-couple, 6-ampere module is capable of providing sufficient heat removal to meet application requirements. We locate the DT=30 line and find that the maximum 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 can see that the module is capable of pumping approximately 18 watts while maintaining a Tc of 20°C. Since this Qc is slightly higher than necessary, we follow the DT=30 line downward until we reach a position (point B) that corresponds to a Qc of 15 watts. Point B is the operating point that satisfies our thermal requirements. By extending a line downward from point B to the x-axis, we find that the proper input current is 4.0 amperes.



Heat Pumping Capacity Related to Temperature Differential as a Function of Input Current for a 71-Couple, 6-Ampere Module

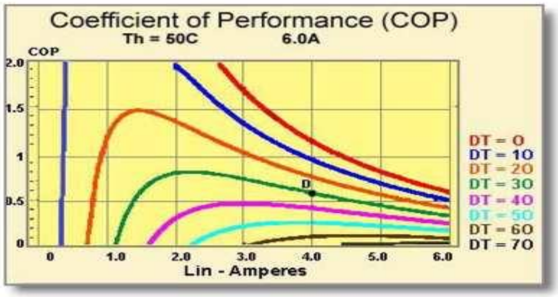
GRAPH: Vin vs. I This graph, shown in Figure (2.5), relates a module’s input voltage (Vin) and temperature difference (DT) as a function of input current (I). In this example, parameters for the TE module include Th = 50°C, DT = 30°C, and I = 4.0 amperes. We locate the DT=30 line and, at the 4.0 ampere intersection, mark point C. By extending a line from point C to the left y-axis, we can see that the required module input voltage (Vin) is approximately 6.7 volts.



Input Voltage Related to Temperature
Differential as a Function of Input Current for a 7I-Couple, 6-Ampere Module

GRAPH:COP vs. I This graph, shown in Figure (2.6), relates 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°C, DT = 30°C, and I = 4.0 amperes.

We locate the DT=30 line and, at the 4.0 ampere intersection, mark point D. By extending a line from point D to the left y-axis, we can see that the module's coefficient of performance is approximately 0.58.

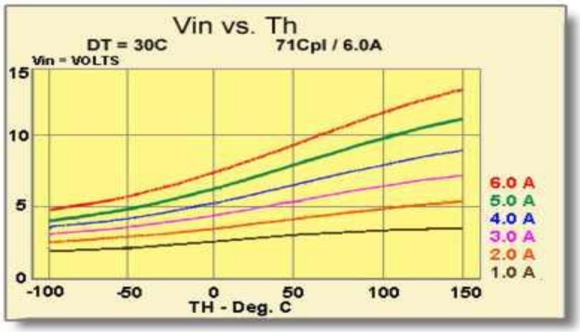


Coefficient of Performance Related to Temperature Differential
as a Function of Input Current for a 71-Couple, 6-Ampere Module

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:

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

An additional graph of Vin vs. Th, of the type shown in Figure (2.7), relates a module's input voltage (Vin) and input current (I) as a function of module hot side temperature (Th). Due to the Seebeck effect, input voltage at a given value of I and Th is lowest when DT=O and highest when DT is at its maximum point. Consequently, the graph of Vin vs. Th usually is presented for a DT=30 condition in order to provide the average value of Vin.



Input Voltage Related to Input Current as a Function of
Hot Side Temperature for a 71-Couple, 6-Ampere Module

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 with related electronics, is to be mounted in a DIP Kovar housing and must be maintained at a temperature of 25°C. With the housing mounted on the system circuit board, tests show that the housing has a thermal resistance of 6°C/watt. The laser electronics dissipate a total of 0.5 watts and the design maximum ambient temperature is 35°C.

It is necessary to select a TE cooling module that not only will have sufficient cooling capacity to maintain the proper temperature, but also will meet the dimensional requirements imposed by the housing. An 18-couple, 1.2 ampere TE cooler is chosen initially because it does have compatible dimensions and also appears to have appropriate performance characteristics. Performance graphs for this module will be used to derive relevant parameters for making mathematical calculations. To begin the design process we must first evaluate the heat sink and make an estimate of the worst-case module hot side temperature (Th). For the TE cooler chosen, the maximum input power (Pin) can be determined from Figure (2.8) at point A.

1. Max. Module Input Power (Pin) = 1.2 amps x 2.4 volts = 2.9 watts
2. Max. Heat Input to the Housing = 2.9 watts + 0.5 watts = 3.4 watts
3. Housing Temperature Rise = 3.4 watts x 6°C/watt = 20.4°C
4. Max. Housing Temperature (T,) = 35°C ambient + 20.4°C rise = 55.4°C Since the hot side temperature (Th) of 55.4°C is reasonably close to the available Tin = 50°C performance graphs, these graphs may be used to determine thermal performance with very little error.

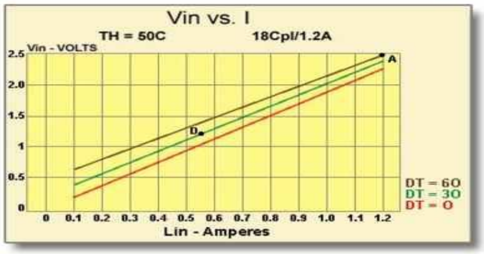


Figure Vin vs. I Graph for an 18-Couple, I.2 Ampere Module

Now that we have established the worst-case Th value it is possible to assess module performance.

Module Temperature Differential (DT) = Th – Tc = 55.4 – 25 = 30°C

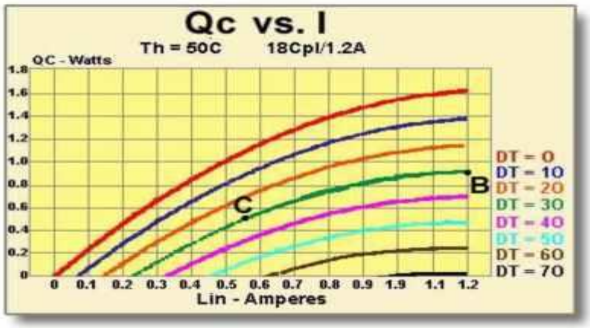


Figure 2.9 Qc vs. I Graph for an 18-Couple, 1.2 Ampere Module

From Figure (2.9) it can be seen that the maximum heat pumping rate (Qc) for DT=30 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=30 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 can see that an input current (I) of approximately 0.55 amperes will provide the required cooling performance. Referring back to the Vin vs. I graph in Figure (2.5), a current of 0.55 amperes, marked as point D, requires a voltage (Vin) of about 1.2 volts. We now have to repeat our analysis because the required input power is considerably lower than the value used for our initial calculation. The new power and temperature values will be:

- Max. Module Input Power (Pin) = 0.55 amps x 1.2 volts = 0.66 watts
- Max. Heat Input to the Housing = 0.66 watts + 0.50 watts = 1.16 watts
- Housing Temperature Rise = 1.16 watts x 6 C/watt = 7°C
- Max. Housing Temperature (Th) = 35°C ambient + 7°C rise = 42°C

Module Temperature Differential (DT) = Th-Tc = 42°C-25°C = 17°C

It can be seen that because we now have another new value for Th it will be necessary to continue repeating the steps outlined above until a stable condition is obtained. Note that calculations usually are repeated until the difference in the Th values from successive calculations is quite small (often less that 0.1 C for good accuracy). There is no reason to present the repetitive calculations here but we can conclude that the selected 18-couple TE module will function very well in this application. This analysis clearly shows the importance of the heat sink in any thermoelectric cooling application.

USE OF MULTIPLE MODULES

Relatively large thermoelectric cooling applications may require the use of several individual modules in order to obtain the required rate of heat removal. For such applications, TE modules normally are mounted thermally in parallel and connected electrically in series. An electrical series-parallel connection arrangement may also be used advantageously in certain instances. Because heat sink performance becomes increasingly important as power levels rise, be sure that the selected heat sink is adequate for the application.

MODULE RELIABILITY RELATED TO ON/OFF POWER CYCLING

As discussed previously, the accepted industry standard for thermoelectric module MTBF is 200,000 hours minimum. This MTBF value is based on relatively steady-state module operation where system power is occasionally (typically a few times per day) turned on and off. In some applications power is turned on and off more frequently especially where thermostatic temperature control is used. A test was conducted using ValueTEC™ Series modules to study the effects of ON/OFF power cycling at a relatively constant temperature. Modules were mounted between a pair of forced convection cooled heat sinks using thermal grease at the module/heat sink interfaces. Full rated current was supplied to the modules for a period of 7.5 seconds followed by a 7.5 second “off” period that resulted in one complete ON/OFF cycle every

15 seconds. The input current to each module was monitored and a failure was indicated by an appreciable current decrease resulting from an increase in module electrical resistance. The test was run until an arbitrary total of 25,000 hours or approximately 6 million cycles was accrued. For these test conditions, the calculated MTBF was 125,000 hours or 3×10^7 on off cycles.

CAUTION: Most conventional thermostats inherently have moderately large open/close temperature differentials. This condition may effectively set up a thermal cycling situation where the temperature of the TE module is continuously varying between the upper and lower differential limits. Since thermal cycling is known to reduce the life of thermoelectric modules, the use of traditional ON/OFF thermostatic temperature control schemes is not recommended for high-reliability applications.

High Temperature Operations and Storage:

150°C for 30,000+ hours

Low Temperature Operations and Storage:

-40°C for 1000+ hours

Thermal Shock:

(a) 100°C (15 sec)/100°C (15 sec), 10 cycles
(b) 150°C (5 min)/-65°C (5 min)/ 150°C, 10 cycles
(c) MIL-STD-202, Method 107
Range for Value TEC™ Series modules: -55°C to +85°C
Range for Super TEC™ Series modules: -65°C to 150°C

Mechanical Shock:

(a) 100G, 200G 2 6msec; 500G, 1000G @1 sec 3-axis, three shocks each axis
(b) MIL-STD-202, Method 213, Test Condition I

Vibration:

(a) 10/55/10 Hz,1 minute cycle, 9.1G, 3-axis, 2-hours each axis
(b) MIL-STD-202, Method 204A, Test Condition B, 15G Peak

CONCLUDING REMARKS

In the foregoing discussion we have emphasized the great dependence of thermoelectric module reliability on application conditions. By following some basic guidelines, and with knowledge of how certain factors tend to affect module life, it should be possible for designers to optimize system reliability. While some may wish to perform a comprehensive analysis and model all relevant parameters, many users having unusual requirements or non-traditional configurations often turn to an empirical approach for determining the reliability of their specific application.

Methodology

- At the junction of two dissimilar metals thr energy level of conducting electrons is forced to increase or decrease.
- A decrease in the energy level emits thermal energy.While an inverse will absorb thermal energy from its surroundings.
- The temperature gradient for dissimilar metals is very small.
- Bismuth-Telluride n and p blocks.
- An electric in N type and holes in P type away from each other on the cold side and towards each other on the hot side.
- The holes and electrons pull thermal energy from where they are heading away from each other and deliver it to where they meet.
- Individual couples are connected in series electrically and in parallel thermally.
- Couples are thermally connected by a ceramic that has high electr- ical resistivity and high thermal conductivity.
- As project is based on peltier effect our first main step is to select a right peltier module.
- The assembly are all made as we reqiuerd.Solar panel gives current.
- The current is passes through the peltier the peltier starts its work.
- The cooling of small chamber will be started.
- Note the temperature before starting the refrigeration. Note the temperature at every 5 mins.

Thus refrigeration was controlled by switch and Tempe ration inside the chamber will be shown by digital temperature indicator. Thermoelectric coolers operate according to the Peltier effect. The effect creates a temperature difference by transferring heat between two electrical junctions. A voltage is applied across joined conductors to create an electric current. When the current flows through the junctions of the two conductors, heat is removed at one junction and cooling occurs. Heat is deposited at the other junction.

The main application of the Peltier effect is cooling. However the Peltier effect +can also be used for heating or control of temperature. In every case, a DC voltage is required.

Thermoelectric coolers from II-IV Marlow act as a solid-state heat pump. Each features an array of alternating n- and p- type semiconductors. The semiconductors of different type have complementary Peltier coefficients. The array of elements is soldered between two ceramic plates, electrically in series and thermally in parallel. Solid solutions of bismuth telluride, antimony telluride, and bismuth selenide are the preferred materials for Peltier effect devices because they provide the best performance from 180 to 400 K and can be made both n-type and p-type.

The cooling effect of any unit using thermoelectric coolers is proportional to the number of coolers used. Typically multiple thermoelectric coolers are connected side by side and then placed between two metal plates. . II-VI Marlow features three different types of thermoelectric coolers including: Thermocyclers, Single Stage, and Multi-Stage.

3.1.HEAT ABSORBTION:Cooling occurs when a current passes through one or more pairs of elements from n- to p-type; there is a decrease in temperature at the junction ("cold side"), resulting in the absorption of heat from the environment. The heat is carried along the elements by electron transport and released on the opposite ("hot") side as the electrons move from a high- to low-energy state.

The Peltier heat absorption is given by Q = P (Peltier Coefficient) I (current) t (time). A single stage thermoelectric cooler can produce a maximum temperature difference of about 70 degrees Celsius. However, II-VI Marlow’s Triton ICE Thermoelectric Cooler will chill electronics as much as 2 degrees Celsius below current market offerings.

As was discussed in the previous section, modeling allows the designer to understand and optimize the critical parameters which influence the performance of a TED system. For accurate prediction, it is critical that the input parameters are accurate, and applicable to the temperature range of interest. It is only from direct measurement these critical parameters can be obtained. The measurement method we will propose offers the high measurement confidence needed to make accurate performance predictions. Moreover, due to the fundamental simplicity of the method, results do not depend on any heat flow or temperature assumptions, as these are directly measured for both control and sink-sides of the TED. In this test method, a TED can be analysed in a state which closely represents the use-condition (i.e. the TED is subject to a heat load, under a given current and voltage input). All temperatures and heat flows can be directly measured. Due to the in-situ nature of the method, the metrology use can easily be extended to many other fundamental characterization studies, including reliability studies, and control scheme studies. The metrology, as will be show, offers many unique capabilities not available using other characterization methods.

A schematic of the metrology can be seen in Figure 8 and Figure 9. The metrology system consists of primarily two large aluminium blocks which can be actuated together with a given pressure, and between which a TED can be inserted. The blocks are the same footprint area as the TED being studied, and serve as a 1D conduction heat-flow path through which heat flow can be directly measured. Insulation was added to the periphery of the aluminium blocks to minimize the heat loss from the sides. To measure the heat flow through the aluminium blocks, a temperature gradient is measured normal to the TED faces, using thermocouples embedded at known locations – these measurement locations are represented in the figure as T_1, T_2, and T_3 for the lower aluminium block, and T_4, T_5, and T_6 for the upper aluminium block. Below the lower aluminium block, a heater is used to simulate power generated from a device. Insulation was included under the heater to minimize heat loss from the bottom of the setup, even though the actual power through the TED is measured directly using the thermocouples. Above the top aluminium block, a liquid cooled cold plate is used as a heat sink. A thermal interface material (TIM) is used between the TEC and aluminium block faces to ensure adequate thermal contact.

All physical temperature measurement locations can be seen in Figure 8. In the metrology, thermocouples are present across the top and bottom faces of the TED. The TED face temperature is measured in three in-plane locations on each the top and the bottom of the TED.

RESULT AND DISSCUSION

The Peltier effect can be used to create a refrigerator that is compact and has no circulating fluid or moving parts. Such refrigerators are useful in applications where their advantages outweigh the disadvantage of their very low efficiency. The Peltier effect is also used by many thermal cyclers, laboratory devices used to amplify DNA by the polymerase chain reaction (PCR). PCR requires the cyclic heating and cooling of samples to specified temperatures. The inclusion of many thermocouples in a small space enables many samples to be amplified in parallel.

The Peltier effect occurs whenever electrical current flows through two dissimilar conductors; depending on the direction of current flow, the junction of the two conductors will either absorb or release heat. In the world of thermoelectric technology, semiconductors (usually Bismuth Telluride) are the material of choice for producing the Peltier effect because they can be more easily optimized for pumping heat. Using this type of material, a Peltier device (i.e., thermoelectric module) can be constructed in its simplest form around a single semiconductor “pellet” which is soldered to electrically-conductive material on each end (usually plated copper). In this configuration, the second dissimilar material required for the Peltier effect, is actually the copper connection paths to the power supply. [10] It is important to note that the heat will be moved in the direction of charge carrier movement throughout the circuit (actually, it is the charge carriers that transfer the heat).

CONCLUSION

From this project we can conclude that without the use of CFC, compressor and other artificial refrigeration’s, it is possible to cool a system. There are several other different types are there for to reduce heat. Buy peltier module refrigeration is an easy and simple way to cool a system.

Since Peltier cooling is not efficient comparatively and due to its small size applications, it is not widely used. It found its application only in electronics cooling etc. But, we have seen that there is a huge scope of research in this field about thermoelectric materials, its fabrication, heat sink design etc. Researcher are working on reducing irreversibility’s in the systems, because Peltier cooler has more potential which we can see from the vast difference between value of first law efficiency and second law efficiency.

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