Thermoelectric Module Installation Guidance

Introduction

The aim of this document is to describe the process for mounting a thermoelectric module for use in a system. Considerations for mounting cooler and generator modules are outlined along with more general tips for achieving the maximum potential from your device.

Correct thermal coupling of a thermoelectric module is paramount for its function in a system as the devices rely on thermal transfer through the module, so any limitations to the thermal transfer will cause significant performance reductions. The most common interface at which thermal losses occur are between the heat exchangers and the ceramic faces of the module; best practice for these interfaces are outlined in this document.

Module Orientation

The first step is to understand which direction the module ought to be mounted for the application. This is important as maximum temperature specifications can often differ for each side.

Cooler Modules

The hot and cold side of cooler module can be identified in a number of ways.

1. The device may have printed markings, for example “Hot side” and “Cold side” or the European Thermodynamics logo is printed onto the hot side.
2. Use the colour coding of the positive (red) and negative (black) wires. Place the module on a flat surface so that the wires are pointing towards you with the positive (red) wire on the left hand side and the negative (black) wire on the right hand side. In this orientation the cold side will be facing down and the hot side will be facing up towards you.
3. Directly measure by operating the cooler module. Before doing this test, check the data sheet for the electrical power input characteristics of the device you are testing. Connect the module to a power supply ensuring the polarity is correct, red wire to the positive terminal and black wire to the negative terminal. Momentarily apply a voltage to the device which is approximately 10% of the Vmax value stated on the data sheet. Pinching the device between your index finger and thumb, a temperature differential will be felt. Take a note of which side is the cold and which side is

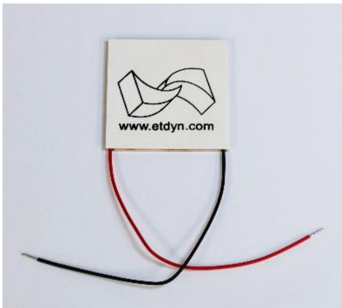


Figure 1. Thermoelectric module. The logo shows the hot side, and the red wire on the left hand side also means that the hot side is uppermost.

the hot side. Terminate the power supply as soon as the temperature differential is observed.

4. For unsealed cooler modules the hot side of the device can be found by identifying which side of the module has the wires soldered to. Looking at the corner of the device where one of the wires enters the module, the side that the wire is soldered to is the hot side.

Generator Modules

The hot and cold side of cooler module can be identified in a number of ways:

1. The device may have printed markings, for example “Hot side” and “Cold side” or the European Thermodynamics logo is printed onto the hot side.
2. Use the colour coding of the positive (red) and negative (black) wires. Place the module on a flat surface so that the wires are pointing towards you with the positive (red) wire on the left hand side and the negative (black) wire on the right hand side. In this orientation the cold side will be facing down and the hot side will be facing up towards you.
3. Directly measure by operating the module as a generator. Attach the wires to the corresponding coloured leads of a voltmeter and place the device on a surface that is likely to be at room temperature or less e.g. a table top. Place your hand on the side of the module which is facing up, this will simulate the module under a temperature differential as your hand should be warmer than the surface of the table. If a positive voltage is recorded on the voltmeter, the hot side is the face touching your hand. If a negative voltage is registered, then the cold side is the face that your hand is touching.
4. The cold side of a generator module can be found by identifying which side of the module has the wires soldered to. Looking at the corner of the device where one of the wires enters the module, the side that the wire is soldered to is the cold side.

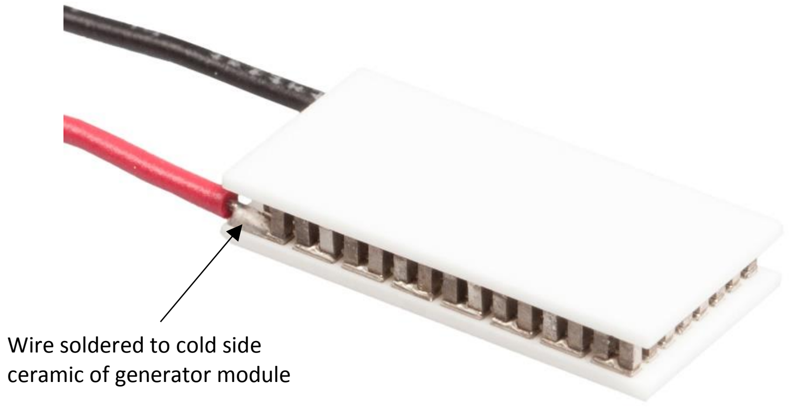


Figure 2. Image of generator module showing how the wires are soldered to the cold side.

Interface Materials

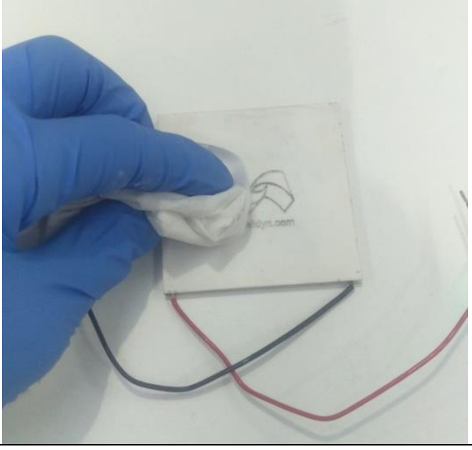
Interface materials between the mating surface and thermoelectric cooler and generator modules are very important for achieving the best performance from your device. To improve the heat transfer between the module and heat exchanger a variety of interface materials can be used, the choice of which depends on the application and working temperature of the system.

The mating surfaces that thermally couple to the module via the interface material must be capable of good thermal coupling. We typically recommend a flatness~0.05mm, and average roughness ~1.6 microns for best results. Note that this surface must also fulfil the clamping requirements discussed in later sections.

Thermal Grease

For operating conditions below 100^{o}C thermal greases are commonly used as the interface material due to their high thermal conductivity. This type of interface material is often used for cooler modules and the cold side of generator modules to thermally couple them to a heat exchanger. The thermal grease is spread onto the ceramic surface of the modules to reduce the air gap caused by surface roughness, thus increasing surface contact area.

The key to achieving a good thermal joint between the module and heat exchanger is to use as little grease as possible while covering the whole area. Figure 3 shows a process flow for applying thermal paste to a thermoelectric module.

Clean the surface of debris and grease with isopropanol (IPA) or a similar degreasing/solvent product. Note: it is recommended to wear the appropriate PPE during this process.	

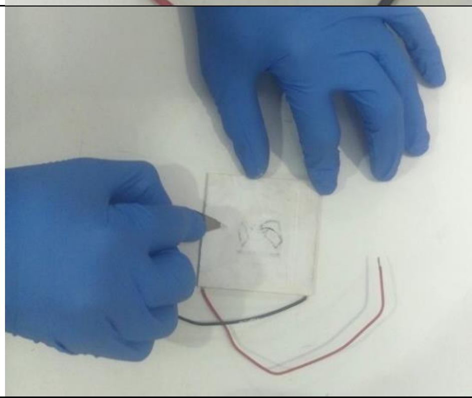
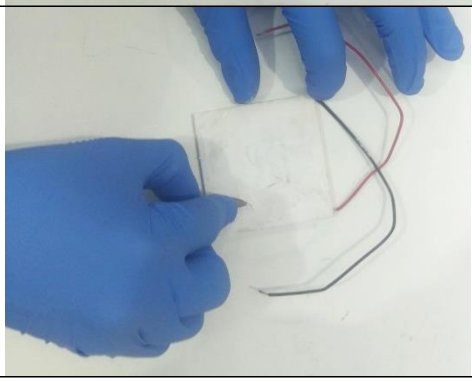
Apply a pea sized amount of thermal grease to the centre of the ceramic surface on the module.	
Use a plastic card or blade to spread the grease over the surface of the ceramic, ensuring no areas are uncovered.	
Do a final scrape to ensure an even coverage is applied and remove as much excess grease as possible. As a gauge of thickness, if a stamp or marking on the module is present, it should be partially visible.	

Figure 3. Process flow for application of thermal grease to a thermoelectric module.

We recommend the silicone grease with RS part number 7074736 for best performance, but 7074724 or 7074733 are lower cost alternatives. If a non-silicone grease is desired, RS part number 9156118 or 9156105 can be used.

Graphite Sheet

Thermal greases can dry out at higher temperatures especially in systems that require very long lifetimes. In these situations graphite sheet materials can be used. Their thermal performance is approximately equivalent (<2% difference) to a thermal grease under adequate clamping pressures. Graphite sheets can be easily cut into shape before assembly, and easily removed, for example if used for test purposes only.

We recommend graphite sheets such as RS product number 707-4786.

Graphite sheets with an added adhesive layer can be used to aid assembly, but note that they can lead to a 5-10% loss in module performance.

Gap fillers

Gap fillers are often made from silicone and offer moderate thermal conductivities (1-5 W/mK). Their significant advantages lie in the complexity of shapes and patterns that they can be supplied in, including a greater tolerance to height variations; furthermore, they offer moderate protection to systems which are subject to vibrational forces. However their thermal performance is typically lower than graphite sheets and greases, due to their higher thicknesses. These are not recommended unless the mating surface requirements below cannot be met.

Bonding Methods

A direct mechanical bonding method can be used to permanently attach the hot side of the module to the heat sink for improved thermal contact and simplification of assembly. However this introduces additional thermal stresses on the module due to thermal expansion mismatches so is not typically recommended, and should only be used with modules <20x20mm. A high thermal conductivity epoxy can be used or a solder in the case where the ceramic has a metallised outer surface.

Epoxy

To mount with a thermally conductive epoxy, the steps are similar to the method explained in Figure 3. When mounting the hot side, apply a thin layer of epoxy and mate the face with the heat exchanger. When curing, apply pressure to the joint to minimise the bond line and remove excess epoxy. Cure the epoxy according to the manufacturer's guidelines.

Soldering

Metallised modules can be mounted using regular methods like thermal grease or gap fillers, but they also enable the user to directly bond the module to the heat exchanger by soldering. A solder must be used which is of a lower melting temperature in comparison to that used within the thermoelectric module. For example, a solder with a melting temperature of 20°C to 30°C lower than the maximum hot side temperature of a module would be used for a typical module i.e. 130°C max hot side would require a 100°C solder (e.g. Bi52 Pb30 Sn18).

Pre-tinning of the heat exchanger and metallisation areas on the module is necessary prior to the final joining stage. When soldering the module to the heat exchanger, ensure a flux is used for optimal bonding and a pressure is applied during the soldering process and in the cooling stages to minimise the bond line.

Module Clamping and Assembly Considerations

The final stage of implementing a thermoelectric module into your system is the clamping and system assembly stage. It is important to achieve sufficient clamping and maintain thermal isolation for the surrounding components to achieve maximum performance from the device. Failure to clamp a thermoelectric module sufficiently can lead to performance losses of ~ 20% or more.

Figure 4 shows an example of a thermoelectric cooler system. A thermoelectric cooler module is used to remove heat from the water through a heat exchanger and the heat is expelled from the system through a heat sink which is actively cooled by a fan. Compression is applied to the module via bolts which are thermally insulated using plastic bushes to reduce parasitic losses to the system. This example is used to describe the three important factors in assembling a thermoelectric cooler system: clamping load, even clamping and reduction of parasitic thermal losses.

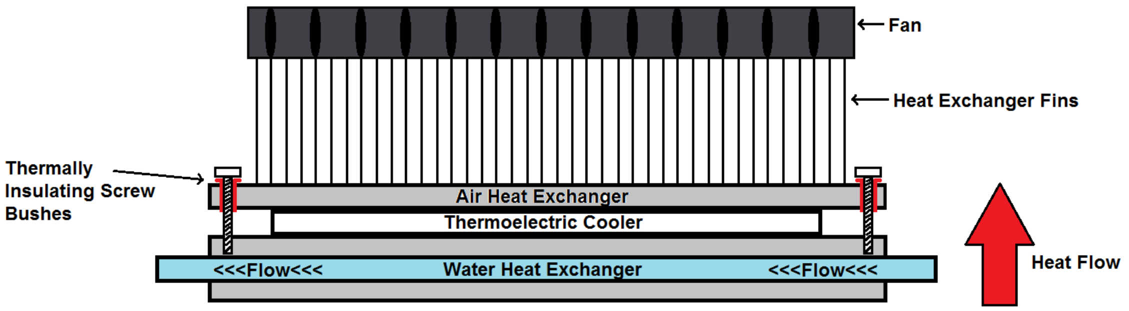


Figure 4. Example of a liquid to air thermoelectric cooler system.

Thermoelectric modules require a clamping load of 0.5-1.2 MPa. To achieve this clamping load in a system, bolts are most commonly used which are tightened to a specific torque. To calculate the torque necessary to achieve the required clamping force, the following formula can be used:

$$T = \frac{c \times D \times P \times A}{N}$$

Where:

c = Torque Coefficient

D = Nominal Bolt Size (in. or m)

P = Compression Pressure (Pa or psi)

A = Total Module Footprint Area (in.^{2} or m^2)

N = Number of Screws

T = Torque per Screw (lb-in. or N-m)

Values for torque coefficient (c) and nominal bolt size (D) will need to be found from the bolt supplier. As an example, steel bolts have an estimated 'c' value of 0.2, and a lubricated steel bolt is between 0.16 and 0.17. The nominal bolt size represents the major diameter of the bolt, for example an M5 bolt will have a major diameter of 5.2mm.

For example, considering the system in Figure 4, four M5 bolts are used to clamp a 40mm x 40mm module. The bolts are applied un-lubricated and so their value of 'c' can be approximated at 0.2. The nominal bolt size 'D' is 5.2mm and we are aiming to achieve 1.2MPa clamping. Therefore:

$$T = \frac{0.2 \times 0.0052 \times 1200000 \times 0.040 \times 0.040}{4}$$

⇨ Torque per Bolt = 0.50N.m

Belleville washers are recommended to be used in conjunction with the bolts to allow for changes in compression as the system settles and to allow tolerance for thermal stresses in the system when in operation.

> ***Tip:*** *Clamp your system to the required amount and then (if possible) run in steady state for 60 minutes to allow the interface layers to relax. Check and re-torque the bolts if necessary to ensure sufficient clamping remains for the lifetime of the system in use.*

To achieve even clamping and optimal thermal contact, it is recommended that care is taken during the bolt tightening stage to ensure an even load and turning rate is applied to each bolt. A bolt tightening sequence can be used for particular types of bolt patterns as shown in Figure 5, opposing bolts are tightened to ensure even clamping is achieved. Tightening in stages can be done by incrementally increasing the torque on each pass i.e. first pass – finger tight, second pass – 25% torque, third pass – 75% torque and 100% torque on final pass. Uneven clamping can cause poor thermal contact and damage to the thermoelectric module.

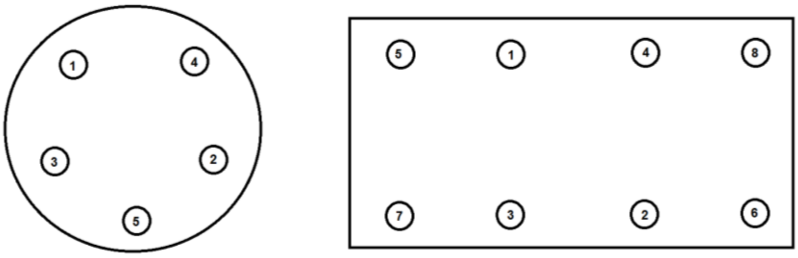


Figure 5. Bolt tightening sequence for a circular pattern and rectangular pattern.

Finally, to reduce parasitic thermal losses in the system, plastic bolt bushes and insulating gaskets can be used. Plastic bolt bushes thermally isolate the hot and cold heat exchangers to reduce thermal losses along the clamping bolts. A thermally insulating foam gasket can be applied around the module which is clamped between the hot and cold heat exchangers to further reduce losses in the system.

Multiple modules

Multiple modules, and/or clamping plates covering large areas can increase the challenges of even clamping pressures on all modules. European Thermodynamics can offer modules with a reduced height tolerance, for example by lapping modules to a pre-set height after production.