The Effect of Power Cycling on the Migration of Thermoelectric Modules Within a Cooling Assembly

Michael J. Nagy
TE Technology, Inc.
1590 Keane Drive, Traverse City, Michigan 49686 USA
Email: cool@tetech.com, Phone: (231) 929-3966, Fax: (231) 929-4163

Abstract

Some thermoelectric modules will shift, or migrate, from their original position in a cooling assembly after the cooler has been in operation. This movement can cause catastrophic failure in the assembly if it is severe enough. This failure can occur in several ways: by moving the module off of the extender block (if used), or by tearing the power wires from their solder connections.

This paper presents a case study to determine if power cycling is a contributor to module migration. Four similar cooling assemblies, of a type that has exhibited module migration in operation, were manufactured under controlled conditions to ensure that each assembly was built in exactly the same way or much as possible. The module position was recorded as each cooler was assembled. Coolers were operated without power cycling, and then the coolers were power cycled by sequencing positive and negative current to the modules. The position of each module was noted at each stage in the test. This data was used to indicate if cycling of applied power caused a migration of the thermoelectric modules, and if this migration was consistent from assembly to assembly.

An alternative construction technique of using a conformable thermal interface was tested to determine if module migration could be mitigated.

Introduction

It has been noted in some thermoelectric assemblies that the modules will migrate from their original positions on the heat sink and cold sink. This does not occur while the assembly is being built, but after some period of operation. Generally, it occurs in assemblies that use more than one module, and it is typical that one or more of the modules remain in their original position while the remaining modules move.

This movement can cause loss of performance or catastrophic failure. If the module shifts and looses some contact with a cold sink extender, for example, there will be a loss of thermal performance. If a module moves enough, the wires may be pulled from their solder connections, and a complete failure will occur.

It has long been suspected by the author that power cycling, and the thermal cycling that it induces, contributes to module migration. This may help explain why migration occurs in some assemblies and not in others. One type of assembly may be placed in a machine where no power cycling occurs, while in other machines the assembly is specifically used for thermal cycling. Still other assemblies may be used in machines where the cooler is not intentionally power cycled, but the machine is turned on and off hundreds of times during its lifetime, thus causing inadvertent power cycling.

Consequently, a set of experiments was designed to answer the following questions:

1. Does power cycling contribute to module migration?
2. If power cycling contributes to migration, is the migration consistent from assembly to assembly?
3. Is module migration dependent on assembly techniques?
4. Do the induced temperatures in power cycling dictate the direction of module movement?
5. Are there any fabrication techniques that reduce or eliminate module migration?

Test Assemblies

Four assemblies, identical in design and specifications, were used for the experiment. These assemblies were chosen because they were used in production quantities and had exhibited module migrations in service. The assembly consisted of a cast aluminum cold plate (Figure 1), two four-amp 127 couple thermoelectric (Figure 2) modules, and an extruded aluminum heat sink (Figure 3). A complete assembly is shown in Figure 4. The mounting surfaces of the heat sink and cold sink were machined flat within 25 μm. The modules were matched in pairs with no more than 15 μm of height difference between the two in any assembly. The modules were wired in series, and the assemblies were bolted together using four 4-40 screws. Each screw had two Bellville, one flat, and one fibre washer. Care was taken during the assembly process to apply the thermal grease evenly and sparingly using a rubber roller. The screws were tightened in four steps. First, they were tightened finger tight, then to 0.28 N•m, then to 0.56 N•m. This was done in accordance with Equation 1 to provide 1520 kPa of compressive pressure. The screws were retorqued after one hour to 0.56 N•m prior to any thermal cycling.

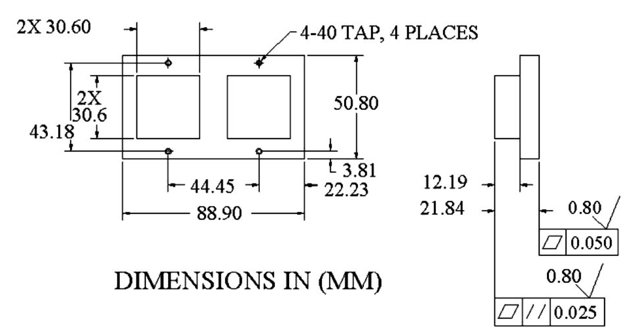

Figure 1. Cold Plate

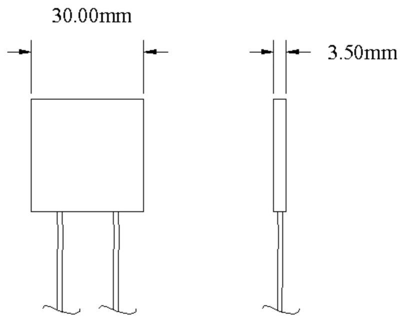

Figure 2. Thermoelectric Modules

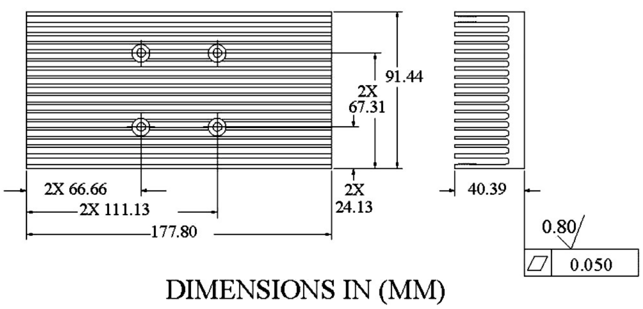

Figure 3. Heat Sink Dimensions in mm

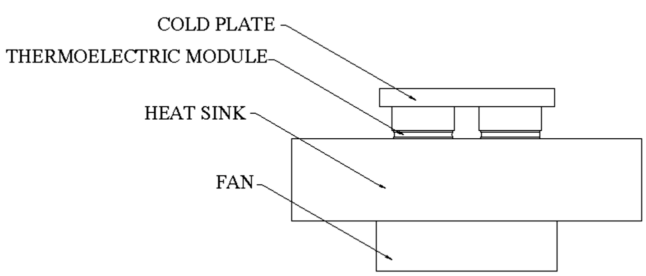

Figure 4. Complete Assembly

$$T = \frac{W\, d_m \left(L \cos\alpha + f\,\pi\, d_m\right)}{2\left(\pi\, d_m \cos\alpha - f\,L\right)} \qquad (1)$$

T = torque (N•m)
W = load per screw (N)
d_m = screw pitch diameter (m)
L = thread lead (m)
α = flank angle
f = coefficient of friction

Equation 1. Torque Required for Module Compression

Care was taken during assembly to position the thermoelectric modules squarely beneath the cold sink extenders. These extenders were used as the original position indicators for the modules. The extender width was 0.6mm larger than the module width and provided an easy reference for visually detecting movement.

Test Method #1

The first test was designed to determine if power cycling could induce movement. First, the assemblies were powered with 24 VDC in the cooling mode for three days. The module positions were noted at the end of the test. Then, the modules were power cycled using a timed cycle. 24 VDC was applied for approximately two minutes until the cold plate reached 5°C and heat sink reached 38°C. Then, -8 VDC was applied for two minutes, warming the cold plate to 31°C and cooling the heat sink to 31°C. The power cycle then repeated itself. This continued for three days. The position of the modules was again noted. Comparisons of module movement with and without power cycling were used to determine whether power cycling could induce module movement.

Results of Test #1

Powering the coolers with the constant 24 VDC did not induce module migration. Power cycling induced migration in only one module per assembly in assembly numbers two and three.

The movement was not linear with the number of cycles, but seemed to occur largely at the beginning of the cycle testing. After 270 cycles, the movement was 3.0 mm and 2.5 mm on assemblies two and three, respectively. At 679 cycles, the movement was 3.6 mm and 2.8 mm, respectively. The movement was inward, toward the center of the assembly, in both cases.

Figure 5 shows the position of a module after power cycling. The original position of the module was outlined on the heat sink with a black marker. The cold plate was removed after cycling was completed without disturbing the module's position on the heat sink.

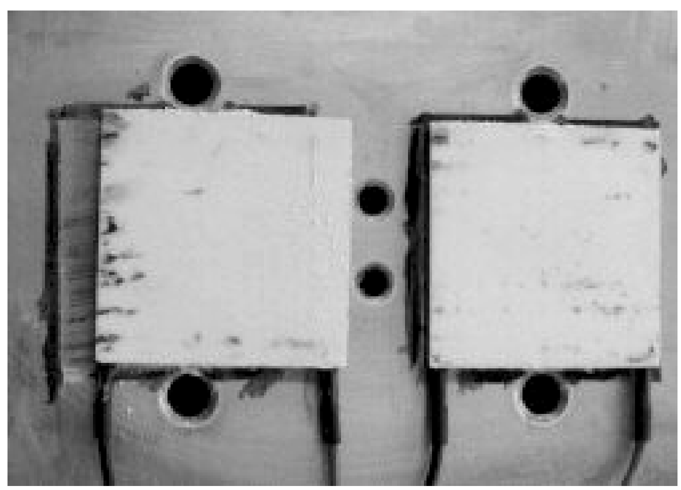

Figure 5. Position of Module after Power Cycling

The screws in each assembly were retorqued at 0.56 N•m to determine if a loss of compression had occurred during the test. The movement was between 1/8 turn or less per screw.

Test Method #2

The next test was designed to determine if the module migration was reproducible, that is, whether migration was a function of the particular assembly or of slight variances in the assembly technique.

The same operator rebuilt the coolers using the same assembly techniques. The same components for each exchanger were re-assembled in the same position and orientations. All assemblies were power cycled as in Test #1, and each module position was recorded at the end of the test.

Results of Test #2

Assembly numbers one and two experienced no detectable module shift. Assembly number three had module shift in the same module and direction as Test #1. Assembly number four showed 3.0 mm of movement in one of its modules. Module movement in both cases was toward the center of the assembly.

The screws in each assembly were retorqued to 0.56 N•m to determine if a loss of compression had occurred during the test. The movement was between 1/8 and 3/8 turn per screw.

Test Method #3

The third test was designed to determine if a different power cycle would reverse the direction of module movement. Each assembly was rebuilt as in previous tests. A new power cycle was applied: 24 VDC for 45 seconds to heat the cold plate to 60°C, then -8 VDC for two minutes to cool the cold plate to 32°C. When the cold plate was heated, the heat sink cooled to 28°C. When the cold plate was cooled, the heat sink temperature rose to 33°C.

Results of Test #3

Module movement was detected only in assembly number three. However, the module movement was still inward, as before, with 4.5mm of movement after 379 cycles.

One hypothesis that could explain module migration is depicted in Figures 6 and 7. A module with slightly non-parallel substrates is placed between the cold plate and heat sink. The thickest portions of the module “dig” into the cold plate and heat sink. Figure 8 depicts the module substrates “digging” into the aluminum surfaces of the assembly on a microscopic level. As the cold plate contracts and the heat sink expands, shear forces are placed on the module. However, the friction forces on either side of the module are not equal. A “ramp” effect is generated on the hot side, and the module becomes mechanically linked to the cold plate. This causes the module to slide inward towards the middle of the assembly. When the cold plate expands, the ramp effect is now generated on the cold side. The module maintains its position relative to the heat sink and the cold plate slides outward from the middle of the assembly. Thus, as the assembly is thermally cycled, the module undergoes a “ratcheting” effect whereby it is eventually driven inward towards the middle of the assembly. The hypothesis is depicted with unparalleled module substrates, but it can easily be applied to uneven heat sinks or cold sinks.

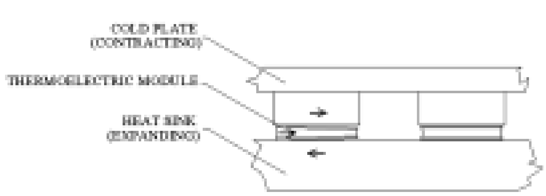

Figure 6. Module Movement with Contracting Cold Plate

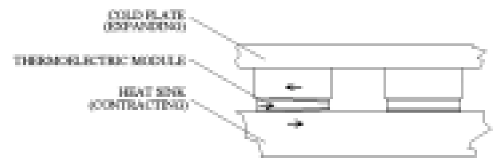

Figure 7. Module Movement with Expanding Cold Plate

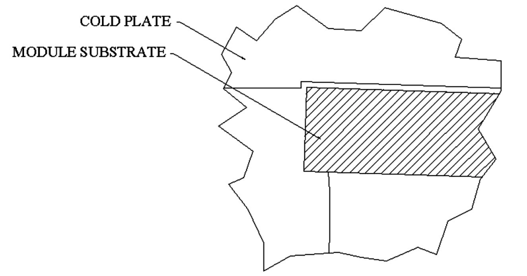

Figure 8. Microscopic View of Module Interface

To mitigate this problem, it was theorized that replacing a greased interface with a mechanically compliant interface would allow a non-parallel module to lie flat with respect to the heat sink surface. The compliant interface material would conform around the uneven surfaces and stop locally high spots of the module from digging into the aluminum. This, in turn, would eliminate the ratcheting effect and thereby eliminate migration (see Figure 9)

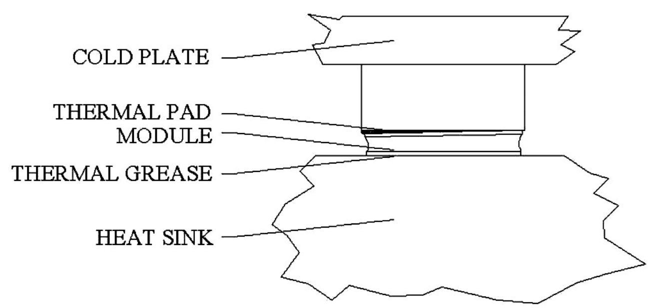

Figure 9. Mechanically Compliant Thermal Interface

Test Methods #4 through #6

The 4th through 6th tests were conducted to determine if this different assembly construction technique stopped module migration. The assemblies were rebuilt as before, except a compliant thermal interface was introduced between the cold plate and the module. The interface was made of a thermally conductive silicone rubber, 125 μm thick. The interface material did not have adhesive on either side. The units were tested under the same conditions as in Tests 1, 2, and 3. The units were rebuilt between each test as in Tests 1, 2, and 3.

Results of Tests #4 through #6

No module movement was detected after power cycling.

The screws in each assembly were retorqued at 0.56 N•m to determine if a loss of compression had occurred during the tests. The movement was 1/8 turn or less per screw after all tests.

Summary of Results

Module migration did not occur when the assemblies were not power cycled.

When the units were power cycled and thermal grease was used for all thermal interfaces, module movement was observed. This is summarized in Table 1.

Table 1. Summary of module movement in assemblies where all interfaces are made with thermal grease.

Test	Assembly 1	Assembly 2	Assembly 3	Assembly 4
1	No Movement	**Movement**	**Movement**	No Movement
2	No Movement	No Movement	**Movement**	**Movement**
3	No Movement	No Movement	**Movement**	No Movement

No movement was detected when the assemblies were constructed using a mechanically compliant thermal interface and power cycled.

Conclusions

Power cycling induced module migration in some thermoelectric assemblies where thermal grease was used at both module interfaces. The movement was not consistent between assemblies.

Module migration appeared to be a function of the specific components. One assembly exhibited module migration after each rebuild and test. One assembly never had module migration during any test. This indicated that in these two particular assemblies the patterns of migration were dependant on the individual components but not the assembly technique.

The other two assemblies had module movement in one of three tests. This indicates that slight variances in the assembly technique contributed to the module migration, but given ideal circumstances the modules would not migrate.

Altering the temperatures in which the assembly was cycled did not reverse the direction of the movement. The movement was always inward, toward the center of the assembly.

Replacing the cold side thermal interface with a compliant thermal pad stopped module movement under test conditions that had previously caused module movement. However, this does not prove or disprove the hypothesis of why the modules migrate. The thermal resistance of a thermal pad is generally higher than that of a greased interface, so a performance penalty will be encountered if a thermal pad is utilized.

References

1. Juvinall, Robert C. and Marshek, Kurt M. *Fundamentals of Machine Component Design*, 2d ed. New York: John Wiley & Sons, 1991