EVALUATION OF THERMAL JUNCTION QUALITY IN THERMOELECTRIC ASSEMBLIES USING TRANSIENT ANALYSIS TECHNOLOGY

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Abstract

This paper describes the application of the Transient Analysis Test method to evaluate the integrity of thermal junctions in a thermoelectric (TE) assembly. The quality of thermal junctions (Qjctn) in assemblies was measured by creating a thermal gradient in the TE modules comprising an assembly and analyzing the decay of the residual Seebeck voltage. A study was made of various junction conditions that exist between the TE module and its heatsinks which are common to most assembly techniques. Poor thermal contacts were deliberately introduced such as insufficient thermal grease, inadequate compression and improper surface finishes in test assemblies in order to simulate typical assembly defects. A direct correlation between good and inadequate thermal junctions was established and illustrated through graphic test data evaluation.

Introduction

It is essential to achieve maximum surface contact between the thermoelectric module and the mounting surfaces of its heatsinks in order to obtain optimum performance in a thermoelectric assembly. Though other conditions such as proper TE module selection and heatsink optimization should not be ignored, there are still variables that exist that can greatly affect performance in the assembly. The quality of the thermal interface at both mounting surfaces of the heatsinks and the TE module are dependent on several conditions. These are insufficient thermal grease or compound, inadequate or uneven compression, rough heatsink and module mounting surfaces and foreign material contamination in the interface medium itself. These factors make it difficult to assure that a quality thermal junction exists in all TE assemblies manufactured.

In the past, junction quality could be verified by performing a complete “cool down” test to measure transient rate and steady state cooling levels. The problem with this technique is the time, labor and equipment required to achieve accurate results. This new transient analysis test method can verify the quality of the thermal interface in only a couple of minutes.

This paper details this breakthrough in thermoelectric assembly testing, describes various test conditions used to verify its sensitivity and repeatability and illustrates results of the tests performed.

Theory

As a TE assembly is powered by a DC current, approximately 3% of Imax, it will create a small temperature difference within the TE module. Upon abrupt power shut-off, a measurable, residual Seebeck voltage will exist at the TE module input power leads. This voltage will decay with time. The nature of the short-term decay wave form will be affected by the quality of the thermal interfaces in the assembly. If the thermal contact with the plates were poor, the short-term rate of decay would be faster, approaching a totally isolated TE module. Conversely, if the thermal contact were good, the rate of decay would be more controlled by the thermally massive plates, and the decay would be slower. Therefore, measuring and analyzing the short-term residual Seebeck voltage as it decays offers a means of quantifying the thermal quality of the junctions between the TE module and the opposing plates. There wasn’t any question as to whether this method would work or not (at least in the extreme cases). The only question was whether or not this method were reproducible and sensitive enough to work as an effective quality control tool for identifying good thermal junctions from those not quite good enough. This, then, is the subject of this paper: to test this method in a production environment and empirically evaluate its effectiveness.

The test procedure was essentially an extension of the “BURST” test described by Buist [1]. A high-speed, high-resolution A/D board was used to repeatedly test the TE module voltage before, during and after power-off in one continuous step. Thus, the data not only defined the decay wave form but also provided the key raw data needed to determine the true and accurate electrical resistance of the modules. Thus, this test method provided the data needed to not only test the thermal junction quality but also confirm the integrity of the TE modules themselves.

A dimensionless factor, Qjctn, was developed by Nagy and Buist [2] via analysis of the short-term (10 seconds) voltage decay wave form. It is given in equation 1:

$$Qjctn = (Vi-Vo)/(Vo-V_{10}) \qquad (1)$$

Where:
Vi = The voltage just before power-off,
Vo = The voltage immediately after power-off, and
V_{10} = The voltage 10 seconds after power-off.

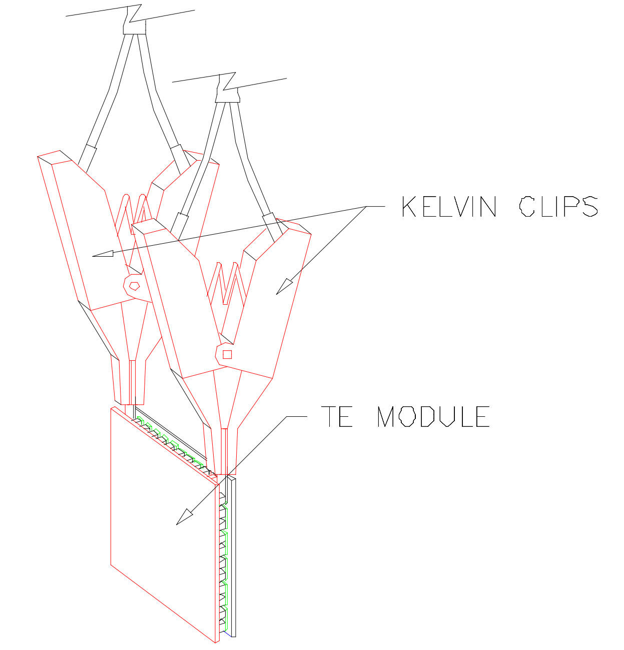

Fig. 1 Individual TE Module Test Configuration.

TE module Tests

The first series of tests were performed using a TE Technology, Inc. model TS-205 computerized test system applied to suspended, individual TE modules. These tests were performed to determine the effects of varying TE module parameters had on Qjctn. Several modules were selected all having varying pellet geometry, numbers of couples and figure of merit, Z. These modules were tested while suspended in air within a small box to stabilize convection and radiation effects (see Figure 1).

Two experiments were conducted in this configuration using different TE module types obtained from various manufacturers around the world. The type of TE module selected was a 127 couple, 6 amp variety because it was common amongst most manufacturers. However, a wide variety of TE module designs were also obtained from one supplier in order to determine the impact of geometry as well TE material parameters on the parameter, Qjctn.

The first of these two experiments was to measure each module's physical and thermoelectric material parameters in order to establish a base line for the subsequent analysis and assembly tests. Each TE module's physical characteristics, overall size, weight, ceramic thickness and pellet tab size were determined. The TE module lead wires were also removed to eliminate any possible variations they might have induced. They were then tested for various TE material properties, including the figure of merit, Z.

The second set of tests consisted of testing for Qjctn using the same test equipment and test software as for the TE material parameter tests, but set up to determine Qjctn as defined in equation 1.

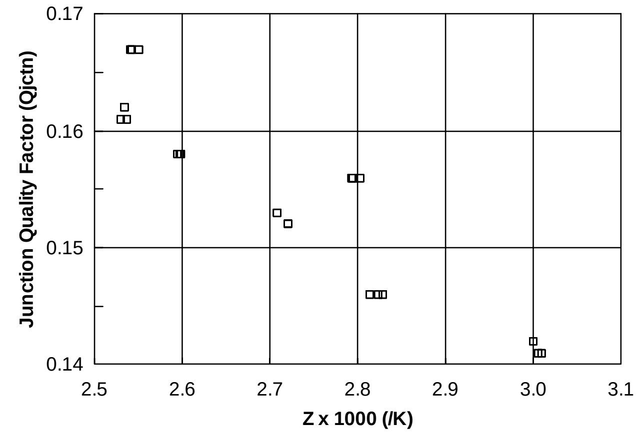

Fig.2 Effect of Figure of Merit, Z, on Qjctn on suspended TE modules from various manufacturers.

The initial results are shown in Figure 2. It was observed that Z apparently inversely affects the measured Qjctn.

Figure 3 illustrates the impact of TE module geometry on the Qjctn value. All modules in this data set were from the same supplier but were of widely different geometrical design. Although there was some variance with other geometrical parameters, the only obvious trend observed was the decrease in Qjctn with decreasing TE pellet height as clearly evident in this plot.

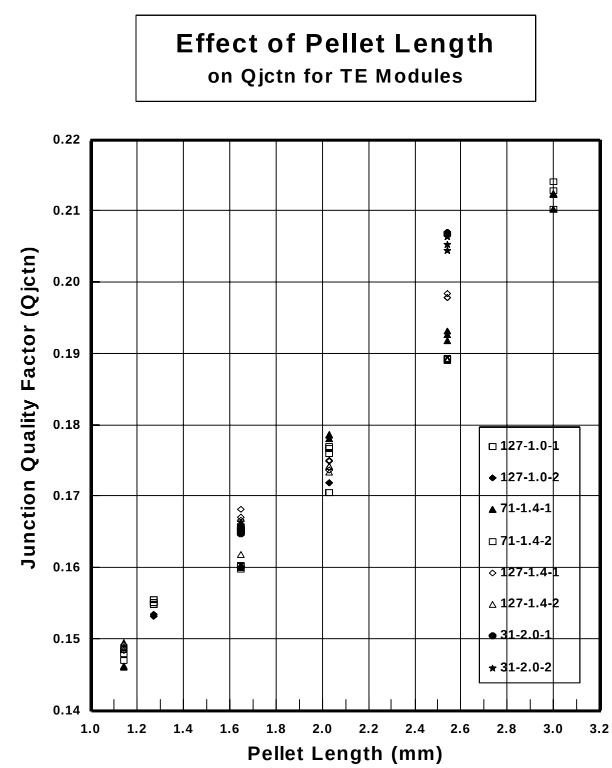

Fig. 3 Effect of TE pellet height on Qjctn of suspended TE modules.

Experimental TE Assembly Tests

With the TE module baseline tests completed, the more important assembly tests were performed in order to establish the effectiveness and value of Qjctn testing. The basic configuration of the experimental TE assemblies is illustrated in Figure 4.

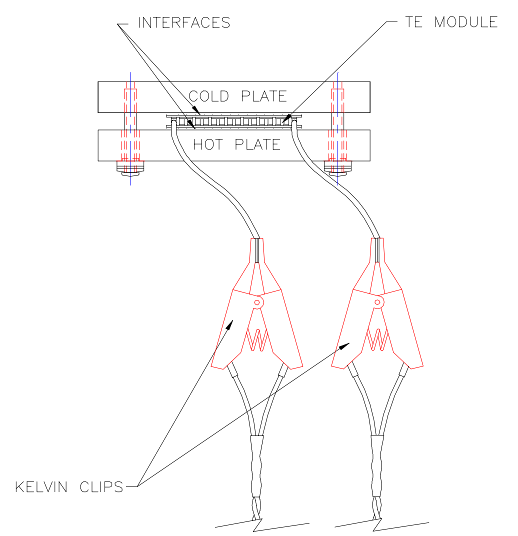

Fig. 4 Assembly Test Configuration.

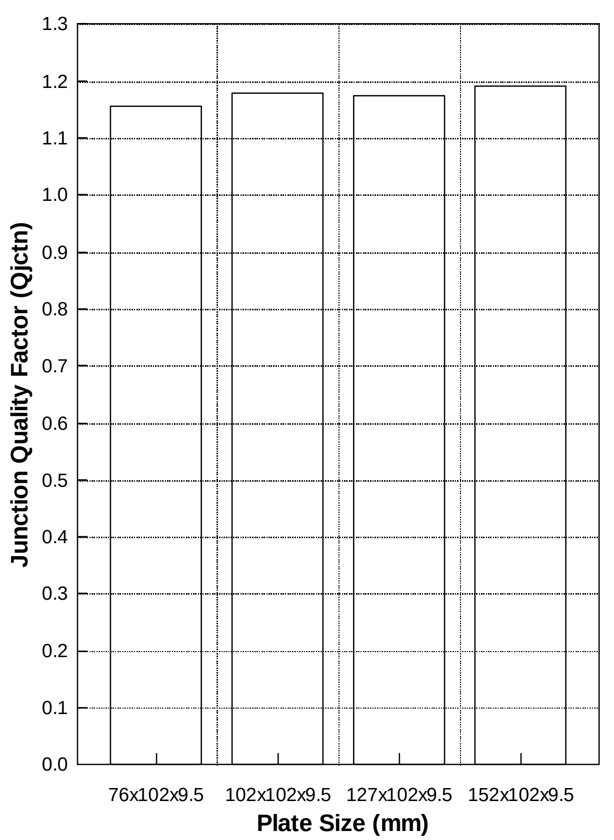

Fig. 5 Effect of plate size on Qjctn of TE assemblies.

The modules used were 127 couples with TE pellet sizes: 1.4mm square x 1.65mm long. All TE modules were screened for a common Z value of 0.0026 /K. The heat sinks were simple aluminum plates of the same 6061-T56 alloy. Except for the tests designed to check variability of these parameters, each assembly was fabricated using thermal grease as an interface medium and a constant predetermined torque value of 1.0 Newton-meter. The mounting surfaces were machined to a 0.8 micrometer finish.

The experimental assembly tests were conducted with the unit sitting on a piece of foam insulation with the other plate exposed to open air. Tests were conducted using the following deliberately imposed conditions in order to observe their impact on Qjctn: a) different size heat sink sizes, b) different surface finishes, c) different interface media versus applied compression force, and d) contaminated interfaces.

The first experiment was designed to determine the impact of plate size on Qjctn. The results of this test are given in Figure 5. In spite of the significantly different plate sizes there was not much observed variance. This was as expected since the temperature difference of module surfaces was so small, the heat sink size did not affect TE module plate temperatures. Following this test, all subsequent experimental assemblies used the smaller, 76 x 102 x 9.5 mm plate size.

The second TE assembly test was conducted using different surface finishes, but the same on both the hot and cold sides. Four sets were fabricated with surface finishes from an extremely smooth 0.8 micrometer value to a very poor 12.5 micrometer finish. The results in Figure 6 illustrate the effect surface finish had on the Qjctn value.

The interesting thing to note by this data is that even what

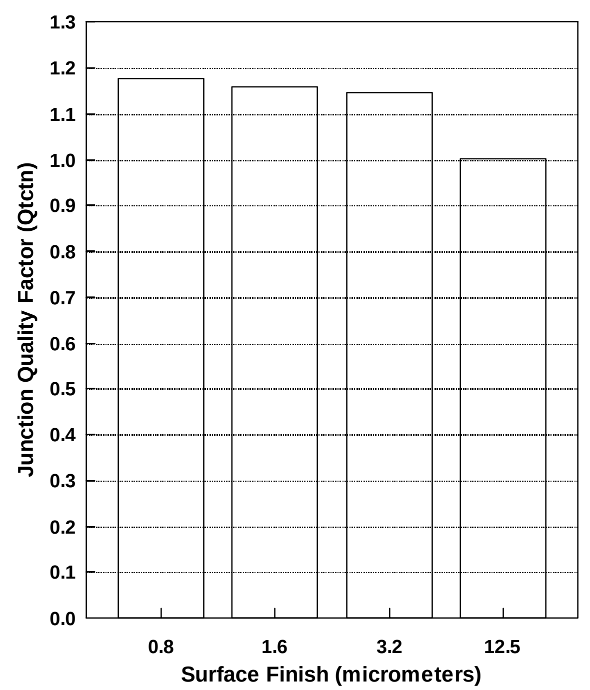

Fig.6 Effect of plate surface finish on Qjctn of TE assemblies.

would be considered a poor surface finish be TE assembly standards (3.2 micrometers) still had relatively minimal effect on Qjctn.

The conditions examined for the final experimental assembly test were the different interface medium between the TE module and the aluminum plate surfaces. Also, it was impossible to isolate the effects of the interface media from the amount of torque applied to the clamping screws used to compress the assembly, so these two factors were studied simultaneously.

The different interface media selected were based on some commonly suggested materials sometimes used in TE assemblies. One assembly was fabricated using a popular silicone thermal grease compound manufactured by Thermalloy, Inc. The second unit was fabricated dry, using no interface medium at all. A third unit was fabricated using a 0.26mm thick graphite sheet material manufactured by Ucar Carbon Co., Inc. known as Grafoil®. The fourth unit was fabricated using a popular Kapton® adhesive tape often used in electronic heat dissipation applications where electric insulation is required. This conductive adhesive tape measured 0.127mm thick and was manufactured by Chomerics, Inc.

The results of these tests are shown in Figure 7. This graph revealed some very interesting facts. The first test, where thermal grease was used as the interface medium, proved to be the configuration which attained the highest (best) Qjctn value. One interesting thing to note is the Qjctn value "leveled off" at approximately 1.0 Newton-meter of torque. This translates to approximately 1.4 Mpa of compression applied to the module. This value corresponds to the specified value of compression recommended for an assembly of this nature.

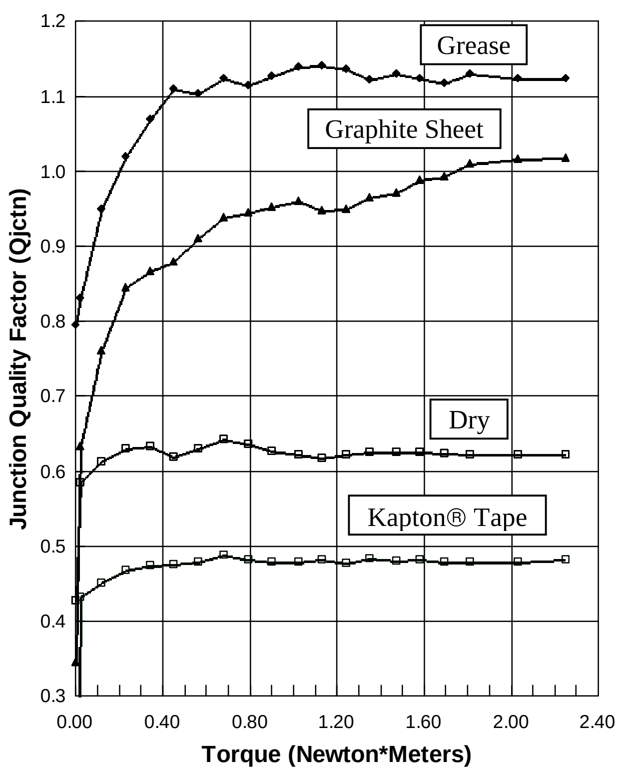

Fig.7 Effect of interface medium and applied torque on Qjctn of TE assemblies.

The assembly configuration with the next highest Qjctn value was the one in which the graphite sheet was used as the interface medium. Although the performance of this medium was not quite as good as thermal grease, it could be argued that this configuration may represent a good trade-off between performance and the benefits of a quicker, and perhaps easier, assembly time. However, it should also be noted that the torque and subsequent compression forces applied to the TE module are far beyond recommended levels.

The final two assemblies using the Kapton® sheet and no interface medium (dry) did not perform well. These interface media are not recommended for use in a TE assembly.

Production Testing

Finally, Qjctn tests were performed on a small production lot of TE assemblies which consisted of a cold plate, finned heat sink and a single TE module. The results of these tests are shown in Figure 8. Notice that Qjctn varied between 2.0 and 2.3 except for two assemblies. The initial Qjctn for these two cases were approximately 0.8 and 1.5, respectfully, and were obviously well below the average Qjctn of the other units in this lot.

At first, the clamping screws were re-torqued and re-tested. However, as observed in the graph, the respective Qjctn for both cases did not significantly change. Therefore, both units were disassembled and their grease patterns inspected. A human hair was discovered in the thermal grease of the first unit (H). It was removed and the unit re-assembled and re-tested. As observed in the graph, the Qjctn increased to a value consistent with the acceptable (A) TE assemblies.

The grease patterns of the second unit (B) were unusually thick and it appeared that this unit was not properly compressed. Upon closer examination a metal burr was discovered in one of the tapped holes used by the clamping screws. These holes were re-tapped and the unit was re-assembled and re-tested. As observed in the graph, its Qjctn value also increased to a value consistent with the other TE assemblies.

Conclusion

This paper has illustrated the effectiveness of using the transient analysis method for measuring the quality of the thermal interfaces for a TE assembly. Demonstrations have been performed to verify the sensitivity and repeatability of this technique. The main conclusion derived was that this test method is a reliable and fast tool for evaluating the thermal junction quality of literally any thermoelectric assembly.

References

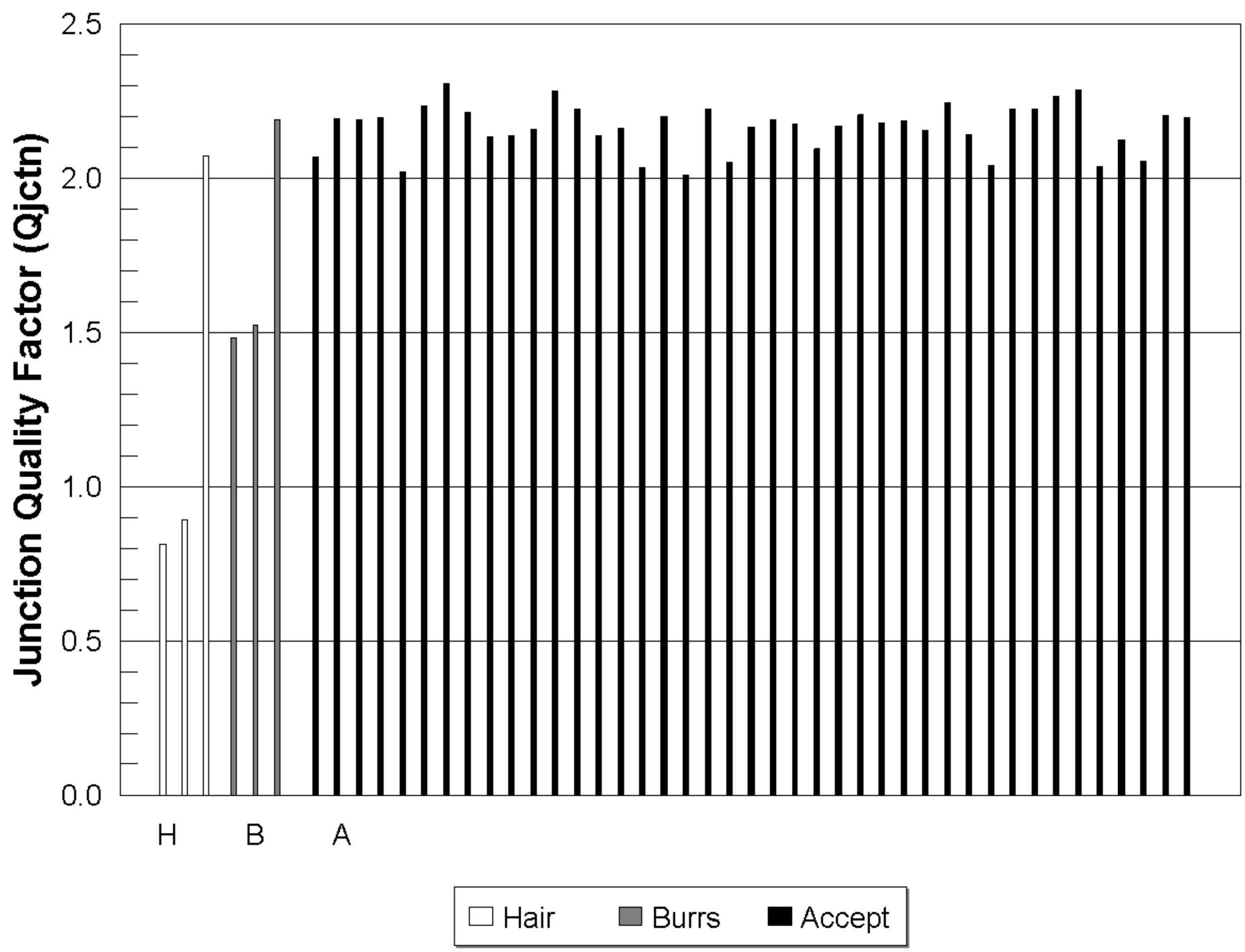

Fig. 8 Qjctn test results on a group of TE assemblies to illustrate sensitivity of Qjctn to imperfect thermal junctions.

[1] R.J. Buist, "A New Method for Testing Thermoelectric Materials and Devices", *11th International Conference on Thermoelectrics*, Arlington, Texas, USA (1992).

[2] M.J. Nagy and R.J. Buist, "Transient Analysis of Thermal Interfaces Within a Thermoelectric Cooling Assembly", in *Proceedings of the XV Conference on Thermoelectrics*, Pasadena, California, USA, (1996).