CONTACT RESISTANCE COMPARISON OF GOOD AND BAD CRIMP JOINTS WITH TINNED WIRES UNDER THERMAL SHOCK

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ABSTRACT

#16 wire gauge crimp joints of good quality were made with tinned wires in the conventional way. Some of them were then subjected to twisting resulting in a gap between the two wings. All of them were heat-soaked at 135°C for 300 hours. They were then loaded into a thermal-shock furnace for thermal cycling from –40°C to 125°C, each cycle lasting one hour for a total of 570 hours. The four-leads method was used to measure the contact resistance for every cycle under the dry circuit condition. The contact resistance of good crimps generally increased at a slower pace over time than the bad ones. The resistance increase of some good and bad crimps would tend to more or less level off after 100-200 cycles while others would continue to increase their resistance without leveling off and some of them might show a sudden jump. Nevertheless, the measured resistance history showed that a crimp with a tinned wire exhibited accepted performance whether it was a good or not so good a crimp. The results also showed that the temperature history would affect the contact resistance measured at a later time. For example, the resistance of a crimp at 125°C would be somehow different depending on whether the previous temperature started from –40°C or from –17°C. Data analysis showed that even with severe thermal shocks for 570 hours and possible consequence of repeated shearing, the contact in the crimp was still essentially a metallic one.

Key words: crimp joints, thermal shock/cycling, contact resistance of crimps, reliability.

1. INTRODUCTION

Crimped terminals are widely used in electric/electronic equipment. The reliability of crimped joints is critical to the long-term performance of the equipment. Therefore, extensive efforts have been made by many groups over the years to investigate various parameters that control the crimp quality and to establish procedures that test the long-term performance of crimps. These efforts have met with various successes. One of widely accepted approach in the engineering community is to use tinned wire to improve crimp reliability. However, there appeared no publication that explicitly discussed the scientific evidence to support this practice. In the present paper we report our effort in which we used an established procedure [1] to test the performance of crimps with tinned wires, whether the quality of the crimp was 'good' or 'bad'.

2. EXPERIMENTALS

The 'good' crimp samples were made with a conventional die set in the conventional way. A 16 AWG tinned wire with 125°C rating was crimped into a 16 AWG tinned crimp terminal of the conventional type. The cross-section of the crimp was checked for its proper shape and compactness. As will be shown later, the initial compactness of the 'good' samples was slightly less than optimum. Nevertheless, we have defined them as 'good' crimps, as they were sometimes found in the field to show reasonable performance, better than those twisted ones. 'Bad' crimps of the same gauge were made by further uniformly twisting the joints in a die-set such that some gap between the two wings of the crimped joint was generated.

All of these crimped terminals were first thermally soaked in 135°C for 300 hours. After that they were loaded on to a test fixture (Fig.1), whose design was used in previous tests [1]. As can be seen in Fig. 1(a), the crimp terminals with 7" long wires were stretched on the fixture. Each aluminum base plate was loaded with eight samples where four good ones (marked with 'C') were interspersed with four bad ones (marked by 'T'). Each crimp was clamped at the right side. Fig 1(b) shows the detail of this process. The crimp 2 was clamped by a lower brass block (shown) and an upper brass block (removed) at the location 3. Because the crimp would experience compression at low temperature, a thin stainless steel tube 1 was slid over the wire so the wire would not buckle when being compressed. The other end of the wire was soldered on a copper block as shown on the left in Fig. 1(a). Each wire was stretched to 26 Newtons force as measured with a force gauge before the copper block was tightly screwed down by a bolt through the block. Each crimp was wired by four 26AWG leads about 6 to 7 feet long for the

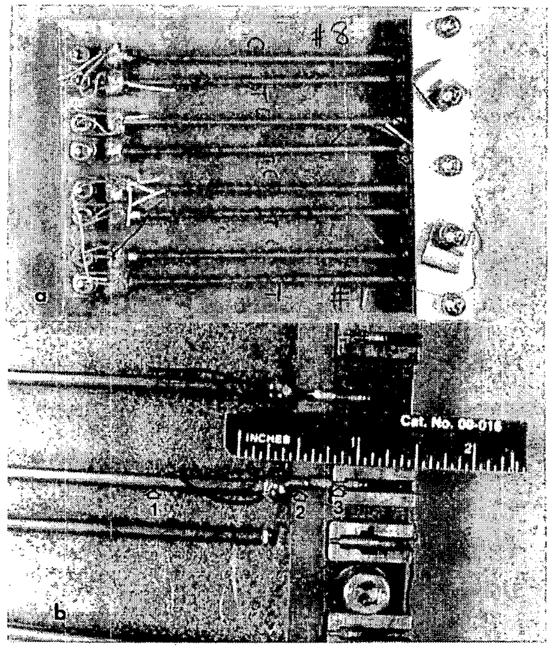

Fig. 1. (a) Layout of the fixture. Leads have been cut off. (b). Detail of the crimp side.

preparation of the resistance measurement. Two leads on the crimp side were soldered to the upper and lower clamping brass blocks instead of being soldered to the crimp barrel to avoid possibly overheating the tin plating on the crimp and wire strands to unrealistic high temperature. Two test plates as shown in Fig. 1(a), with 16 samples in total, were assembled.

A Tenny Versa Tenn 3 tabletop thermal shock furnace was used for the present experiment. The two plates were put in a basket in the test chamber. The wires from all samples were tied together and led through a hole on the furnace wall to the outside. All the wires were connected to two Keithley 7014 multiplexer cards, which were then plugged into a Keithley 7002 switch system box. The resistance was measured by four leads method under dry circuit condition with a HP4338A milliohmmeter. The thermal cycling schedule for the Tenny furnace was such that the basket would be in the 125°C zone for 30 minutes and then transported in to the -40°C zone for another 30 minutes in each cycle. The cold zone was assisted with liquid nitrogen so that it took about 5 minutes to get the samples cooled down to -40°C after the basket was transferred. The resistance was measured at each temperature three minutes before the basket was transported to another temperature zone. The operation of the electric measurement instruments and the thermal shock furnace were controlled by the LABVIEW software through a PC.

The thermal cycling lasted for 570 hours in total. During this period, great care was taken not to disturb the samples. In order to check if the contact resistance between the two clamping brass blocks and the neck of the terminal, as indicated by '3' in Fig. 1(b), had contributed significantly to the crimp resistance recorded during the cycling, an additional 26 AWG lead was soldered to each crimp barrel. This was performed after 570 hours thermal cycling. The soldered location is on the left side of the crimp 2 as shown by the short wire there in Fig. 1(b). This way, the voltage over the crimp and the 16 AWG wire was measured whereas in the previous wiring, the voltage over the terminal-brass block, the crimp, and the 16 AWG wire was measured. The difference of their resistance was the resistance of the interface (clamping resistance) between the brass block and the crimp terminal.

3. RESULTS AND DISCUSSION

The quality of the 'good' and 'bad' crimps can be seen from their cross-sections of the crimp joints (Fig. 2). It can be seen that the cross-sections of both samples show the same compactness, which was slightly less than optimum. For the good group, the 'gap' between the two wings is small.

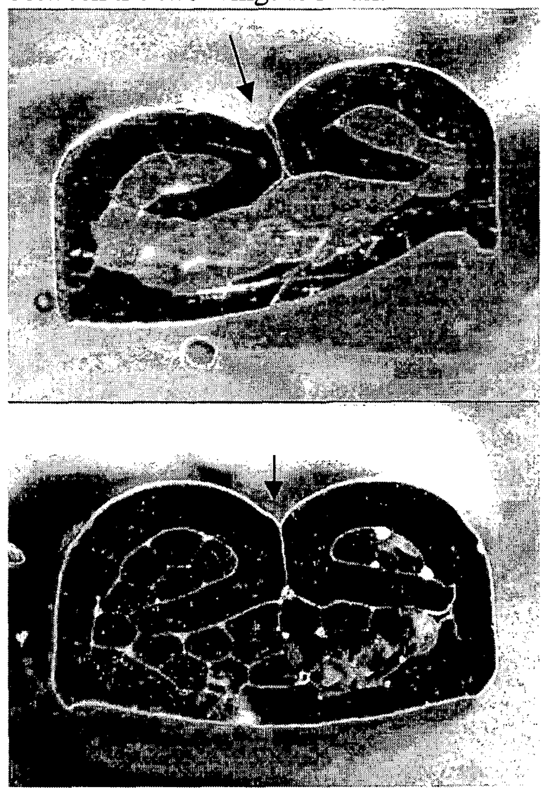

Fig. 2. Photo at top shows the cross section of a bad crimp. Note the gap between two wings as marked by an arrow. Photo at the bottom is of a good crimp.

On the other hand, the 'bad' crimp shows a larger opening between the wings. We now present the resistance vs. time (hours) plots from both the good ('C') and bad ('T') samples, eight in all, in the first plate. The resistance measured was that of the crimp plus the 7" wire. The resistance of the 7" wire was not subtracted from all the measured resistance curves shown as we were mainly interested in the crimp resistance change from initial values. The resistance of a 7" wire was relatively small and would change very little with time at a particular temperature.

First let us examine the behavior of all the samples in the first 140 hours of the thermal shock. Fig. 3 shows the temperature history for this time period. A short low temperature rise to -17°C after the 83rd hour was due to the liquid nitrogen run-out in a weekend. The liquid nitrogen was re-supplied. The temperature from 120th hour gradually changed to the room temperature due to the programmed basket stoppage at the hot zone and the shut-off of the heating power in the zone in another weekend. Figs. 4 and 5 show the resistance change over the time period for the good samples and the bad samples. All the features (sudden changes) on the curves are of the genuine behavior of the crimps in the thermal cycling except for those at around 84th hour, which were mainly due to the liquid nitrogen run-out at 83rd hour as indicated in Fig. 3.

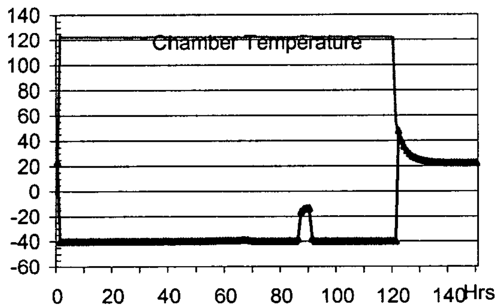

Fig. 3. The temperatures in the hot zone (top curve) and the cold zone (lower zone) over 140 hours. The two curves merged at 122nd hour. The unit on the vertical axis is °C.

Note that this sudden resistance change at –17°C around the 84th hour was a decrease for some samples and an increase for others from the general trend lines. The results also showed that the prior temperature history would affect the contact resistance measured at a later time. For example, the resistance of a crimp at 125°C would be somehow different depending on whether the previous temperature history started from –40°C, or –17°C. At about 84th hour when the samples were heated up from –17°C, the resistance of the samples #1, #2 and #7 at 125°C, for example, showed some drop from the trend of the curves whereas this deviation was minimal for the samples #5 and #6. (It is reasonable to assume that if the temperature cycling around the 84th hour were between –40°C and 125°C, the resistance curves would be smoother.)

However, when the resistance at different temperatures were compared, the trend is clear. As shown by the different line thickness, whether the sample was 'good' (#2, #4, #6 and #8) or 'bad' (#1, #3, #5 and #7), the resistance at 125°C was always higher than that at -40°C. The rate of the resistance increase for the 'bad' samples was also higher as well. It may be seen that in general, the resistance of the 'good' group was less than that of the 'bad' group. We also note that if the initial resistance increase was low in the first, say, 50~70 hours, then for most samples the later increase would be also low. (This observation is still true, when we examine the resistance behavior up to 570 hours late.) However, if this time period in consideration was only around 20 hours or shorter, the resistance difference between different samples was too small and the small difference did not correspond well to their later behavior. This observation could be considered as supporting evidence for the justification and the possibility of predicting the service life of a crimp. One might use test results gathered in less than 100 hours to predict the performance of a crimp over its entire service life.

We may also note the resistance of all samples at the room temperature after the 120th hour. The resistance could fall in to

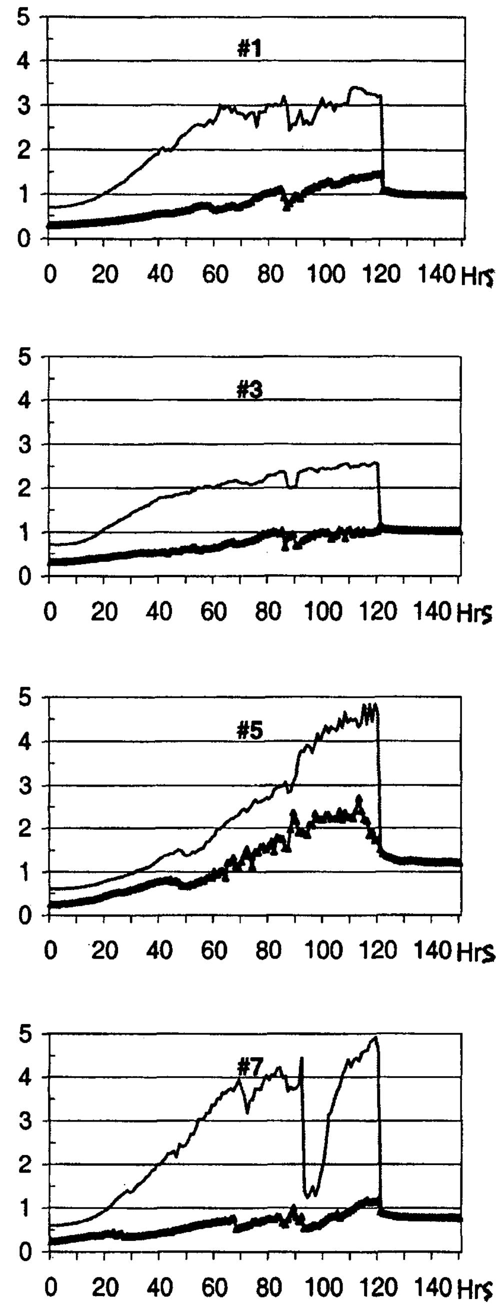

Fig. 4. Resistance recordings of four bad samples (#1, #3, #5 and #7) over 140 hours. The fine lines are for high temperature while the thick lines with triangles are for low temperature. The unit on the vertical axis is milliohm.

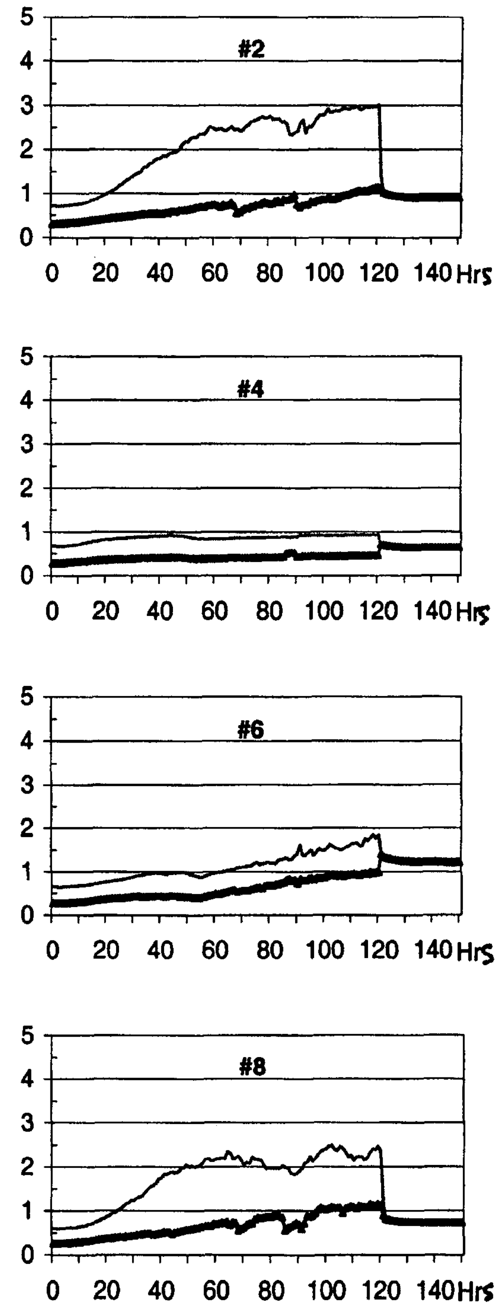

Fig. 5. Resistance recordings of four good samples (#2, #4, #6 and #8) over 140 hours. The fine lines are for high temperature while the thick lines with triangles are for low temperature. The unit on the vertical axis is milliohm.

one of three situations that the resistance was: (1) between those at 125°C and –40°C, e.g., the sample #6; (2) same as those measures at –40°C, e.g., the sample #2; (3) below those at –40°C, e.g., the sample #1. This indicated some uncertainty in the effort to infer the high temperature resistance with the value measured at room temperature.

Figs. 6 and 7 show the resistance recordings over 570 hours period. As with Figs 4 and 5, each curve was a collection of many segments. Each segment included only the data collected when the liquid nitrogen was on. The portion of collected data while the liquid nitrogen ran out was discarded. It can be noted that there are many downward spikes from the curves. As we have discussed previously, most of these spikes could be attributed to the influence of prior temperature history when the cold zone was not properly cooled by liquid nitrogen. Therefore, the real resistance behavior over the time period should have been smoother. We note that the samples #1 and #5 had sudden resistance jump at around 470th hour. That indicated that the resistance of a 'bad' crimp with loose wings had increased suddenly in its later stage of life. However, this resistance was still not very high. The contact resistance at the neck of the crimp at room temperature is shown in Fig. 8. It is seen that the clamping resistance is small compared with the crimp resistance in Figs. 4 to 7 and thus does not affect the above discussion.

During the thermal cycling, the stretch/compression and the force which a 16 AWG wire and its crimp experienced could be calculated with the known thermal expansion coefficients of the material (α=23x10^{-6}/C for aluminum and α=16x10^{-6}/C) [2]. From 25°C to 125°C, the Al base plate expanded 0.42 mm while the copper wire expanded 0.29 mm. Therefore, the wire was stretched by 0.42-0.29 = 0.13 mm. The stretching force on the wire (the stress multiplied by the cross-section of the 16 AWG wire) could be calculated to be 100 Newtons. Under this force during cycling, the stretched wire would tend to loose up the contact in the crimp joint in the stretching direction. From 25°C to -40°C, the Al base plate contracted 0.27 mm while the copper wire contracted 0.19 mm. Thus, the wire experienced compression of 0.08 mm. The compression force would be 56 Newtons if the wire were not pre-loaded to 26 Newtons. Therefore, the real compression in the wire was 30 Newtons. Under this force during cycling, the compressed wire would tend to loose up the contact in the crimp joint in the compressing direction. It then seemed that the crimp of a wire could experience repeated shearing between the terminal and the strands in the thermal cycling. Under this condition the fretting corrosion could have been generated in the crimp if a bare copper wire were used to form the crimp with tinned terminal [3].

However, this was not the case for a crimp formed between a tin plated wire and a tin plated terminal, as was the case in the present report. The fact that the measured resistances were in the order of a few milliohms to 20 milliohms indicated the contact in the crimps was metallic. The following calculation should further prove this point. We noticed that in any particular hour, the ratio of the recorded crimp resistance at 125°C to that at –40°C was mostly about the same for all the curves in Figs. 4 to 7 and the ratio was around 2.1. This interesting observation can be explained as follows. The resistance change with temperature can be expressed by the equation of $\rho(t_2)=\rho(t_1)[1+\alpha(t_2 - t_1)]$, where $\rho(t_2)$ and $\rho(t_1)$ are the resistivities at the temperatures t_2 and t_1, and α the temperature coefficient of the resistivity. With α being 0.0046/°C for tin, we could calculate the

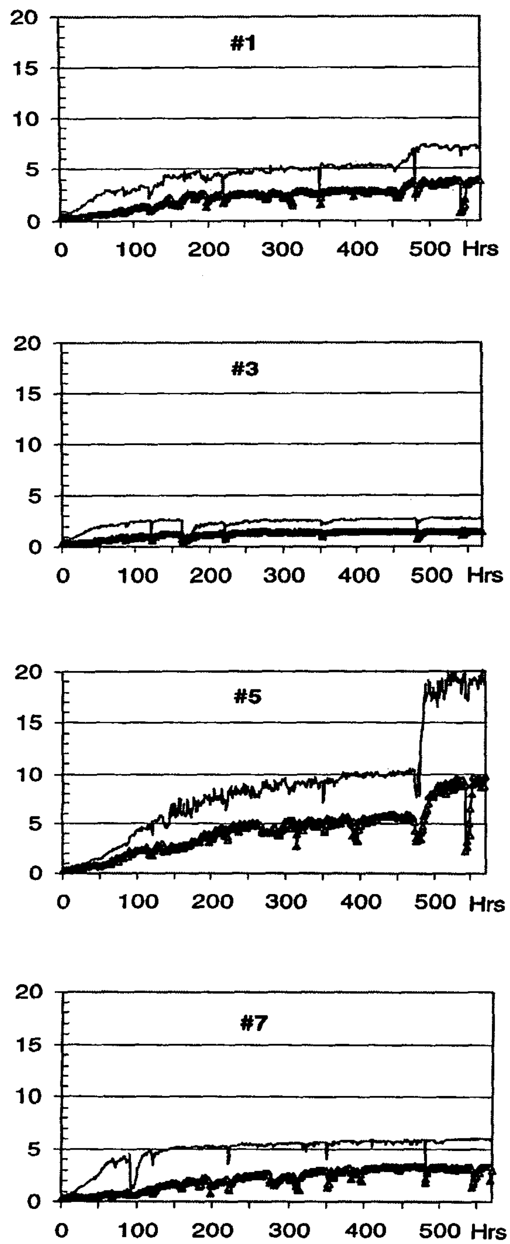

Fig. 6. Resistance recordings of four bad samples (#1, #3, #5 and #7) over 570 hours. The fine lines are for high temperature while the thick lines with triangles are for low temperature. The unit on the vertical axis is milliohm.

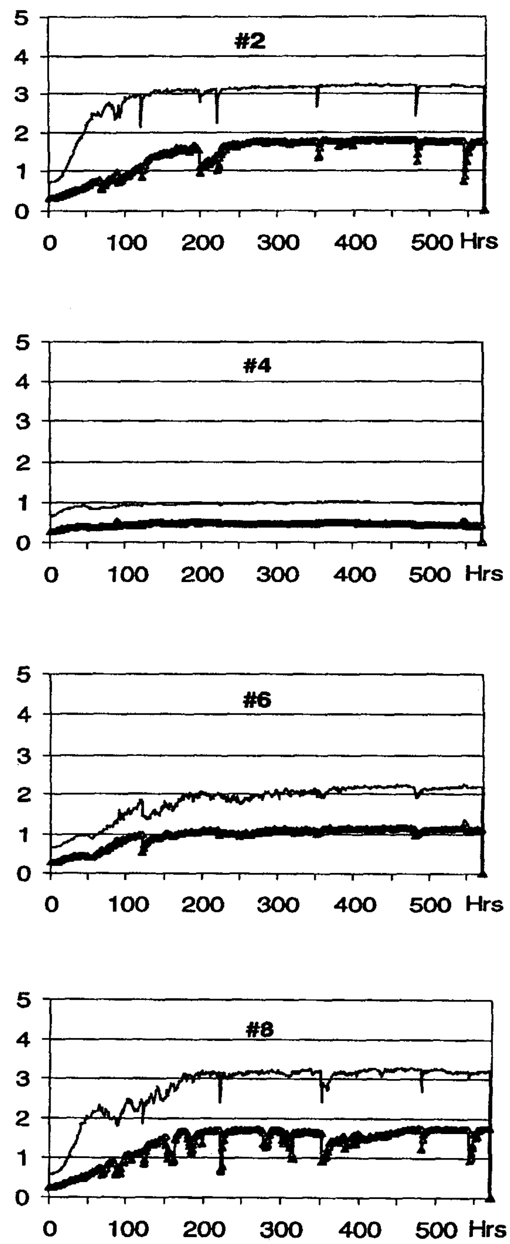

Fig. 7. Resistance recordings of four good samples (#2, #4, #6 and #8) over 570 hours. The fine lines are for high temperature while the thick lines with triangles are for low temperature. The unit on the vertical axis is milliohm.

ratio of the contact resistances at 125°C and –40°C. This resistance ratio was 2.05. Over the 570 hours thermal cycling period, it was not important whether or not the low contact resistance in a crimp was made between the same asperity pair. In most cases of our resistance curves in Figs 4-7, the resistances on nearby points on the same curve are almost the same when compared to the resistance difference in the same hour between 125°C and –40°C. It was conceivable that, under the repeated shearing due to the thermal expansion and contraction, the data at the next cycling stage could be collected from adjacent points. This situation might resemble the experiment described by M. Antler [4]. In his set-up, the contact resistance between solder plated members was measured. When the resistance in question was in the order of 0.1 Ohm, the resistance change over wiping distances in 10 μm increments was small.

The faster increase of resistances with time of bad samples reflected harsh forming conditions of their crimps. The big jump of the resistances in some curves indicated a sudden deterioration of the contact in the crimp. The gradual increase of the contact resistance might be explained partially as the result of the gradual decrease of the normal force inside a crimp. The reduction of the normal force must result from the material's stress relaxation at the high temperature and repeated thermal stretch/compression forces on the crimp. Another possible reason for the gradual increase of measured resistances could be the gradual oxidation of some of conducting metallic tin in the cracks of broken oxide films in the contact areas of the crimp.

It is well known that tinned wire for crimped joints can keep the resistance low for a long service life [5]. In the present 570 hours thermal cycling test, the samples experienced thermal stress that was much more severe than that experienced by crimp joints in most service applications.

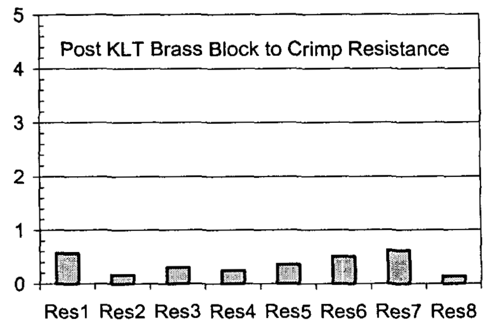

Fig. 8. The resistance (in milliohm) between the crimp body and the clamping brass blocks.

However, the final resistances of the four 'good' crimps were still quite low when compared with the widely accepted value of 20 milliohms. Even with the 'bad' ones except for the #5 sample, the final resistance was very low. The resistance of the #5 did not reach 20 milliohms till it was almost 500 hours. If it were in real automotive application, all the four 'bad' ones probably would still function OK. However, some sudden rise of resistance in their later life might be possible.

4. CONCLUSION

In the present paper, we discussed the resistance change of 'good' and 'bad' crimp joints with tinned wires over more than 500 hours' thermal shock. We can see that the final resistances were still good enough even though the thermal shock was very severe compared with the real situations that crimp joints possibly experience in service. We argued that the contact in the crimp was still metallic even after 570 hours severe thermal shocks. Tinning of the wire also made it more tolerant to the gross quality of the 'bad' crimp. But it was possible to have some sudden increase of the resistance in their later life.

It is important to note that the initial resistance increase rate and its value of a crimp joint closely related to the crimp's final resistance at 570 hours' thermal shock. If the initial rate of resistance increase and its value at 50 to 70 hours was small enough, the final resistance would also be reasonably small. This may provide a venue to shorten the test time for the crimp joint reliability. That is, one may only need to thermally cycle the crimp joints for 50 to70 (or 100) hours, for example, and use the results to infer the reliability of the crimp for much longer service life. This approach would accelerate the crimp joint reliability test considerably. However, the present work also exhibited some uncertainty in the effort to predict the high temperature resistance with the value measured at room temperature. The room temperature value may underestimate the resistance the crimp joint would display at elevated temperatures.

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