Long Term Reliability of Spring Pin Pressure Contacts in an Industrial Environment

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Abstract

The connection between a power module substrate and printed circuit board can be established by spring pin pressure contacts. This type of contact allows easy assembly without additional soldering. Spring pins are used for a variety of current ranges, from sensor currents of a few milliamps to load currents of several amps. Environmental stresses by mechanical wear, rapid temperature changes and corrosive atmosphere were deemed significant for the application. The experimental results of various harsh environment test conditions are presented.

1 Introduction

Long term reliability of spring pin pressure contacts is often compared to the reliability of wrap- or solder-connections. However, the failure modes cannot easily be transferred from one system to the other.
The contact forces forming the contact system vary between classical wrap connectors and the spring pin system. The different types of connections are shown schematically in **Fig 1**.

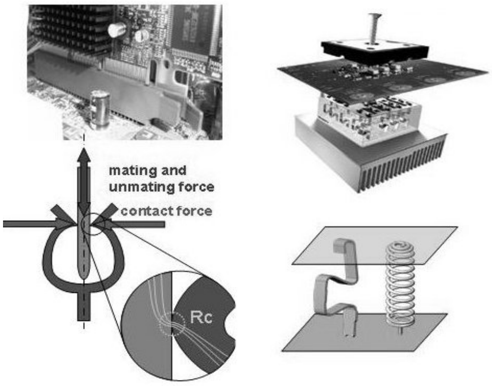

Fig. 1 Comparison of wrap connection and different types of spring pin contact.

In the spring pin system an interconnection between a printed circuit board (PCB) with driver components and power connections and a ceramic substrate (DBC) with dies is formed by spring pins (**Fig. 2**).
The PCB metallization has recently changed from SnPb HAL (hot air levelling) to RoHS conformal immersion tin, HAL tin or nickel/gold-flash. The spring pins are formed from a conductive spring copper material (base metal) plated with tin, silver or nickel/gold. The ceramic substrate is clad with copper, nickel or nickel/gold-flash.
One spring pin thus has two contact spots and a series of at least two spring pins is used for measurement. Due to the assembly, a single contact or spring pin is not accessible.

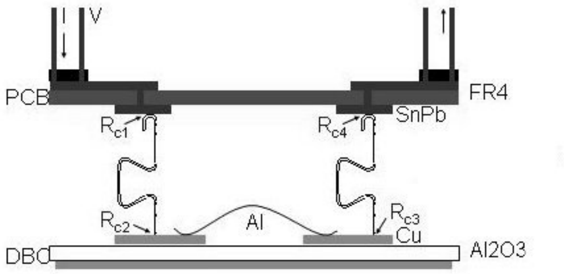

Fig. 2 Schematic overview of the spring pin contact system. PCB connected to DBC by spring pins.

The pressure range determines the choice of contact materials for the different connectors. Tin and silver platings are suitable for a contact force of approximately 2N to 20N, while gold platings require approximately 1N to 2N.

The most common types of strain in an industrial environment were determined to be mechanical vibrations, temperature changes and high temperature storage and corrosive atmosphere. The reliability of a spring pin pressure contact under these conditions – singly and in extreme combinations – was examined.

2 Fretting

Fretting corrosion describes the phenomenon of the growing, abrasion and compacting of oxide particles by repeated micro-movement, as can be induced by vibration. This process is well understood and documented for wrap connectors and limited to a small number of contact material combinations. Each movement cycle abrasively removes oxide flakes from the contact surface, generating new surface at the same time. This surface can be very prone to oxidation. This results in the formation of a native oxide layer of a few nanometers. Repeated movement accumulates oxide flakes while wearing down elevated regions of the metal. An increase of the contact resistance follows (**Fig. 3**).

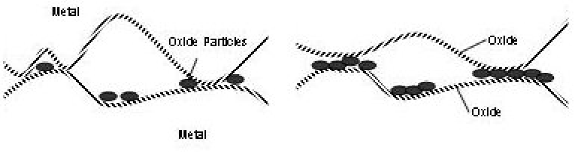

Fig. 3 Development of a dense layer of oxide flakes by alternating micro-movement and oxidation steps.

Especially critical are tin/tin connections in wrap connectors, where low contact forces combined with a soft metal lead to contact resistance increases by several orders of magnitude after less than a thousand cycles (**Fig. 4**) [1].

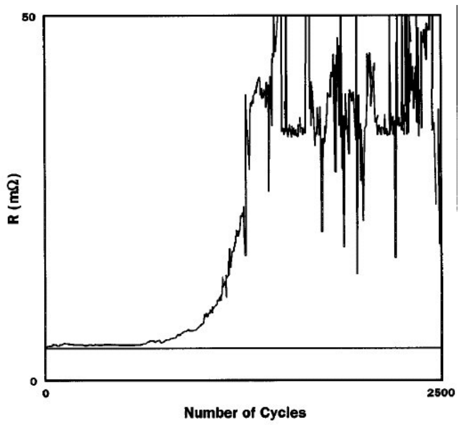

Fig. 4 Wrap connector: Contact failure of a tin/lead on tin/lead contact system after approximately 1000 insertion/withdrawal cycles of 40µm [1].

Based on the knowledge of wrap connector technologists, extensive care has been taken to ensure the reliability of a spring pin system under micro-vibration. To simulate a repetitive movement of the contact partners, as caused by vibration or thermal movement due to different coefficients of expansion, a setup was designed that forces a movement of a PCB over a spring pin at a defined frequency, load and amplitude (**Fig. 5**).
Test results on the spring pin contact system proved to be entirely different from the published results on wrap connectors.

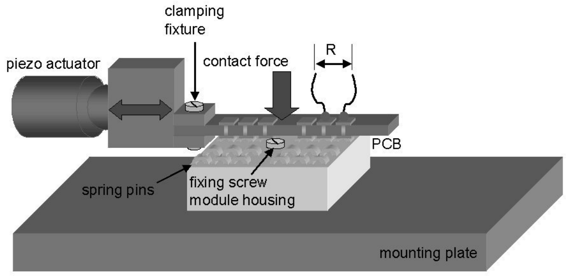

Fig. 5 Test setup for micro-vibration. The contact resistance of the system can be monitored using four conductor measurement.

Displayed in **Fig. 6** is the change of contact resistance of two spring pins versus the initial value. The contact resistance decreases initially. This process is associated with the cleaning of the contact spot. Contamination is removed. Daily temperature changes are represented by the cyclic fluctuation of the contact resistance. No increase of the contact resistance was detected during 4.65 million movement cycles. This is attributed to the higher contact forces involved in the spring pin contact, as well as the shape of the spring pin's head and the contact materials.

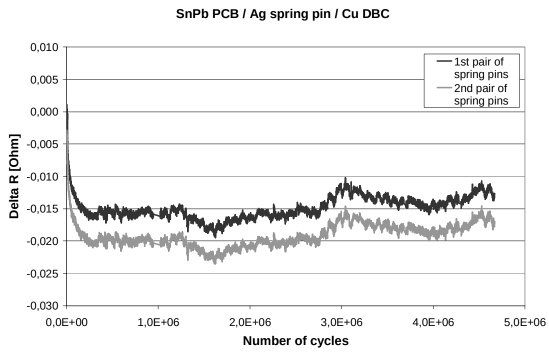

Fig. 6 Spring contact: Contact resistance change of two pairs of spring pins: 4.65 million cycles, 50µm, 1Hz.

3 Temperature Shock

Temperature shock tests are commonly used to evaluate lifetime reliability. The rapid thermal shock stresses interconnections between materials with different coefficients of expansion.

3.1 Material selection

As the spring pressure pin connection is not form locking, thermal movement and potential wear would be possible. This could lead to a change of the contact force, orientation and interface.
To evaluate the development of the contact resistance the change of the resistance against the first full cycle is plotted. The temperature evolution of each cycle was measured by a soldered thermocouple attached to the device under test (DUT).

It was found that some contact systems were susceptible to degradation of the contact resistance: As an example, **Fig. 7** shows the rise of the contact resistance of a test system with nickel DBC due to oxidation. The other contact partners were found to be undamaged. The contact resistance increases during cold storage temperature and rapid temperature changes.

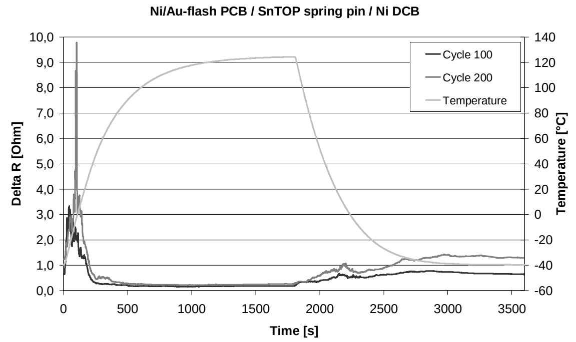

Fig. 7 Test system: Temperature shock test using a nickel DBC.

3.2 Current Load

Experiments were performed to verify the beneficial effect of higher currents on the contact resistance. In literature a change of the contact resistance is often attributed to thin surface layers [2]. Dry-circuit conditions are chosen not to destroy surface films. Those are limited to a current of up to 100mA and a voltage of up to 20mV to avoid melting and dielectric breakdown, respectively.

High Current: A test system was prepared with a material combination that allowed an increase in contact resistance over time. The current was increased in steps from 1mA to 400mA. **Fig. 8** shows the contact resistance development. With an increase in current, each step also shows a significant reduction of the contact resistance.
Testing performed at higher permanent current levels confirms there results. Practically no changes in contact resistance could be found at 6A over 200 cycles. The reliability of spring pins for load contacts is thus proven.

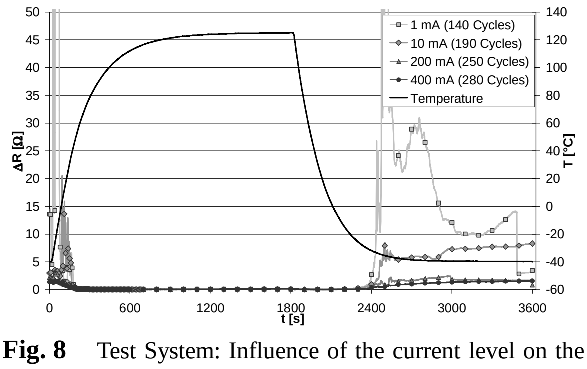

Fig. 8 Test System: Influence of the current level on the contact resistance of an aged contact system using a copper DBC.

Low Current: Low current levels are typical for temperature sensor applications. A change in contact resistance of 10 Ohm for a MiniSKiiP® temperature sensor is equivalent to an error in temperature reading of approximately 1°C.
In contrast to the test assemblies in **Fig. 7** and **8**, the contact resistance development of a genuine power module is displayed in **Fig. 9**. The optimized material selection leads to a stable contact resistance. 100 cycles with extreme temperature swings are considered equivalent to the total lifetime in the field. The largest change in contact resistance across eight spring pins in series (equals 16 contact spots) is measured to be only 100mOhm even after 200 temperature cycles.

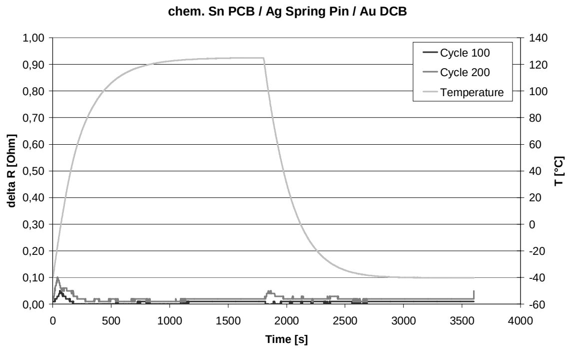

Fig. 9 MiniSKiiP® II contact system: Temperature shock test using an ENIG DBC.

To compare a MiniSKiiP® II system with integrated temperature sensor connected via spring pins to a soldered thermocouple an extended temperature cycling test was performed.
Fig. 10 displays the temperature measurement for selected cycles. The temperature evolution of the thermocouple and the temperature sensor show a slightly different gradient due to the differences in thermal capacity. The temperature sensor signal was stable for 2000 cycles; for the extreme changes in temperature this is equivalent to 20 times the normal lifetime of a power module. The soldered connection of the thermocouple failed at 1000 cycles and had to be replaced (see arrow in **Fig. 10**).

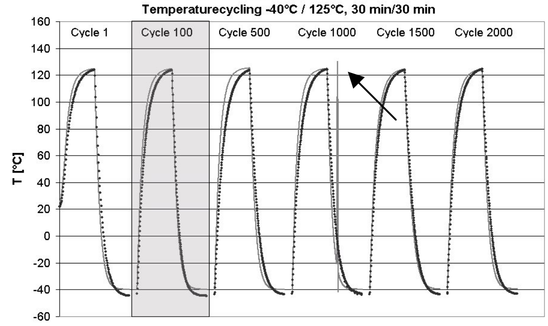

Fig. 10 Temperature recording using a soldered thermocouple (grey line) and a temperature sensor connected via two spring pins (black dotted line).

4 Corrosive Atmosphere

Corrosive atmosphere testing is performed as an accelerated test to ensure the reliable operation of spring pin connections – and power modules in general – in an industrial environment.

First tests were performed according to DIN EN 60068-2-43 Kd (10 ppm H_2S, 10 days, 25°C, 75% RH) as a highly accelerated corrosive atmosphere test. This test is specially designed to examine the stability of silver plated surfaces with and without tarnish protection. As expected, minor traces of tarnishing were found on all exposed silver surfaces. Scanning electron microscopy proved the contact interface to be resistant to the corrosive atmosphere. Due to the high contact forces of the spring pin system, the metallic contact partners form a cold-welded interface. This joint is impervious to outside contamination. Corrosion products could not be detected by EDX analysis inside the contact area (see **Fig. 11**).

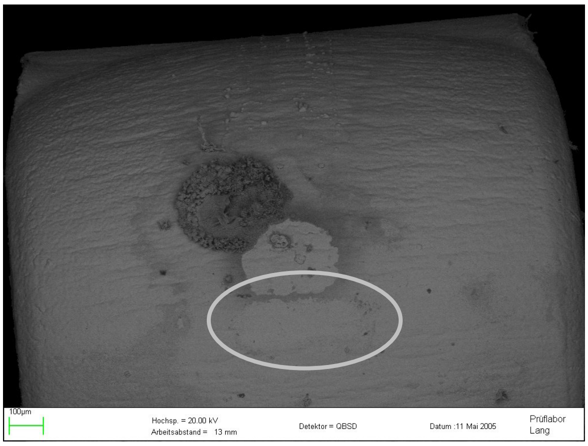

Fig. 11 Contact area (marked by circle) on the head of a spring pin after corrosive atmosphere test (10 ppm H_2S, 10 days, 75% RH, 25°C). The dark stain was caused by a droplet of liquid condensed during the test.

The failure criterion for testing was not the visible corrosion of the electrical contact metals, however. Testing was evaluated by measuring contact resistance before and after the test. The change in contact resistance for various systems was negligible.

While H_2S is the suitable atmosphere to check for silver tarnishing, the composition of industrial atmospheres is more complex. A combination of multiple corrosive gases will affect other types of materials included in inverters as well.

Thus, test parameters were defined using the four most common corrosive gasses in a concentration sufficiently high to provide accelerated test conditions. **Tab. 2** shows testing conditions selected for systems with a variety of contact metal surfaces. The test conditions are based on a combination of DIN EN 60068-2-60 Ke: method 3 (H_2S, SO_2 and NO_x for harsh environmental conditions) and DIN EN 60721-3-3 class 3C3 for heavily polluted industrial areas.

H_2S	0,4 ppm
SO_2	0,4 ppm
Cl_2	0,1 ppm
NO_x	0,5 ppm
25 °C, 75% RH, 21 days of exposure	

Tab. 2: SEMIKRON mixed gas test conditions.

5 Electromigration

Electromigration is a process of two consecutive phenomena which do not necessarily impair electrical contact behaviour. However it can lead to the formation of undesired conductive paths.

First a direct corrosion of metal surfaces may occur. The metal ions generated by corrosion, as well as anions present from any other source, are susceptible to migration in an electric field. As soon as a conductive surface of negative potential is reached, the anions can be reduced and deposited as metallic dendrites. Many factors have an influence on the development of these conductive paths. Among them are the rate of corrosion, the wettability of the insulating material between two potential levels, the mobility of the metal ions and composition of the electrolyte.

Testing was performed by applying an 80V bias to a spring pin module between the closest possible spring pin positions on the PCB during a corrosive atmosphere test. The voltage drop over the DUT was monitored and was expected to drop rapidly in the case of a formation of an electrically conductive path. Unlike standard SIR (surface insulation resistance) testing, a full assembly was examined. This allows the evaluation of the spring pins as well as the open PCB and DBC metals at the same time. As shown in **Fig. 12** the monitored signal over the tested parts closely followed the voltage source. No deviation of the voltage drop could be detected.

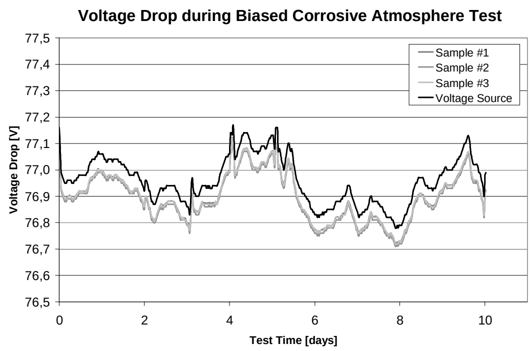

Fig. 12 Voltage drop over module assemblies during exposure to 10 ppm H_2S, 25°C, 75% RH, 10 days, 80V bias.

Analysis of the modules after the test revealed corrosion of the spring pins and contact metal parts, except for the metallic contact spot. Of special interest was the formation of brightly coloured, purple spots surrounding the spring pin contact on Ni/Au-flash PCBs (see **Fig. 13**).

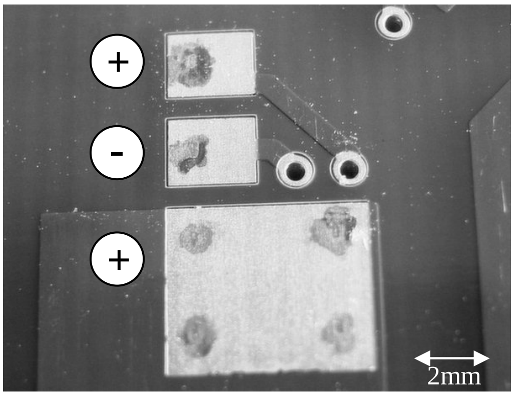

Fig. 13 PCB pads of a Ni/Au-flash PCB after corrosive atmosphere test (10 ppm H_2S, 25°C, 75% RH, 10 days, 80V bias). Bias indicated next to the contact pads

Analysis of the discoloured spots was performed by energy dispersive X-ray analysis. The contact centre was found to be free of corrosion products. The surrounding area was covered by Ag_2S and Cu_2S. Source of the copper is the tarnish protection of the spring pin. The corrosion products were spread on the gold finish of the PCB by a surface diffusion process – responsible is the high diffusion rate of copper in gold.
The appearance of gold plated PCB pads in contact with the tarnish protected silver spring pin is identical after a corrosive atmosphere test without bias. The concentric alignment of the discolouration around the contact spots is further evidence that the bias did not cause this creep. Incidentally, other lead-free plating systems do now show this creep of corrosion products. The observed effect did not impair the electrical properties of the contact system. All corrosion effects happen outside of the electrical contact area.

6 Intermetallic Phases

A phenomenon specific to certain metal combinations is the growth of intermetallic phases. Tin on copper plating – as commonly used as PCB metallization on copper base material – are known to grow into intermetallic phases with changed mechanical properties. Those intermetallic phases can impair soldering due to the formation of oxide layers that are difficult to remove with normal fluxes.
The growth of intermetallic phases is based on a diffusion process, and thus dependent on temperature. This is more of a concern for lead-free solder profiles with the associated higher temperatures.
A relation between the reduction of remaining pure tin thickness and temperature is given by the following formula:

$$\Delta d_{Sn} = 0.125 \cdot e^{-\frac{(428-T)}{17}}$$

with: Δd_{Sn}: reduction in pure tin thickness and
T: temperature of storage in K

This formula is valid for the formation of Cu_xSn_y-phases in the temperature range from 20°C to 330°C [3].
The above formula limits the shelf life of Sn HAL (Hot Air Levelling) and chem. Sn (immersion tin) PCBs for soldering processes typically to six months. The pressure contact system used in power modules has a service life of much more than that, however, and contact on the same material of the PCB pads.

To validate the reliability of a contact after long periods of time, an extreme aging of a contact system was tested with the following parameters:

- Storage of an immersion tin PCB and a tin-lead hot air levelling PCB at 150°C for 90 hours. Both PCBs were test PCBs used without any SMD components.
- Storage in a corrosive atmosphere (0.4 ppm H_2S, 0.4 ppm SO_2, 0.5 ppm NO_x, 0.1 ppm Cl_2, 25°C, 75% RH, 21 days).
- Temperature cycling with permanent current load of 1mA.

The first step ensures that no remaining pure tin layer is present at the surface and that intermetallic Cu_xSn_y-phases have grown through the metallization layer. The storage is equivalent to a predicted loss of a tin metallization thickness of 8.4µm – much more than the actual thickness of immersion tin on the PCB of approximately 1.2 µm.
The second step exposes the open intermetallic phases to an extremely aggressive mix of corrosive gases.
For the third step, current leads had to be connected to the PCB. Soldering to the heavily aged PCB proved to be difficult. **Fig. 14** shows a picture of a soldering attempt to attach a sense wire. Without mechanical cleaning and the use of extremely aggressive flux, soldering was impossible. The corrosive damage to the PCB was much more extensive than on any PCB observed after years of service and it can be assumed that no populated PCB would have survived this extreme aging.

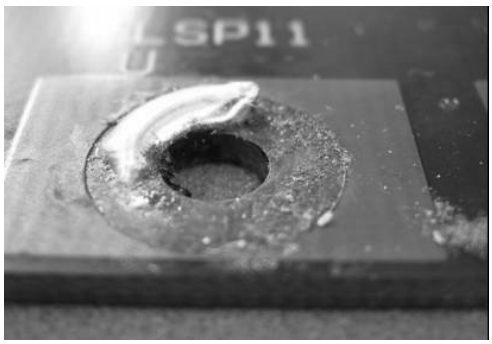

Fig. 14 Poor wettability of solder after extensive storage at high temperature and subsequent storage in corrosive atmosphere.

Then this extremely aged PCB was assembled to a new MiniSKiiP® module. Temperature cycling with permanent voltage drop monitoring was performed on the assembly.

The contact resistance evolution over a series of eight spring pins is displayed in **Fig. 15**. The initially increased resistance drops quickly to a stable value, once different coefficients of thermal expansion cause some micro-movement of the contact partners.

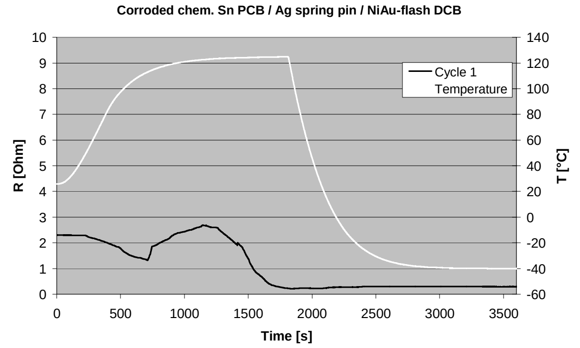

Fig. 15 Test system: First temperature cycle of corroded intermetallic phases as PCB surface after assembly for a series of 8 spring pins plus electric path.

The resistance increases during continuous cycling (**Fig. 16**). Total resistance changes for four pairs of spring pins reach 1.5Ω in high temperature storage. During cold storage, the change in resistance is up to 20Ω. Those values are obtained on a printed circuit board in worse shape than field returns after many years of service, though.

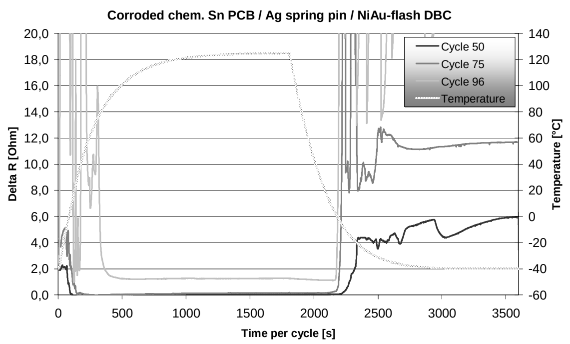

Fig. 16 Test system: Temperature cycling results of eight spring pins after assembly to heavily aged PCB.

For the MiniSKiiP® temperature sensor, used in the current ranges of 1mA, the hot storage change is equivalent to an error in temperature reading of approximately 0.1°C, the cold storage change to approximately 2°C. As the temperature sensor is mainly used to detect excess temperatures, this change has low impact on the application.

As discussed before, this contact resistance evolution is only valid for the observed current range of 1mA. At higher current levels the contact resistance will drop rapidly.

7 Conclusion

Extensive testing has proven the reliability of the spring pin pressure contact system in a variety of conditions associated with an industrial environment. The contact materials currently in use show no correlation to the problems feared in classical wrap connectors.

Temperature shocks with constant current proved to be a sensitive test for pressure contact systems. Authentic low-power experiments show only negligible fluctuations in contact resistance. Higher current levels, as used for load contacts, were seen to support contact stability. Therefore, special care is taken to ensure the reliability of low voltage, low current operations.

The influence of corrosive atmosphere on two different effects was examined closely. Due to the high contact forces of the spring pin contact system and the associated deformation of the contact metals, the access of corrosive gas to the contact area is suppressed. No signs of electromigration could be found in a test with additionally applied bias.

The growth of intermetallic phases on the PCB metallization leads to a change in mechanical and corrosion behaviour, which can affect solderability. However, the spring pin did establish a reliable metallic contact to the PCB even on a heavily aged and corroded PCB.

The spring pin contact system shows a high reliability towards various industrial influences while retaining the ease of assembly.

8 Literature

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