

Reliability of spring pressure contacts under environmental stress

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Abstract

Spring contacts are an excellent solution for connecting a power module with a printed circuit board (PCB). They can be applied in a wide current range from sensor currents of a few milliamps to load currents of several amps. They offer many advantages like easy assembly without soldering and also easy disassembly for maintenance purposes. The reliability of spring contacts under environmental stress by mechanical wear, rapid temperature change and corrosive atmosphere is significant for the application. The experimental results presented in this paper certify that spring contacts are reliable even under harsh environmental conditions.

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1. Introduction

While the many advantages of implementing spring contacts for the electrical connection between a power module and the PCB are obvious, concerns regarding the long time reliability in the harsh environment of power electronic applications are often observed. These concerns are based on experiences with pin-and-socket connectors or wrap connectors well known from PC main boards.

Therefore it is important to understand, that the spring connectors in power modules are completely different from wrap connectors, because they do not have to consider mating and unmating forces.

For power modules, the contact force is much higher than for wrap connectors – it is more comparable to a terminal-to-busbar connection by nut and bolt. Therefore, reliability results cannot be transferred from wrap connector systems (Fig. 1).

In the discussed power module assembly, an electrical interconnection between a printed circuit board (PCB) – with driver components and power leads – and a power module composed of ceramic substrate (DBC) carrying the power devices is established by springs (Fig. 2).

The PCB metallization systems in use today are RoHS conformal immersion tin, hot air levelling (HAL) tin, immersion silver, organic solderability preservation systems (OSP) or nickel/gold-flash (ENIG). The springs are formed from a conductive spring material (like bronze or steel) plated with tin, silver or nickel/gold. The available surfaces for ceramic substrates in power modules are copper, nickel or nickel/gold-flash. Different combinations of these materials will be investigated in the following test results.

The spring material used below is always a bronze. Each spring has two contact spots and a series of at least two springs is used for measurement. Due to the assembly of the power modules, a single spring is not accessible without intrusion into the module housing.

The applied pressure determines the choice of contact materials. Tin or silver plating is suitable for a contact force of approximately 2–20 N while gold plating is available for approximately 1–2 N. Since the spring force is between 3 N and 6 N per spring for the discussed systems, only Ag or Sn are recommended [1].

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

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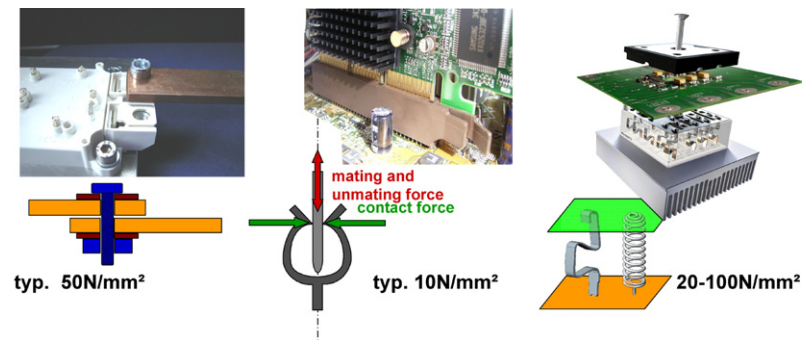


Fig. 1. Comparison of nut and bolt connection, wrap connector and spring contacts.

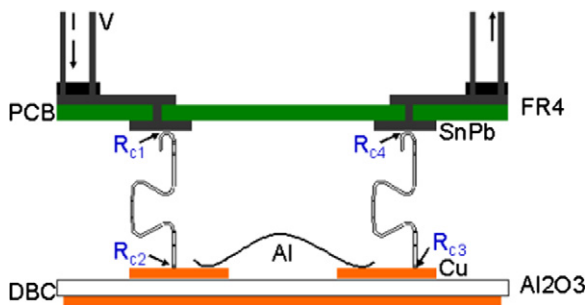


Fig. 2. Schematic overview of the spring contact system. PCB connected to DBC by springs.

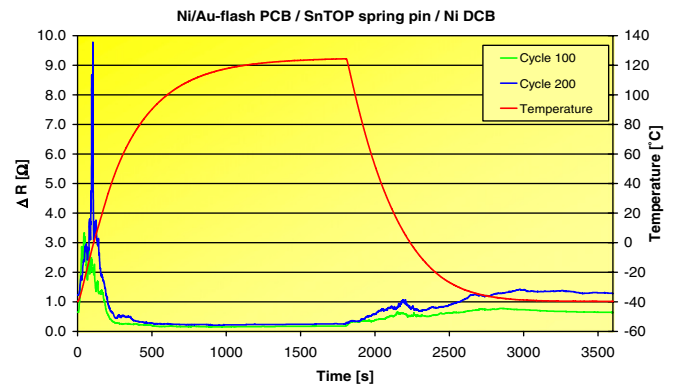


Fig. 3. Test system: temperature shock test using a nickel DBC.

2. Temperature shock test

Temperature shock tests combine the effects of temperature change, high temperature storage and movement induced by differences in thermal expansion.

2.1. Material selection

As the spring connection is not form locking, thermal movement and potential wear can be expected. This might impact the contact force and/or lead to an increase of contact resistance.

To evaluate the development of the contact resistance the change of the resistance against the first 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 material combinations were susceptible to degradation: For instance, Fig. 3 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 unaffected.

2.2. Impact of current load

In literature a change of the contact resistance is often attributed to thin surface films [1]. Dry-circuit measurement conditions are therefore chosen not to destroy surface films. Those are limited to a current of not more than

100 mA and a voltage of not more than 20 mV to avoid melting and dielectric breakdown, which would re-establish a good electrical contact. Experiments were performed to verify the beneficial effect of higher currents on the contact resistance. A (1 mA) sense current was used in the temperature shock test in Fig. 3.

To investigate the influence of higher currents a test system was prepared with a material combination that showed an increase in contact resistance after few cycles. Temperature shock was performed at a current of 1 mA until the contact resistance increased. The current was subsequently increased in steps from 1 mA up to 400 mA. Fig. 4 shows the contact resistance development. With an increase in current, each step also shows a significant reduction of the contact resistance.

Low current levels are typical for sensor applications. A change in contact resistance of 10 Ω for a MiniSKiiP® temperature sensor is equivalent to an error in temperature reading of approximately 1 °C.

In contrast to the test assemblies in Figs. 3 and 4, the contact resistance development of a genuine power module is displayed in Fig. 5. The optimized material selection leads to a stable contact resistance. Hundred cycles with extreme temperature swings are assumed equivalent to the total lifetime in the field. The largest change in contact resistance across eight springs in series (equals 16 contact spots) is measured to be only 100 mΩ even after 200 tem-

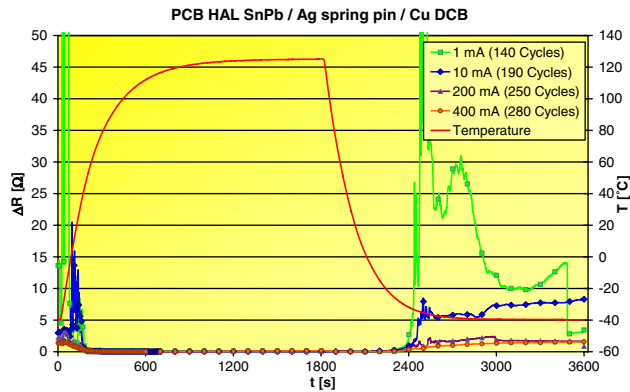


Fig. 4. Test system: influence of the current level on the contact resistance of an aged contact system using a copper DBC.

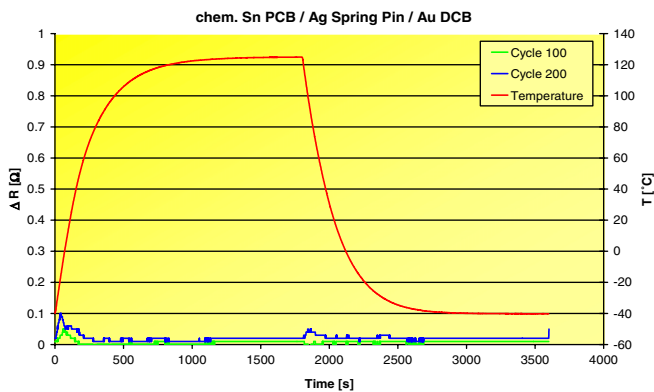


Fig. 5. MiniSKiiP® II contact system: temperature shock test using an ENIG DBC.

perature cycles, equivalent to an erroneous temperature reading of approximately 0.01 °C.

To compare a MiniSKiiP® II system with integrated temperature sensor connected via springs to a soldered thermocouple an extended temperature cycling test was performed.

Fig. 6 displays the temperature measurement for selected cycles. The temperature evolution of the thermo-

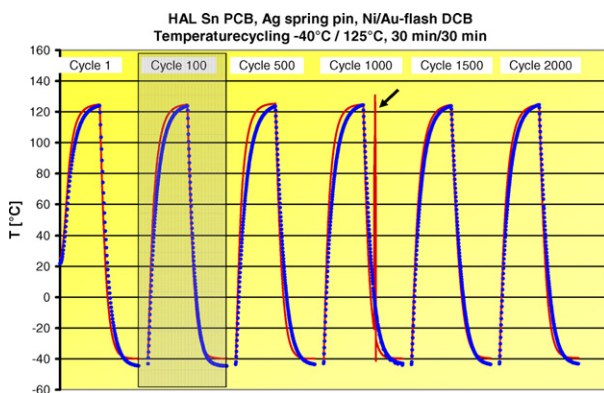


Fig. 6. Temperature recording for selected cycles using a soldered thermocouple (line) and a temperature sensor connected via two springs (dotted line).

couple 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. 6).

3. Mechanical fretting test

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 only for wrap connectors and limited to a small number of contact material combinations. Each movement cycle oxide flakes are abrasively removed from the contact surface. The newly generated surface can be 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 is the consequence (Fig. 7).

To simulate a repetitive mechanical movement of the power module contacts, a setup was designed that forces a movement of a PCB over a spring at a defined frequency, load and amplitude (Fig. 8).

Displayed in Fig. 9 is the change of contact resistance of two pairs of springs against the initial value. The contact resistance decreases initially. This process is associated with the cleaning of the contact spot; contamination is removed. Ambient temperature changes and a day/night fluctuation affect the contact resistance, but no increase of the contact

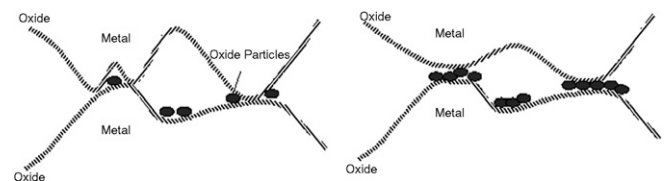


Fig. 7. Development of a dense layer of oxide flakes by alternating micro-movement and oxidation steps.

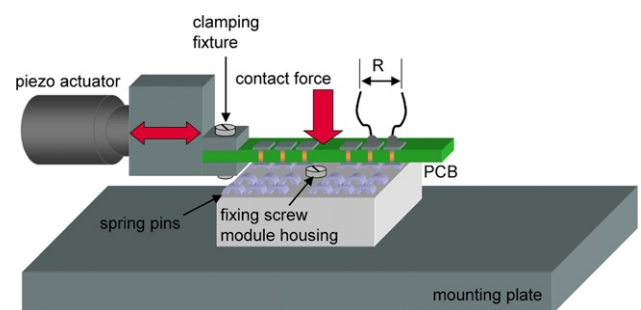


Fig. 8. Test setup for micro-vibration. The contact resistance of the system can be monitored using four conductor measurement.

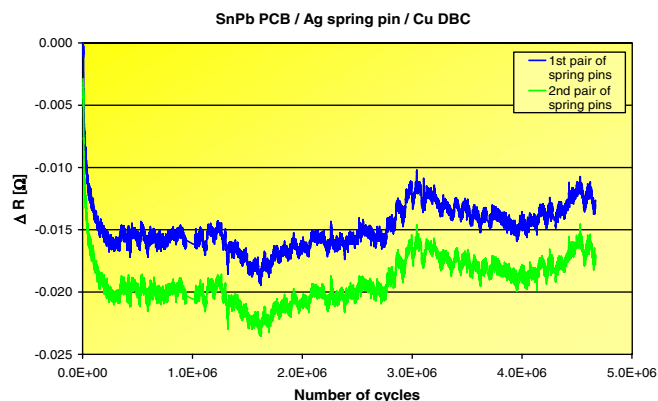


Fig. 9. Spring contact resistance change of two pairs of springs: 4.65 million cycles, displacement 50 μm , 1 Hz.

resistance was detected during 4.65 million movement cycles. This is attributed to the higher contact forces involved in the spring contact, as well as the shape of the spring's head and the contact materials. In contrast to literature results on wrap connector systems, no increase of contact resistance could be evoked by micro-movement of the contact system.

4. Corrosive atmosphere tests

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

Tests were performed according to DIN EN 60068-2-43 Kd (10 ppm H_2S , 10 days, 25 $^{\circ}\text{C}$, 75% RH) as a highly accelerated corrosive atmosphere test. This test is specially designed to examine the behaviour of silver plated surfaces. It can also verify the function of a tarnish protection. As expected, even surfaces with tarnish protection showed minor traces of tarnishing. Scanning electron microscopy proved the contact interface to be unaffected by the corrosive atmosphere. Due to the high contact forces of the spring system, the metallic contact partners form a quasi hermetically sealed interface. This joint is impervious to outside contamination. Corrosion products could not be detected by energy dispersive X-ray analysis (EDX) inside the contact area.

Even though the EDX analysis gives a good understanding of the impact of corrosive gases, the measured contact resistance before and after the test is the most important criterion for contact reliability. The change in contact resistance for various systems was found 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 the system as well.

Thus, test parameters were defined using the four most common corrosive gases in a concentration sufficiently high

Table 1

SEMIKRON mixed gas test conditions

H_2S	0.4 ppm
SO_2	0.4 ppm
Cl_2	0.1 ppm
NO_x	0.5 ppm
25 $^{\circ}\text{C}$, 75% RH, 21 days of exposure	

to provide accelerated test conditions. Table 1 shows testing conditions selected for systems with a variety of contact metal surfaces. The test conditions are derived from the climate class 3C3 in DIN EN 60721-3-3 for heavily polluted industrial areas and exceed the requirements of DIN EN 60068-2-60 Ke: method 3 (H_2S , SO_2 and NO_x for harsh environmental conditions):

This combination of gas conditions provokes corrosion of materials typically unaffected by pure H_2S like tin and aluminium. The test system again was not affected by the corrosive atmosphere due to the quasi hermetical contact interface.

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 corrosion of metal surfaces may occur. The metal ions generated by corrosion are susceptible to migration in an electric field. As soon as a conductive surface of negative potential is reached, the ions are reduced and deposited as metallic dendrites. 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 are all influencing factors on the rate of electromigration. Testing was performed by applying an 15 V bias to a spring module between the closest possible spring positions on the PCB during a corrosive atmosphere test. The voltage drop over the DUT was monitored and was expected to decrease in the case of formation of an electrically conductive path. No voltage breakdown was detected.

Analysis of module and PCB after the test revealed slight corrosion of the springs and a brightly coloured corona surrounding the clean metallic contact spot (see Fig. 10).

EDX analysis of the discoloured spots was performed. 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. The concentric alignment of the discolouration around the contact spots is evidence that the bias did not accelerate the process. No sign of beginning electromigration can be detected. The observed effect was caused by surface diffusion of the copper rich tarnish protection along the gold plating of the PCB. It did not impair the electrical properties of the contact system.

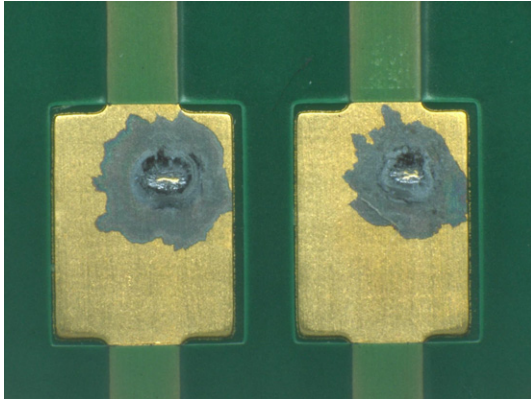


Fig. 10. PCB pads of a Ni/Au-flash PCB after corrosive atmosphere test (10 ppm H₂S, 25 °C, 75% RH, 10 days, 15 V bias). Bias indicated next to the contact pads.

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:

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

with: Δd_{Sn} , reduction in pure tin thickness in μm ; T , temperature in K.

This formula is valid for the formation of Cu_xSn_y -phases in the temperature range from 20 °C to 330 °C [2].

The above formula limits the shelf life of Sn HAL and chem. Sn PCBs for soldering processes. The spring contact system in power modules, which establishes an electrical contact to these PCB pads, requires a much longer service life. 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 h.
- Storage in a corrosive atmosphere (see Table 1).
- Temperature shocks with permanent current load of 1 mA.

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 thick-

ness of 8.4 μm – much more than the actual thickness of immersion tin on the PCB of approximately 1 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. 11 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 more extensive than on any PCB after years of service and it can be assumed that no populated PCB would have functionally survived this extreme aging.

Then this 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 springs is displayed in Fig. 12. The initially increased resistance drops quickly to a stable value. This is attributed to a cleaning of the contact partners due to movement induced by different coefficients of thermal expansion.

The resistance increases during continuous cycling (Fig. 13). Those values are obtained on a printed circuit board in worse shape than field returns after many years

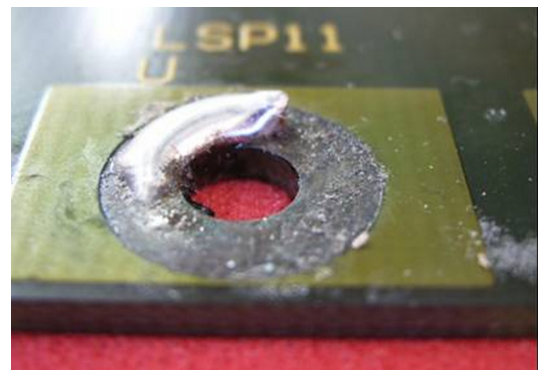


Fig. 11. Poor wettability of solder after extensive high temperature storage followed by corrosive atmosphere.

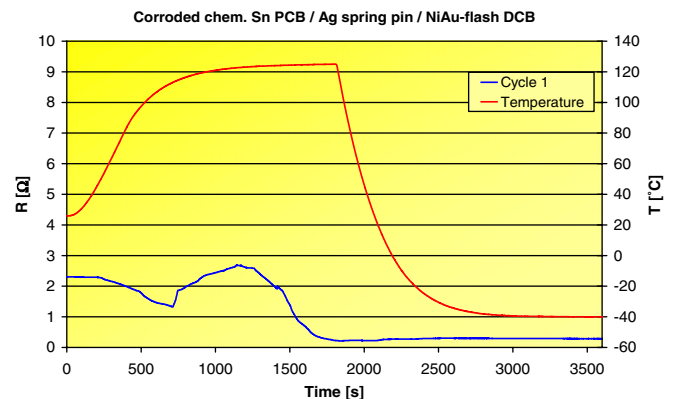


Fig. 12. Test system: first temperature cycle of corroded intermetallic phase PCB surface after assembly.

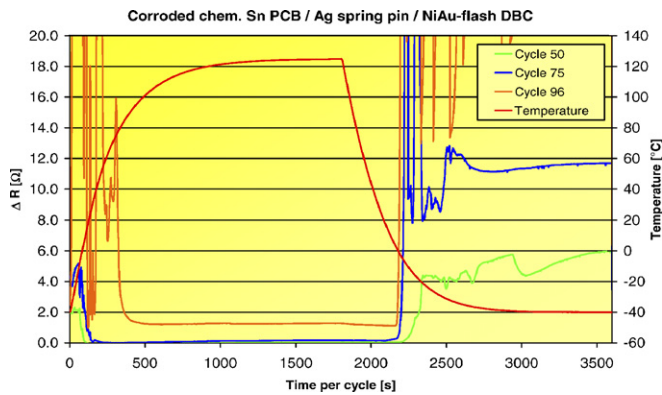


Fig. 13. Test system: temperature shock results of eight springs after assembly to heavily aged PCB.

of service, though. As discussed before, this contact resistance evolution is only observed in the current range of 1 mA. At higher current levels the contact resistance increase will be negligible.

7. Conclusion

Extensive testing has proven the reliability of the spring pressure contact system in a variety of extreme conditions associated with an industrial environment.

The stress in applications of the power modules can best be reproduced by temperature shock, which combines sev-

eral different conditions in one test. Authentic low-current experiments show only negligible fluctuations in contact resistance. Higher current levels, as used for control and load contacts, were seen to enhance the 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 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 voltage 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 did establish a reliable metallic contact to the PCB even on a heavily aged and corroded PCB.

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

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