Failure for Mechanical Reasons

In this topic we have gathered together some of the ways in which components may fail to function as intended for reasons that can be broadly grouped as ‘mechanical’, other than those that are described in *Board failures*. As with board warping, you will find that some of these also principally affect the manufacturing stages; others, more akin to the cracking of through-hole plating, are more serious, in that they affect the life expectancy of the product.

Lead damage

High lead-count packages have typical lead pitches of 0.4 or 0.5 mm, and exceptionally 0.3 mm pitch is used. The thin and weak leads of these packages easily bend unintentionally, especially those at the package corners.

The bending of a lead severely damages the package and may affect the reliability. The stress induced may result in microscopic cracks or chips in the package, and reduced adhesion, particularly where the lead enters. This reduces the ability of the package to resist ingress of moisture and may lead to failure through internal corrosion.

Correction of bent leads, before soldering, is very difficult in practice and faulty components are usually discarded. Bends may be:

- lateral, so that specifications of lead-lead distance are violated
- in a vertical plane, producing non-coplanarity failure, as discussed below.

The fine pitches place extreme requirements on:

- the manufacturing technology of PCBs
- paste application
- component placement, even if the position of the leads is within specification.

Coplanarity failures

Whenever a package with more than three leads is placed on a flat surface, only the lowest three have to be in contact with the surface. If the leads are distorted, a number of them may end up above the surface. This deviation from flatness is referred to[1] as ‘non-coplanarity’, and the plane of the surface on which the package would naturally sit is called the ‘seating plane’. Figure 1 shows a multi-lead package with the coplanarity given as the vertical distance measured from the lowest lead, and a maximum deviation of 0.08mm (80µm).

[1] *Non-coplanarity is the correct term, but the issue is often referred to as ‘coplanarity’.*

A set of non-coplanar leads

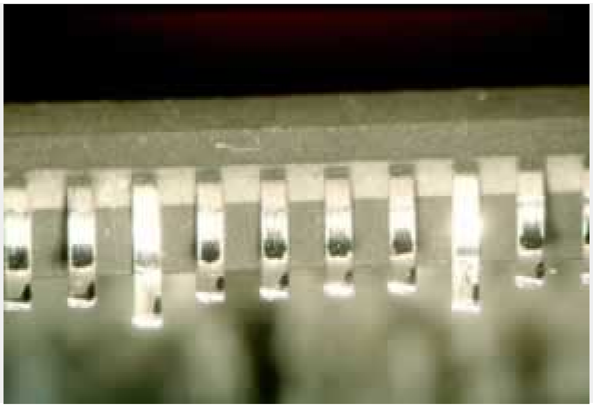
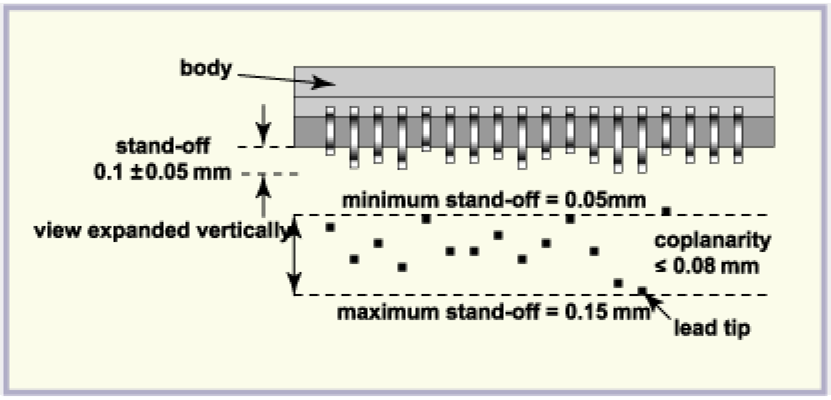


Figure 1: Non-coplanarity and stand-off on a QFP



After the leads have been formed during package manufacture, their position is usually well within the specified tolerance, and lead non-coplanarity often finds its origin either in the socket used in the functional testing of the IC or in its packaging. The exception is the case of J-lead components, where consistent problems can be caused by tooling wear or damage, or by fragments of lead-frame being caught on the tool.

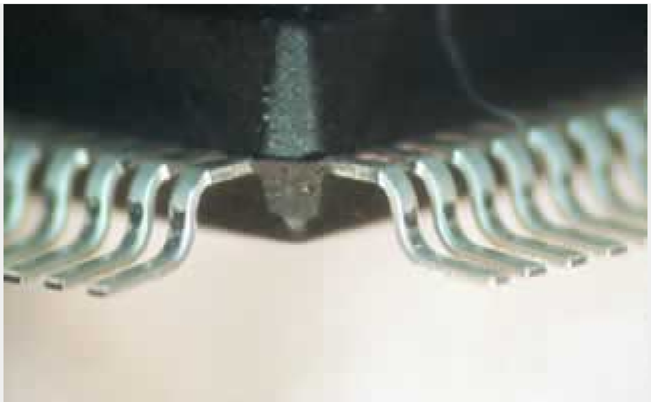
The maximum package non-coplanarity that can be accommodated depends on the thickness of the solder paste layer and is generally allowed to be about 50% of this thickness. However, what dictates whether or not a joint is formed is the combined non-coplanarity of the component and board, and board warp is often even more important than component non-coplanarity.

The seating plane is usually taken as the ‘plane of reference’ for coplanarity measurement. Not only is this convenient, but it indicates what will be the effect of mounting the part. However, other views are that the plane of reference should be parallel either to the component body, or to the average position of the leads. Consider a component with 100 leads (25 per side), with 99 of them precisely in one plane and only one bent downwards: would you judge 74 leads to be out of planar position?

Coplanarity measurement

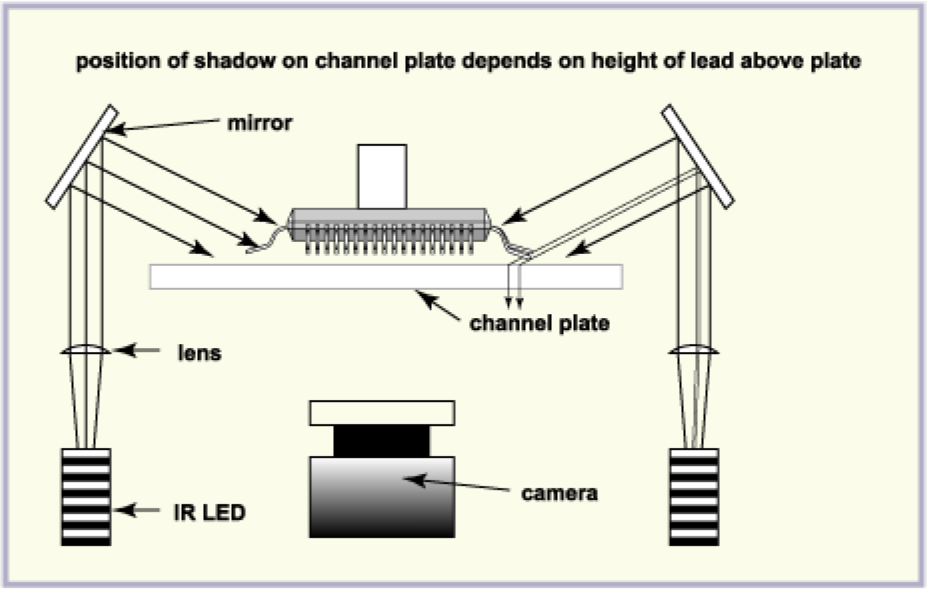
Coplanarity checking has increased in importance as finer pitch components have become more common. Previously, coplanarity defects were nasty but not fatal: with the availability of large fine-pitch components, assembly yield problems forced suppliers of placement equipment to add an option for coplanarity checking to the machines.

Are these QFP leads coplanar?



An optical reference method is shown in Figure 2, which compares the shadow length of leads illuminated by a light beam at a low angle. By using four different light sources sequentially, or by turning the component, the four sides of the IC can be inspected in turn. An alternative method uses ‘laser range-finding’ to measure the height of each lead, determining which are the lowest leads, and calculating the worst-case lead height above the seating plane.

Figure 2: Schematic set up for coplanarity measurement



Whichever the method used, there are several practical implications:

- Where a part has been shown to be out of limits, the software has to allow for further placement attempts to be made
- There has to be some means of collecting rejected parts for return to vendor
- The placement rate will be reduced, because of the time taken for measurement and computation. It is common for coplanarity checking devices either to be disabled or else to be used only with problem components.

Stand-off

Related to coplanarity is the stand-off distance of the package, that is, the gap between the underside of the component body and the seating plane. If this is too small, the component body may actually touch the surface of the solder mask, which is normally higher than the surface of the lands, in order to be effective in minimising solder bridging. Some leads may then not make sufficient contact with the pads for a good fillet to be formed. More significantly for cosmetic and reliability reasons, too small a gap between package and board can lead to the entrapment of flux and contamination.

The stand-off achieved for a particular component will depend on:

- The design and manufacturing tolerance of leads and body
- The combined effects of board warp and lead non-coplanarity
- Any distortion of the component body (for example, popcorning)
- Any additional copper tracks or legend under the component
- The thickness and variability of the solder mask.

Glass components

Whilst some signal diodes are wire-bonded and transfer-moulded in SOT-23 format, in the same way as transistors, others make compression connections to the die. One method can clearly be seen on examining MELF parts: the semiconductor die is pressed between two copper alloy ‘nail heads’ by the contraction of the surrounding glass ‘sleeve’ as it cools from a softened state. The glass forms a hermetic seal around the terminations, and the internal compression forces ensure adequate permanent contact with the die metallisation. This ‘double crunch’ seal is both reliable and cost-effective, and has been widely used since the 1960s.

MELF diode, showing copper slugs between which the chip is held

Although MELFs are quite robust, their wire-ended equivalents present a particular hazard, as any strain applied to the leads can crack the glass. This destroys the hermeticity of the seal, and reduces the integrity of the compression connection. Parts may then fail due to high leakage currents or become open-circuit. A particular problem is that the device becomes vulnerable to strain induced by temperature changes or board flexure, and may present as an intermittent failure.

Cracks in glass seal around lead

Many axial diodes (such as the DO-7, DO-35 and DO-41 formats) have a transfer-moulded polymer casing, but the same style of compression connection. In fact, apparently 'plastic' diodes may still use an internal glass seal! With all such parts, it is important to realise their vulnerability to shock and stress applied during cutting, forming or clinching operations, and to use appropriate techniques and tools. For example, during forming, leads should be clamped close to the body to reduce the impact on the component, but not so close as to cause impact damage to the glass. It is also preferable to cut or form the component leads as two separate operations rather than together.

The same comments about vulnerability to damage from shock and stress, and precautions to be taken during mechanical operations, also apply to the sealed reed switches used in reed relays and for proximity detectors, and to glass-to-metal seals used in components such as crystals.

Although these problems are specific to glass components, the dangers of uncontrolled mechanical operations are also seen with some types of plastic encapsulation, where lead stresses are transmitted internally. The IPC TechNet Web Forum reported a problem with plastic through-hole LEDs, which were inserted without a stand-off, and damaged during swaging at 90° to the board. This stressed the die, and the problem turned into an open-circuit during soldering, or soon after.

Note that problems such as these have been seen before – 'we ran into a problem exactly like this years ago' – but recur far too regularly!

Mechanical wear-out

Many mechanical components have wear-out mechanisms. For example, switches and relays have life expectancies expressed as the number of operations under given load conditions. Degradation of any moving contact pair is complex, being affected by:

- The mechanical life of the moving member, which itself may be limited by the service life of any lubrication, or determined by metal fatigue, or reduced by gross abuse by the end-user. Mechanical failures normally result in open-circuits

- Any erosion of the contact surface caused by the making or (usually) breaking of the circuit being controlled, which produces variable high contact resistance and eventually open-circuits
- In the case of high current overloads, induced premature failure may take the form of contacts being welded together
- Any corrosion of the contact surface due to the environment, often accelerated by humidity and/or moisture. Oxide and sulphide build-ups produce variable degrees of high resistance/open-circuit. Unlike most other failure mechanisms, the situation is worst under low-current and low-voltage conditions, and special structures and finishes are often specified for applications such as instrumentation.

In all cases, the expected life of the component has to be taken into account during the design of the assembly. For example, with connectors, it is important to establish the expected number of insertions, and in particular whether the contacts will be made and/or broken during circuit operation. These parameters will affect both the design of the contact and the specification of its plating. For relays and switches, one needs to know the maximum circuit voltage and current, as well as information on the inductance of the load – when inductive loads are switched off, transient high voltages will be generated, and damaging arcing may occur.

Problems with mechanical components can be exacerbated by heat and moisture degrading the surfaces, and by mechanical damage, so correct storage and handling are important. For sealed designs, such as switches and variable components, the ingress of fluids can affect the surfaces, and such components are often supplied with a protective tape which is only removed once assembly has been completed.

Other mechanical components, such as connectors, may combine the problems of maintaining high-quality contact surfaces with issues of materials compatibility with the process, in particular when the part is to be subjected to the heat of reflow. It is important to keep within the specified peak operating temperature for the component, to avoid the distortion or softening which may accompany exposure to over-temperature.

Mechanical forces

Most equipment is subjected during life to varying degrees of shock and vibration. These exert forces on the components, and stress the joints. This is a common cause of failure with the connections to relatively heavy or unsupported components such as transformers and electrolytic capacitors, as these are associated with high stresses.

The mass of a surface mounted component is less than that of its through-hole equivalent: all things being equal, the stresses on the joints will be reduced pro rata. However, this ignores the facts that the assembly mass/unit area remains very much the same, and SM boards are frequently more flexible. The result is that shock and vibration can produce flexure in the board, and this stresses the component joints, particularly in the case of the rigid joints used for ceramic components.

When designing the overall system, adequate board support must be provided, and the board material selected to give sufficient rigidity. Proper handling during assembly is also important in preventing flexure damage.

Note that apparently similar laminates have different properties (for example, CEM-1 flexes more than FR-4) and the situation is more complicated for flexible circuits. Computer modelling the structure is recommended for critical applications, and recent advances allow the thermal and mechanical performance of an assembly to be predicted.

The stresses on all components can then be assessed, bearing in mind that repeated stress has long been known to give rise to fatigue failure at stresses well below the ultimate strength of a structure – be conservative!

It must also not be forgotten that vibration and shock can excite resonance, which increases the component excursion for a given level of applied vibration. Where an assembly contains large elements, and relatively flimsy leads, some damping may need to be built into the structure.

Substrate-related thermal stress

Most boards have CTEs which differ from those of the components mounted on them. For example, with MLCs, an FR-4 board expands further than the chip when heated, subjecting the component to tensile stress, whereas on an alumina substrate, such as that used for hybrids, the stress is compressive. The converse is the case when the board is cooled.

The effect of thermal cycling is thus to produce stresses caused by CTE mismatch, which can result in component or joint failure. The situation is worst for rigid assemblies such as MLCs, or for those (such as potted components) where there are substantial thermal gradients caused by poor conductivity.

Failure of an assembly can be induced during service by ‘natural thermal cycling’, which happens as a result of:

- The ‘diurnal excursion’: the daily increase in temperature during the day, and subsequent nightly drop. Changes in ambient temperature can be significant in some military/aerospace and automotive applications
- The ‘operating cycle’, where the temperature increase is caused by the power dissipated by the assembly. In this case, a major issue is that the temperature reached is not the same in all parts of the assembly, power semiconductors normally seeing the highest temperatures.

Whilst these are problems which are inherent in the design, failures will usually only result when the construction is sub-optimal. In many cases, accelerated stressing by ‘temperature cycling’ or ‘power cycling’ is used to weed out potential failures, although this type of testing is very expensive.

Where rigid components such as large MLCs, ceramic filters, and LCCs are used, the better the CTE match between components and board, the better will be the reliability as regards stress-induced failure. The desirable, albeit expensive, alternatives to using epoxy-glass laminates are polyimide-glass (whose CTE of 12ppm/°C is reasonably close to the inter-termination figure of 11ppm/°C for an MLC) or metal-cored boards, whose CTEs can be tailored to the application.

Source: http://www.ami.ac.uk/courses/topics/0182_fmr/index.html