IEC TR 61760-5-1

Edition 1.0 2024-01

TECHNICAL REPORT

colour inside

Surface mounting technology –
Part 5-1: Surface strain on circuit boards – Strain gauge measurement applied to chip components

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SURFACE MOUNTING TECHNOLOGY –

Part 5-1: Surface strain on circuit boards – Strain gauge measurement applied to chip components

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The text of this Technical Report is based on the following documents:

Draft	Report on voting
91/1915/DTR	91/1927/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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INTRODUCTION

This Technical Report applies to electronic and electromechanical circuit board assemblies and describes current best-practices for dealing with mechanical stress induced cracks in the body of surface-mount ceramic components soldered onto circuit boards.

Circuit boards are becoming smaller and thinner, design margins are decreasing, and components are becoming more sensitive to mechanical stresses. In consequence in-depth strain control on a circuit board is getting more and more important to prevent mechanical damage to components.

This Technical Report is an informative document which serves to illustrate the technically feasible options and provides a basis for customer and supplier discussions and agreements. It is based on many years of experience of component manufacturers and users in measuring surface strain on circuit board surfaces during various assembly processes. It is not intended to be regarded as a specification or standard. Formulations and data expressed in the form of provision such as requirements or recommendations do not claim to be provisions and are just suggested as the results of the discussion.

Related standards are gathered in the bibliography.

SURFACE MOUNTING TECHNOLOGY –

Part 5-1: Surface strain on circuit boards – Strain gauge measurement applied to chip components

1 Scope

This document describes examples of methods using electrical strain gauges for determination of critical mechanical stresses in assembly processes. These stresses can damage chip type ceramic components, causing so called "bending cracks". Area-array components are excluded from the scope of this document.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60194-2 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
principal strain
maximum and minimum normal strains in a plane, always perpendicular to each other and oriented in directions for which the shear strains are zero

3.2
maximum principal strain
maximum value of principal strain developed in the component body

Note 1 to entry: Failure of a material or component will occur when the maximum principal strain developed in the body exceeds the limiting value of strain for a certain component.

4 Damaging mechanisms of chip type ceramic components

4.1 Surface strain by board bending

When a board is bent, lands are pulled outwards and generate mechanical stress on the solder-joints, electrodes or components (Figure 1, Figure 2). This mechanical stress causes defects, for example a bending crack in a ceramic capacitor (Figure 3). The root cause of this defect is the local strain at the surface on which the component is mounted.

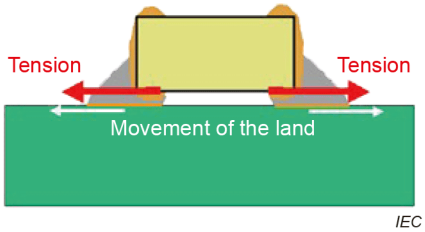

Figure 1 – Mechanical stress by board bending

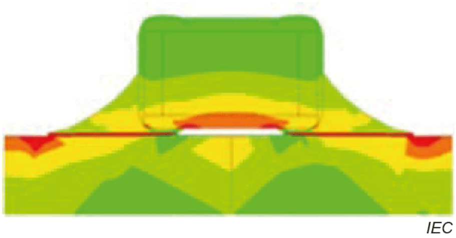

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Figure 2 – Strain simulation

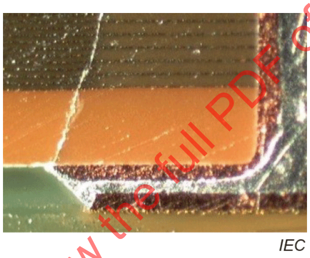

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Figure 3 – Typical bending crack at a ceramic capacitor

4.2 Typical cracking modes

Bending stress can occur in any direction, see Figure 4 and Figure 5. The cracks were made visible by grinding from the board side. The position and shape of cracks can be used to estimate the direction of stress. The local strain at the position at which the component is mounted causes the cracks. Therefore, even if a board does not look bent, this defect could occur by local surface stress or short time impact.

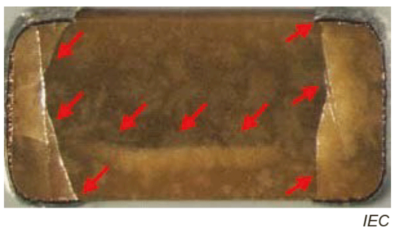

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Figure 4 – Longitudinal stress

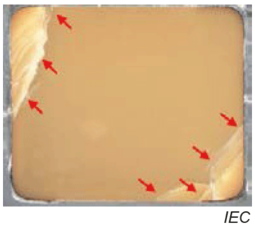

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Figure 5 – Diagonal stress

4.3 Measurement of local strain

Local strains can occur in any direction, see Figure 4 and Figure 5. 3-axes strain gauges provide a full assessment of the strain state. The use of 1-axis or 2-axes measurements provides limited information on the strain state.

5 Crack prevention

5.1 Strain control

To prevent bending cracks described in 4.1 and 4.2, strain control on a PCB is needed. The bending strength of SMD for example can be determined by the so-called substrate bending test, as provided in IEC 60068-2-21. However, the real mechanical strength of a surface mount component depends on various design and process factors (e.g. land size, solder quantity/type, PCB material/type, Cu foil thickness, strain rate, etc.). Furthermore, considering the strain measurement accuracy, measurement repeatability, and irregular stresses in assembly processes, a certain safety margin is needed, see Figure 6.

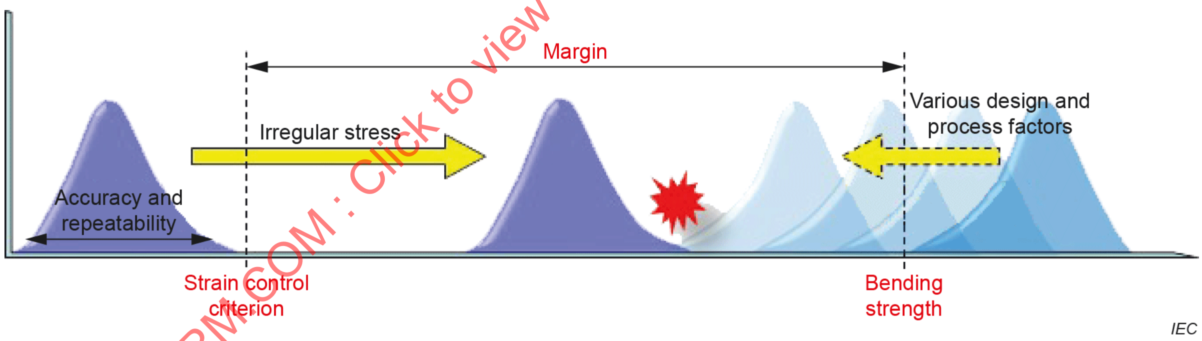

Figure 6 – Strain control and bending strength

5.2 Critical board design factors

5.2.1 Distance from circuit board cutting position

Components mounted close to a cutting or singulation position are at risk. A slit can reduce the cutting stress if it is placed between the component and the cutting line. Also, a deep v-groove can reduce the cutting stress.

5.2.2 Distance from screw clamping position

Components mounted close to a screw clamping position are at risk.

5.2.3 Mounting direction

Risk can be reduced, if a components' longitudinal axis is oriented perpendicular to the maximum principle strain.

5.2.4 Warpage

Warpage can be the cause of surface stress when a circuit board is flattened when fitted into the housing.

5.2.5 Orientation of the component related with the loading point

The mechanical load to components is influenced by their orientation relative to the forces applied to the board.

5.3 Critical assembly process factors

5.3.1 General

In general, an assessment of all processes which involve mechanical loads applied to populated circuit boards is needed. This implies that such an assessment needs to start after the first reflow cycle. All process steps, including solder paste printing for the second reflow side (top side), conveyor movement, pick-and-place etc. occurring after the first reflow cycle need to be considered. Further information on such processes is gathered in Clause A.1.

5.3.2 Circuit board singulation

Stresses depend on the singulation method.

The strain levels depend on various factors. For example, in the cutting process, the strain levels depend on the wear of the blades, the quality of V-groove and the machine settings. On the other hand, in the milling process, the strain levels depend on the tooling geometry and the machine settings.

5.3.3 Circuit board fitting into the housing

Local stresses or short time impacts can occur in this process, and these kinds of stress are sometimes overlooked. These stresses and impacts could generate strain on a circuit board.

5.3.4 Screw clamp

In a screw clamp process, misalignment of screw holes, misalignment of the screwing tool or an excessive tightening of screws (e.g. if screwing torque is not well controlled) might generate a deformation and strain of the circuit board. In this case, strain occurs near a screw hole and on a ridgeline linking screw holes, see Figure 7. Special care needs to be taken if the system is mechanically over-determined (i.e., number of degrees of freedom of a system is less than the number of constraints, e.g., if more than two screwing points exist along a straight line), as bow and twist of circuit boards as well as mechanical tolerances of clamping surfaces can also result in strains at circuit-board level.

In addition, if a sealing, thermal interface material or similar connection is established during the screwing process, the compression of such material can also result in deformation and thus strain on the circuit board.

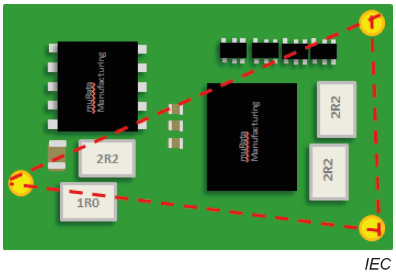

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Figure 7 – Strain during screwing

5.3.5 Manual handling

In handling processes (e.g. manual connector insertion to circuit board, snap into the housing, manual mounting of a large component or a heat sink, etc.), a wider variation of loads exerted on circuit-board assemblies can occur due to different operators, and that might generate irregular stresses on components. Furthermore, processes such as removing a mounted or inserted component might generate high irregular stresses to components. That is why strain management, considering such variations or irregular stresses, as well as worst-case scenarios, is needed.

5.3.6 ICT (In-Circuit Test) / FT (Functional Test) / Programming on assembly level

Complex strain states can occur in these processes, where a few of multiple ('bed of nails') test needles, touch an assembly at designated contact points. It is particularly important to estimate the most critical area on a circuit board and to understand the stress levels in such areas. Where support pins or many contact pins contact the underside of an assembly beneath components on the opposite side, the possibility that these components are subjected to local stress is high. To estimate such unexpected strain areas, experiential know-how or stress simulation, etc. are needed.

6 Example of an instruction on board preparation for strain measurement

6.1 General

6.1.1 Introductory statement

The following 6.2 and 6.3 provide information on how to position and attach the strain gauges to perform the strain measurements. It constitutes the example of an instruction based on experience and best practice. The imperative mood used in some cases does not constitute a requirement, alternative methods can be used as well.

6.1.2 Theory of strain gauge measurement

An external tensile force (compressive force) increases (decreases) the electrical resistance by elongating (contracting) a strain gauge. The change in electrical resistance can be measured precisely. Normally, for strain measurement, a Wheatstone bridge is formed, see Figure 8. The output voltage E_0 (V) is calculated by Equation (1). The output voltage is proportional to a change in resistance, i.e. a change in strain. Thus, strain is calculated by measured output voltage, applied bridge voltage, and gauge factor.

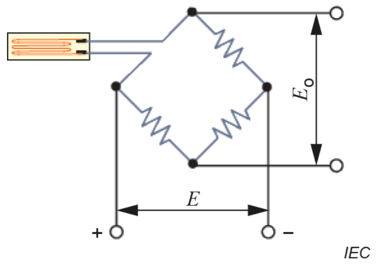

Figure 8 – Resistor bridge for strain measurement

$$E_o = \frac{1}{4} \times K \times \varepsilon \times E \tag{1}$$

where

E_o is the output voltage;

E is the bridge voltage;

K is the gauge factor;

ε is the strain.

6.1.3 3-axes strain measurement

When it is difficult or impossible to predict the angle of the maximum principal strain, a 3-axes strain gauge can be used to determine the maximum principal strain and the direction in which it occurs. See Figure 9. The maximum principal strain ε_{max} and the angle θ are calculated by rosette analysis, using Equations (2) and (3):

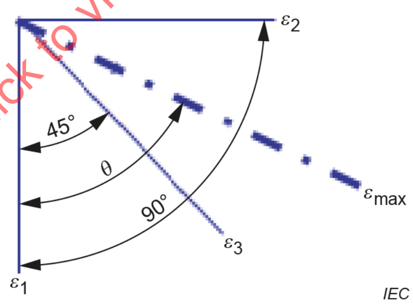

Figure 9 – 3-axes strain gauge and maximum principle strain

$$\varepsilon_{max} = \frac{1}{2}\left[\varepsilon_1 + \varepsilon_2 + \sqrt{2\left|(\varepsilon_1 - \varepsilon_3)^2 + (\varepsilon_3 - \varepsilon_2)^2\right|}\right] \tag{2}$$

$$\theta = \frac{1}{2}\tan^{-1}\left[\frac{2\varepsilon_3 - \varepsilon_1 - \varepsilon_2}{\varepsilon_1 - \varepsilon_2}\right] \tag{3}$$

A 1-axis strain gauge measures the strain along the direction of the gauge. The use of a 1-axis strain gauge can for example be related to space constraints in the surroundings of the component to be analysed (see Annex A).

6.2 Position of strain gauges (example)

6.2.1 General

Place the strain gauge at the same position as the component to be investigated. If it is placed on the opposite side of the circuit board, the strain values measured will be significantly different. For selecting the most suitable position of the gauges, all critical steps of the assembly process need to be considered.

If a uniaxial strain gauge is used, the axis of the strain gauge needs to be aligned with the axis of the component. The measurement grid of the strain gauge needs to be present on both soldering pads of the component and the size of the strain gauge grid needs to be adapted to the size of the component.

In the case of a rosette gauge, the first layer of the rosettes needs to be aligned with the longitudinal axis of the component.

6.2.2 Determination of critical positions on a circuit board

6.2.2.1 By experiment or experience

From experience or experimental assessments, critical strains could be generated:

- near a cutting position and during insertion of the panel to the cutting blades,
- near a screw hole,
- on a ridgeline linking screw holes,
- near the back side of support pins or many contact pins, and
- near a large component.

6.2.2.2 By simulation

Critical positions can be determined by simulation. The simulation needs to determine the strain at the position of the component at least along the axis of the component as well as in the perpendicular direction and at an angle of 45°, so that a full analysis of the strain state is possible. Simulation results need to be verified by experiments before use. Without additional simulations and/or experimental assessments, a 3-axis strain gauge measurement needs to be done in order to reliably detect critical strain levels.

6.2.3 Rules for determination of sample size for performing the investigations

Experience had shown that it is sufficient to measure at the most critical position using 3-axes strain gauge, if there is enough space to use a rosette gauge. If space does not permit the use of a rosette gauge, the strain state (direction of maximum principal strain) needs to be assessed based on additional measurements with uniaxial gauges or mechanical considerations, e.g. by simulations. In deciding the number of circuit boards to be tested, the process variation and operator influence needs to be considered.

NOTE The number of samples will be different in case of a process qualification or of a failure investigation, where a higher number of samples can become necessary.

6.3 Attachment of strain gauges (example)

6.3.1 Step 1 – Remove components

Removal of components within the attachment area, e.g., by de-soldering. Remove solder residues carefully to achieve a flat surface. See Figure 10.

NOTE The removal of components within the attachment area generally affects the strain state at the measurement location. Component removal needs thus to be restricted in as far as possible.

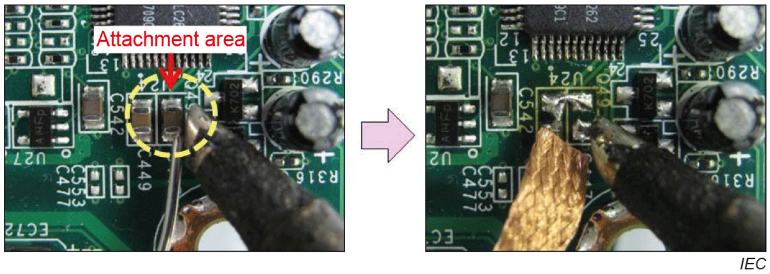

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Figure 10 – De-soldering of components

6.3.2 Step 2 – Polish the attachment area

Grind an area larger than the size of strain gauge either by sandpaper or fibre-glass pen to remove solder residues and make the board surface smooth. Select type and grit of the sandpaper following the recommendations provided by the suppliers of strain gauges. Common grit numbers are #300 or #400.

Remove grinding residues from the surface by polishing with a piece of cloth wetted with acetone or isopropyl alcohol (IPA). See Figure 11.

Check the smoothness of surface whether it complies to the requirements in strain gauge specification.

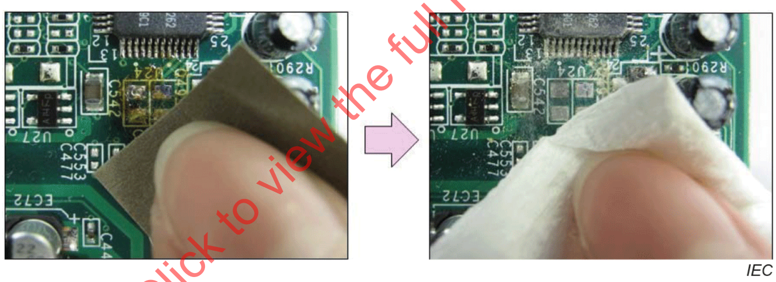

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Figure 11 – Polishing the attachment area

6.3.3 Step 3 – Indication of attachment point

Mark the attachment point and orientation of the strain gauge, e.g., by use of a pencil. See Figure 12.

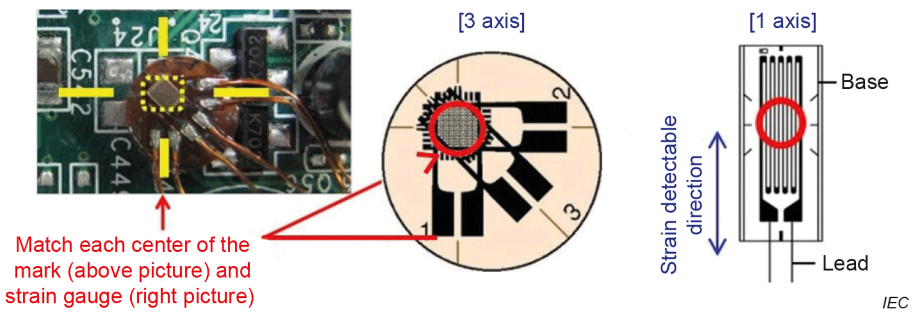

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Figure 12 – Marking of the attachment point

6.3.4 Step 4 – Application of instant glue

Cyanoacrylate instant glue can be used for strain gauge attachment. There are different procedures for applying glue to strain gauges:

– Apply glue to a polyethylene sheet. Then the strain gauge is taken by its leads and a thin layer of instant glue is applied to the reverse side of the strain gauge as shown in Figure 13.
– As an alternative procedure, glue can be directly applied to the strain gauge already placed near the measurement location (see Figure 14).

As there is a variety of make and types of strain gauges, specifying a default glue volume and thickness is not possible. The strain gauge supplier recommendation regarding strain gauge attachment needs to be taken into consideration (see 6.3.5).

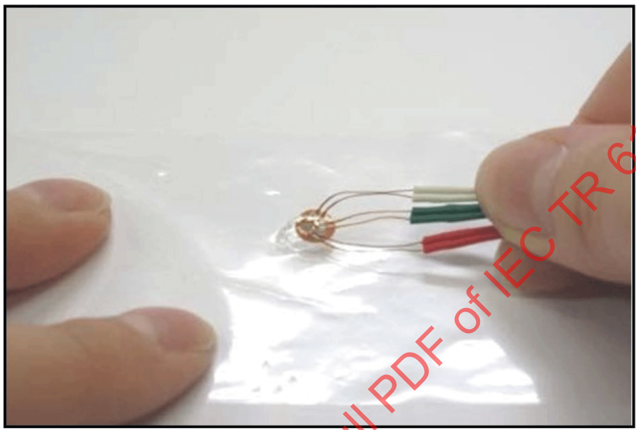

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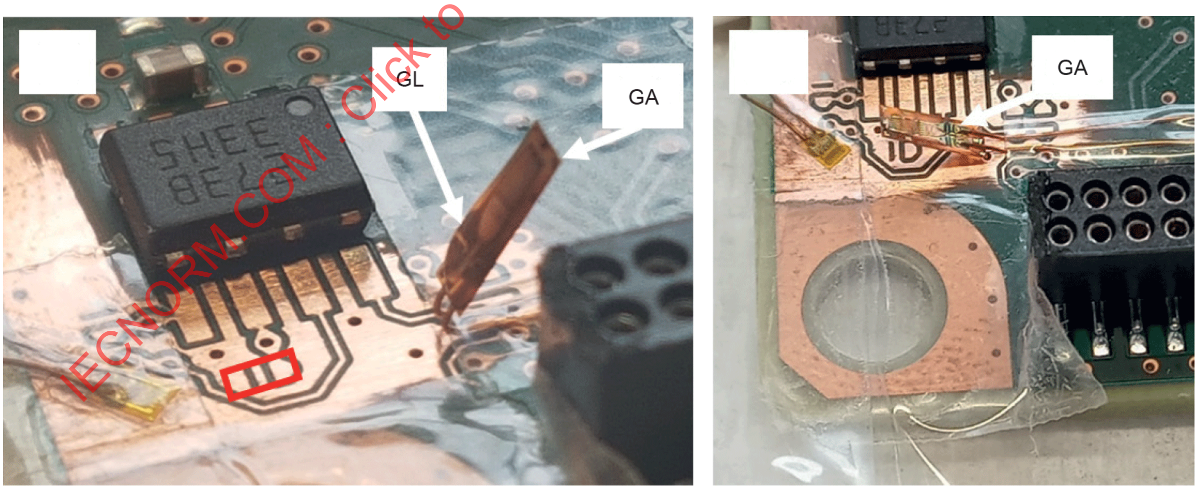
Figure 13 – Application of glue by transfer from polyethylene sheet



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a) Direct application of glue **b) Attachment to board**

Key:

GA: Gauge

GL: Glue

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Figure 14 – Direct application of glue

6.3.5 Step 5 – Attachment of strain gauge

Attach the strain gauge at the position marked in step 3.

Cover the strain gauge with a polyethylene sheet and push the attachment area down using finger pressure, following the recommendations by the supplier of strain gauge for the degree of pressure and application time. It needs to be assured that there are no entrapped air bubbles present under the strain gauge and that glue being displaced during the attachment process from underneath the strain gauge is present all along the perimeter of the strain gauge (see also 6.3.4. and recommendations by strain gauge supplier).

Fix the leads to the circuit board by use of a tape to prevent movement of the leads, which can detach the strain gauge.

Ensure the instant glue is fully cured (above 1 hour) before performing the measurements.

7 Typical mistakes and faults occurring in practice

7.1 Strain gauge attachment

Poor attachment of the strain gauge can be the cause of low strain detection.

If some area of the strain gauge is not attached properly to the surface (e.g., contaminated surface, insufficient instant glue, insufficient curing time, etc.), the measured strain will be less than the actual strain.

7.2 Wrong type of strain gauge used

Unless the strain state and in particular the direction of the maximum principal strain are known from experiments or simulation, 1-axis or 2-axes measurements involve a high risk of not determining the maximum principle strain which could cause a failure. To assess complex strain states on a populated circuit board, the use a 3-axes strain gauge is beneficial.

7.3 Circuit board without components is used

Use of a circuit board without other mounted components can result in poor measurement.

When a strain gauge measurement is carried out in an assembly process, a circuit board which is already assembled up to that process step needs to be used. Measurement accuracy can depend on previously mounted components. For example, a large component tends to inhibit deformation in a circuit board. As a result, if the component is missing, a large strain in the circumference of a large component could not be detected.

7.4 Irregular stress is not considered

The strains which occur in processes are roughly divided into the two types below:

- steady strain caused by working methods;
- unexpected strain caused by irregular works (rework, retouch, manual adjustment, change of tools, etc.).

Especially during handling processes, there can be a wide variation in how operations are undertaken by each operator, and these could generate irregular stresses to components. Therefore, it is necessary when investigating the causes of strain, to assume various irregular operations.

7.5 Insufficient measurement settings

Strain measurements are sensitive to sampling frequency as well as data signal bit width and strain signal limits. The following considerations regarding the sampling rate are important:

- For low strain rate assembly processes, e.g., mechanical assembly by screwing in a housing, a minimum sampling frequency of 500 Hz is needed.
- For high strain rate assembly and testing process, e.g., in-circuit testing on a bed of nails or single-pin insertion in compliant press-fit technology, an assessment of the required sampling frequency needs to be undertaken. Sampling frequencies of 2 000 kHz are typical.
- If measured data appears to be truncated, the measurement frequency can be increased to investigate if strain excursions related to high-frequency events could occur.

The sample rate can be determined using fast Fourier transformation analysis of the strain signal. The data reading frequency normally is at least 2 times the Nyquist frequency.

8 Evaluation of data and report

The maximum principal strain and the angle can be calculated by rosette analysis. See 6.1.3.

The measurement results can be used to estimate the risks of assembly processes as described in Clause 9 with consideration of the following:

a) This method is measuring the tensile stress on the surface of a circuit board without the specific component attached. But the actual strain force applied to the component body is transferred by the soldering fillet. Its value is mainly determined by the following factors:
   - type of board material,
   - shape of solder fillet,
   - solder material,
   - land pattern shape and dimensions,
   - thickness of land pad, and
   - the board design surrounding the measurement point.

b) The orientation of the component axis relative to the angle of maximum principal strain is essential to estimate the actual strain force applied to the component body. For example,
   - if the angle between the longitudinal axis of a chip type component and the direction of maximum principal strain is 90°, the actual stress to the component terminations is very low, but
   - in case the angle is different to 90°, the strain is transferred into the component.

c) The factors listed under a) and b) above determine the value and the point, where the maximum stress is located inside the body (trigger point for component crack).Thus, unfortunately, it is not possible to calculate the actual stress to the component body by use of the simple Equation (4):

$$\varepsilon_{comp} = \varepsilon_{max} \times \cos\alpha \quad (4)$$

where

ε_{comp} is the actual strain applied to the component;

ε_{max} is the highest measured strain;

α is the angle between the direction of highest measured strain and the component longitudinal axis.

See also 4.1 and 4.2.

Only by an in-depth investigation including trials and physical analysis of the components, e.g. by cross sectioning, it can be determined, if the highest measured strain and direction is critical for a specific component. That is why a large safety margin between strain control criterion and bending strength is set in 5.1.

A measurement report needs to contain at least the following information:

- Process and equipment investigated;
- Part number investigated;
- Sampling rate and analysing electronics used;
- Strain gauge type used;
- Measurement results;
- Location of gauge (including photographs).

9 Assembly process control

9.1 Machine/Process capability

When a machine or process is set up, the strain needs to be measured at the most critical position on a circuit board and confirmed to be below the specified control criterion. Experience had shown that periodical strain measurements, especially after process or tool changes, are essential to ensure that assembly stresses remain within the control criterion.

9.2 Machine maintenance

Process control regarding all processes affecting the strain state of circuit boards is a key factor to mitigate risks. This typically involves machine maintenance within appropriate periods, is a key factor to mitigate risks. For example, in the circuit board cutting process, blades need to be changed after a specific number of cuts before getting blunted. In the ICT/FT process, support and measurement pins need to be periodically checked in order to prevent the occurrence of damaged or jamming pins.

When performing a risk evaluation to consider all the factors which have influence on measurement results, a risk analysis check list of machine parameters affecting strain control is helpful.

Annex A
(informative)

Examples and relevant processes

A.1 Typical measurement results – Press-fit operation, Example 1

Clause A.1 shows an example of good practice in achieving measurement results. Figure A.1 shows a dosing control unit for the exhaust treatment system of passenger vehicles consisting of a populated surface mount technology circuit assembly in which a press-fit connector is inserted prior to assembling the housing. The insertion of the press-fit connector is a process exerting considerable stresses on the circuit assembly and thus an analysis of the strain state is mandatory to assure that strain levels on multilayer ceramic capacitor (MLCCs) components do not surpass their bending strength.

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Figure A.1 – Dosing control unit for exhaust treatment system equipped with a connector using compliant press-fit technology

The top and bottom sides of the populated circuit assembly are shown in Figure A.2. MLCCs in potentially critical locations in the proximity of the press-fit connector have been de-soldered and uniaxial gauges with different orientations (parallel and perpendicular) to the long edge of the circuit assembly and the connector footprint have been attached. The positions of the gauges are color coded.

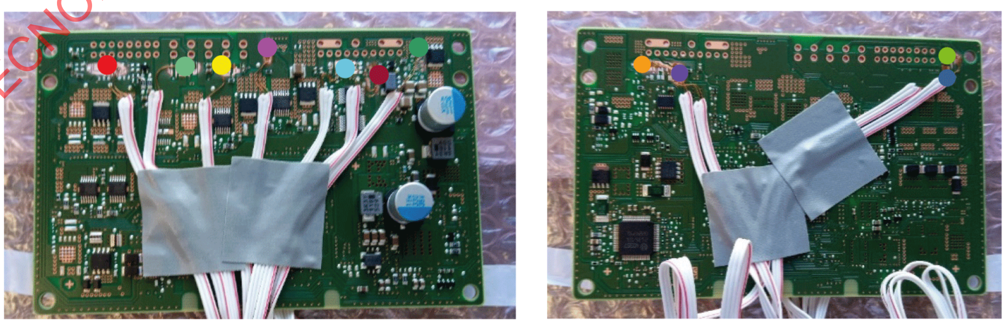

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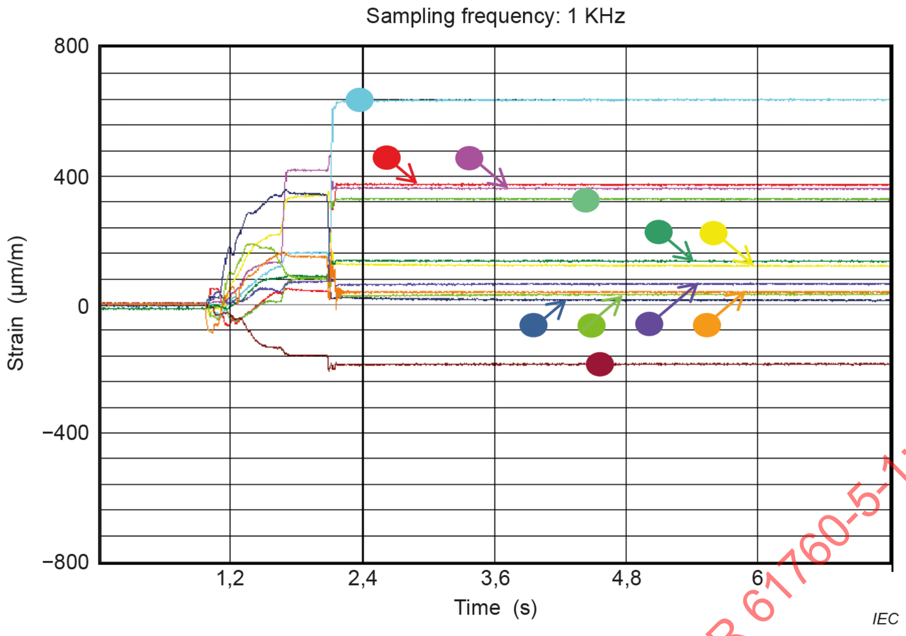
Figure A.2 – Top and bottom side of circuit assembly of dosing control unit with strain gauges replacing passive multilayer chip capacitors



Key:

The color dots indicate the positions of the gauges as shown in Figure A.2

Figure A.3 – Strain measurement evolution for the different strain gauges during the press-in process

The measurement results obtained for the different strain gauges at a sampling frequency of 1 kHz are shown in Figure A.3 by plotting the measured strains (y-axis) versus the time (x-axis). The press-fit pins come into contact with the circuit assembly after roughly 1.2 s. The press-in operation is completed within about 1 s. The highest measured strain of 600 µm/m is well within the bending strength of the MLCCs used in this assembly.

A.2 Typical measurement results – Press-fit operation, Example 2

Clause A.2 shows an example of good practice in achieving measurement results with different gauges and gauge placements during the insertion of a press-fit connector into a populated circuit board. Figure A.4 is showing the populated circuit board of a control unit for the airbag system of passenger vehicles. Due to keep-out zones related to the tooling required for the press-in operation, only a uniaxial gauge can be placed exactly in the position of the component being investigated due to its small size. The readings from a triaxial gauge mounted as closely as possible to the component locations are lower than the readings from the uniaxial gauge, which indicates that the strain decreases with the distance from the press-fit connector (see values in Table A.1). Even lower values are obtained with a triaxial gauge mounted near the component investigated. The use of a uniaxial gauge is therefore preferable in this particular situation (with tight space constraints) for obtaining the final reading for releasing the process after a preliminary investigation of the directional and spatial strain distribution.