

Q&A Session for BGAs and High Density PCBs: The Effect on Solder Joints – Tools and Solutions for Reducing UUT Risk

Date: March 21, 2007

Q: You mentioned a customer limit of 500 micro strains. How is this limit determined?

A: Several component manufacturers have started to include on their product data sheets micro strain limits for specific board thicknesses. These data sheets strongly state these strain limits cannot be transferred to other components. A quick comparison of these data sheets reveals a range from 450 μ s to 750 μ s. We suspect these limits are being applied to a broad spectrum of components without further study. While some of our customers have performed their own research and others have found a rule-of-thumb number that has seemed to work for them.

About 70% of the time our customers leave it to us to choose the strain limits for the fixtures we strain gage test. When this is the case our default is the IPC/JEDEC-9704 spec that Circuit Check has adopted.

Q: What was the IPC spec number?

A: IPC/JEDEC-9704

Q: How does the designer decide what changes to make to reduce strain? Do any of the approaches suggest changes automatically, or is it up to the designer?

A: All refinements of the fixture design or the fixture assembly during FEA and strain gage testing are based on the investigation and experience of the testing engineer. Sometimes the results of FEA or strain gage testing point directly to what needs to be changed, but especially with strain gage testing, the root problems can take some time to figure out.

Q: I have noticed some fixtures that I have ordered in the past have rubber strips as a board stops and some have hard rubber plugs. How does the use of rubber strips typically affect strain and what is suggested.

A: Because Circuit Check does not use rubber type materials for supporting the UUT, we haven't performed any research on the effects of doing so. It would make an interesting topic of study.

Q: Can FEA be done without strain limits provided - and action taken to compensate for relative measurements?

A: Yes. Circuit Check will follow IPC/JEDEC-9704 standards whenever the customer allows. Because the FEA that Circuit Check performs is static, the strain rate must be assumed when comparing with the IPC/JEDEC spec. In an effort to be conservative, the strain rate is assumed to be 5000 microstrain/second.

Q: Is this process needed to be done before the board design?

A: FEA is performed during the fixture design process, and cannot be performed during PCB design. All board pushdown features, probes and other fixture features need to be identified and designed into the FEA model.

If a few general rules are followed during board design and later, however, the UUT can be designed to be more test fixture friendly:

1. Keep components at least 0.100" away from the perimeter of BGA's to allow for thorough support all the way around the BGA. Do not place components in this area on the opposite side of the board either...this allows for top supports to be directly matched with bottom supports.
 2. Keep probes under BGA's toward the BGA perimeters -- try not to concentrate the probes near the center of the BGA. The closer the probes are to the center of the BGA, the further they are from the BGA's support, and the more strain they will induce. The distance between the probes and the nearest support can be thought of much like a lever arm...the further the probe is from the counteracting support, the more leverage that probe has for deflecting the board.
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Q: What is the cost of CCI FE Analysis? Does it add time to the fixture build interval?

A: Finite Element Analysis prices vary by board size and complexity, probe count, fixture actuation method and whether a contour plate is required. The price for a simple small board can be as low as \$700 to as high as \$3400 for larger, densely populated complex fixture. Please remember, there is a lot of engineering time required for modeling the circuit board and test fixture. Computer processing time also increases with complexity and probe count.

Typically, when a fixture's design is complete, there are essential parts of the fixture such as the probe plate that can begin fabrication without the FEA being complete...this way the fabrication process doesn't get held up on the FEA. Test fixtures are often a work in progress until they leave our facility, and so changes that are deemed necessary in the FEA can be implemented any time throughout the fabrication process.

With that said, FEA does sometimes lengthen the total lead time of the fixture build, especially if a customer asks to review the FEA results before initiating fabrication. Some factors that can affect whether there is a delay are: how smoothly the FEA process goes, how many changes to the fixture seem necessary, and how many FEA's and strain gage tests are flowing through Circuit Check at a given time.

Q: In order to perform the Strain Gauge analysis, does the FEA have to be performed?

A: No, strain gage testing does not require that FEA be performed; however, performing an FEA lends several benefits to the strain gaging process:

1. Design refinements may occur due to the FEA which might not be caught if the FEA weren't performed. In general fixtures that have been FEA'd are safer for the UUT, and will therefore require less modification during strain gage testing.
 2. It is helpful during strain gage testing to be able to compare the strain gage values to the baseline FEA values.
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Q: We notice a lot of BGA potato chipping in the lead-free process. Anything you can recommend to reduce the warpage of the BGA.

A: I can not answer this one!

Q: How does FEA account for any board warping during assembly?

A: In general, assumptions made during FEA are meant to be conservative and exaggerate strains; however, warpage varies from board to board and would also be very difficult to model (would probably require a 3D scanner), so it is not accounted for in the FEA. FEA's assume that the UUT is perfectly flat.

This would be better addressed by strain gage testing.

Q: What probe forces were used in the experiments around the BGA's?

A: The FEA example was modeled using 536 10.8 oz. 100 mil probes and 104 10.1 oz. 75 mil probes.

The strain gage example had the following amount of probes loaded during test. 1348 6.5 oz., 30 10.8 oz. and 159 3.5 oz 100 mil probes. 518 7.0 oz. and 92 3.1 oz. 075 mil probes and 24 6.1 oz 50 mil probes.

Q: Is there any data that shows how well FEA aligns with Strain gage testing?

A: While Circuit Check has one of the most extensive and detailed modeling processes provided in the industry, there are several known reasons why FEA and strain gage testing do not always strongly correlate. Keeping in mind that FEA is still an important and fine tuned design tool, here are some reasons why the real world fixture might deviate from the ideal world of FEA:

1. There are many known reasons why actual strains deviate from those predicted by FEA. FEA is a useful design tool that has led to general enlightenment in regards to what factors have the greatest potential for putting the UUT at risk and has also led to the refinement of hundreds of specific fixtures. Its utility is not diminished by this lack of correlation with strain gage testing. FEA results are not intended to be a final statement as to whether the fabricated fixture will be safe for the UUT.

There are many phenomena that are not modeled in the FEA and, in part, explain why there is dissonance between the FEA and the strain gage results. Some examples of these phenomena are:

- UUT warpage
- Tolerances of pushdown finger, deadstop, BGA stilt, pushdown lengths, plate thickness variation, etc.
- Slight differences in the flexural strength of plate materials and pushdown features from batch to batch
- The springs in test probe can have tolerances as wide as +/-15%
- The dynamic strains that are occurring during the actuation and de-actuation processes. The FEA Circuit Check performs is a static analysis and reflects the fully actuated fixture state.

Q: How would strain vary over time during usage? Do we need to revalidate periodically?

A: If the fixture is in proper working order, strains can probably be expected to decrease over time due to the weakening of probe springs. Other factors could contribute to increased strain and should be checked throughout the fixture's life:

1. No board supports (top side or bottom side) should be deformed. If any are deformed they should be immediately replaced.
2. No other critical components of the fixture should ever be removed from or added to the fixture (e.g. tooling pins or board supports).
3. Fixtures are shipped from the factory with probes loaded in specific locations. A probe load plot is typically shipped with each fixture, this must be used during replacement of the spring probes to insure the FEA or strain gage is still valid.

Whether a customer strain gage tests their fixtures periodically is purely at their own discretion. Circuit Check is mostly involved with the test fixtures when they are new, so

we do not have experience with longitudinal studies of fixture induced strain over the years.

Q: How well does FEA correlate to actual results of SG testing using rosettes?

A: While Circuit Check has one of the most extensive and detailed modeling processes provided in the industry, there are several known reasons why FEA and strain gage testing do not always strongly correlate. Keeping in mind that FEA is still an important and fine tuned design tool, here are some reasons why the real world fixture might deviate from the ideal world of FEA:

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Q: When probe spring forces are changed to improve the FEA results, how is that information provided to the customer to insure that the same spring force probes are used during routine maintenance or replacement?

A: Often, Circuit Check's customers are made aware of probe force changes during the design process. The probe force changes are documented in the fixture design, the probe load plot that is supplied to the customer, and on the fixture label typically adhered to the front side of the fixture.

Q: How does the customer come up with the micro-strain specification? Is this from experience with the assembly?

A: Several component manufacturers have started to include on product data sheets micro strain limits for specific board thicknesses. These data sheets strongly state these strain limits cannot be transferred to other components. A quick comparison of these data sheets reveals a range from 450 μ s to 750 μ s. We suspect these limits are being applied to a broad spectrum of components without further study. While some of our customers have performed their own research and others have found a rule-of-thumb number that has seemed to work for them.

IPC/JEDEC has greatly benefited the strain gaging process by giving us experimentally justified limits that yield reasonable safety for the UUT while avoiding wasted time spent trying to lower strains further than need be. Often, times fixtures pass IPC/JEDEC's specification, but out of obligation to meet our customer's spec we spend one or more days trying to lower the strain, though we in good faith believe the fixture to be safe for the UUT. This causes delays in fixture shipments and, in general, raises the cost of strain gage testing for both Circuit Check and Circuit Check's customers.

Following the well supported IPC/JEDEC specifications is Circuit Check's trusted and preferred method for determining whether a fixture is safe for its UUT.

Q: What are some typical costs for the FEA?

A: Finite Element Analysis prices vary by board size and complexity, probe count, fixture actuation method and the inclusion or exclusion of a contour plate. The price for a simple small board can be as low as \$700 to as high as \$3400 for larger, densely populated complex fixture. Please remember, there is a lot of engineering time required for modeling the circuit board and test fixture. Computer processing time also increases with complexity and probe count.

Q: Is there any correlation between your FEA and actual strain gage testing? i.e. how do you prove modeling accuracy?

A: Some of Circuit Check's founding methods for performing FEA's have been tested on book problems to verify the accuracy in simple cases; however, because of the complex nature of the way the fixture interacts with the UUT and because perfect fixtures and perfectly flat circuit boards are impossible to come by, Circuit Check has not been able to verify the FEA results. As stated since FEA's induction into use by Circuit Check, the engineers are designing safer fixtures to begin with and then have a means of double-checking their work.

While Circuit Check has one of the most extensive and detailed modeling processes provided in the industry, there are several known reasons why FEA and strain gage testing do not always strongly correlate. Keeping in mind that FEA is still an important and fine tuned design tool, here are some reasons why the real world fixture might deviate from the ideal world of FEA:

1. There are many known reasons why actual strains deviate from those predicted by FEA. FEA is a useful design tool that has led to general enlightenment in regards to what factors have the greatest potential for putting the UUT at risk and has also led to the refinement of hundreds of specific fixtures. Its utility is not diminished by this lack of correlation with strain gage testing. FEA results are not intended to be a final statement as to whether the fabricated fixture will be safe for the UUT.

There are many phenomena that are not modeled in the FEA and, in part, explain why there is dissonance between the FEA and the strain gage results. Some examples of these phenomena are:

- UUT warpage
- Tolerances of pushdown finger, deadstop, BGA stilt, pushdown lengths, plate thickness variation, etc.
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- The springs in test probe can have tolerances as wide as +/-15%
- The dynamic strains that are occurring during the actuation and de-actuation processes. The FEA Circuit Check performs is a static analysis and reflects the fully actuated fixture state.

Q: What is the cost of a standard FEA analysis?

A: Finite Element Analysis prices vary by board size and complexity, probe count, fixture actuation method and the inclusion or exclusion of a contour plate. The price for a simple small board can be as low as \$700 to as high as \$3400 for larger, densely populated complex fixture. Please remember, there is a lot of engineering time required for modeling the circuit board and test fixture. Computer processing time also increases with complexity and probe count.

Q: Do you recommend doing multiple types of analysis, like FEA and strain gage testing, to ensure that the board under test is under the customer specified strain?

A: To put it simply, FEA verifies the fixture design, and strain gage testing verifies the assembled fixture. Strain gage testing is the final authority in assuring that a fixture is safe for the UUT's sensitive components, but FEA helps build better fixtures proactively. Circuit Check would like to have the opportunity to FEA every fixture that is strain gage

tested and vice versa to ensure the design proactively and then to assure that the fabricated fixture is UUT friendly.

Q: If different probe forces were used on a fixture do we have any info on that location and what the force is for that probe so in house replacements will be correct

A: Often, Circuit Check's customers are made aware of probe force changes during the design process. The probe force changes are documented in the fixture design, the probe load plot that is supplied to the customer, and on the fixture label typically adhered to the front side of the fixture.

Q: Has there been any validation between the 3D Element Analysis and Strain Gage?

A: While Circuit Check has one of the most extensive and detailed modeling processes provided in the industry, there are several known reasons why FEA and strain gage testing do not always strongly correlate. Keeping in mind that FEA is still an important and fine tuned design tool, here are some reasons why the real world fixture might deviate from the ideal world of FEA:

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Q: Do you use min/max principal, e1, e2, e3, e4 (e4=e1+e3-e2), angle to make final determination or any of them exceeding the limit?

A: IPC/JEDEC-9704 specification refers to the max and min principal strains and to the speeds at which the strains occur (strain rate). When Circuit Check is attempting to meet the IPC/JEDEC spec, the principal strains and the strain rate are the main concern. However, when the customer supplies its own specification then different quantities can be analyzed accordingly.

Q: As far as in modeling the board -- are there component libraries for physical attributes available so that its more cost effective to generate board as you do more FEA projects --i.e.can you accumulate a model base to make the process go faster

A: In regards to modeling the circuit board: Because the interaction between the components and the circuit board are complexly dependent on the geometry and mechanical characteristics of the solder joints, detailed component models aren't used by Circuit Check. Doing so would require much more time in the model building process and in the FEA solving. With that said, strain tends to be quite sheepish when it comes to stiffeners (such as components) on the UUT and finds its way around a component regardless of how stiff or thick that component is modeled to be.

In regards to the modeling the test fixture: because of how much each fixture varies from the next, it seems likely if fixtures were templated, then the process of modifying and adding to the template could take nearly the same time as to build the model from scratch; also templating would make error more likely, as anyone who has worked with templates can attest to. Perhaps templating could be integrated somehow in the future, but the efficiency gains are difficult to predict at this point.

Q: If your test fixture passes FEA, it is still unclear when you should perform SGA. Can one skip the FEA and just perform SGA testing?

A: Yes.

But, FEA verifies the fixture design, and strain gage testing verifies the assembled fixture. Strain gage testing is the final authority in assuring that a fixture is safe for the UUT's sensitive components, but FEA helps build better fixtures proactively. Circuit Check would like to have the opportunity to FEA every fixture that is strain gage tested and vice versa to ensure the design proactively and then to assure that the fabricated fixture is UUT friendly.

Q: Is there any way to ensure consistent strain across a board under test, versus varying strain - even though the varying strain is under the customer specified max strain?

A: This is a question I haven't been asked before. My first response is that the only way to ensure less variation in the strain across the board is to decrease the higher strains and, therefore, decrease the overall strain spread. As FEA's show, the strains usually vary quite locally around each support, each cluster of probes, and each component on the board.

Q: Can strain gage testing and FEA be done on PCBs that require top and bottom probing?

A: Top side probing often makes it more difficult for the fixture designer to place ample support for the UUT because:

1. The top side probes displace possible pushdown feature locations
2. The UUT's need for support becomes more complex when there is top side probing because some parts of the board will tend to deform upward and other areas will tend to deform downward.

With FEA, the answer to the question above is "definite yes". Besides being a challenge to the designer when designing in sufficient UUT support, top side probing is no problem for an FEA.

Limited top side probing is not a big problem when it comes to strain gage testing. If one probe is hitting a rosette, the probe can usually guiltlessly be removed during test without risking significantly skewing results. However, intense top side probing, especially if the probes contact the UUT where the strain gage rosettes will be mounted, can make the strain gaging process more difficult or impossible.

Q: Can the strain gage testing measure during the actuation of vacuum.

A: Yes. Circuit Check runs the fixture through three actuation cycles each time strain gage data is collected. The strain gage results reflect the strains that the UUT experiences throughout the actuation and de-actuation processes.

Q: How does ROHS solder effect the results?

A: ROHS approved solders, fluxes and OSP coated PCBs are generally more difficult to penetrate than the softer leaded solders. This has resulted in the use of higher spring force probes which can lead to increased stress in critical areas.

Q: Or to rephrase the question, does the spec. take into account that the ROHS solder is more brittle?

A: The IPC/JEDEC-9704 specification is based upon the assumption that the UUT is fabricated with SnPb solder. If you take it upon yourself to verify this with IPC/JEDEC, please let Circuit Check know of your findings.

Q: It seems like it would be useful to have a dynamic model for the FEA which would show the change in microstrain as the fixture is actuated. Is that something that is possible with the typical tools available?

A: With a bleeding edge computer setup and a lot of time, a model could be constructed and run in the dynamic mode. Some of the factors that would greatly increase the time to construct and solve the model are:

- Rather than being modeled simply as a force, the probes would have to each be modeled as springs with a preload so that their interaction with the UUT during actuation could be simulated realistically.
- In general, when running in transient mode, it takes much, much longer to derive a solution than when in static mode. Increasing the complexity of the model, as by modeling each preloaded probe, would exponentially drive up the solution time even further.
- In the case of a vacuum box, the collapsing foam seal between the vacbox and the top plate and between the top plate and probe plate would have to be modeled. Because the foam experiences very large deformation relative to its size, it would require special methods to model and would increase the solution time further.
- Friction is a big player in how a fixture actuates, so friction constants would need to be determined for each of the surface to surface contacts
- The list goes on...

Please also keep in mind that FEA would not necessarily be a better design tool because of such refinement. With FEA's you always have to draw a line in the sand somewhere and call it good enough. Also, even such a dynamic/transient model would not verify the strains caused by the physical, fabricated fixture.

Q: Does FEA work if analyzing items such as flying probe systems?

A: FEA may be helpful in designing a safe board support system if there were a clamping force between top and bottom supports that could potentially strain the UUT. However, probe induced strain would probably have negligible effects if only one or two probes were pressing on the board at a time.