# Effect of vibration on solder joint reliability engineering essay

# CHAPTER 01

# INTRODUCTION

## SOLDER JOINT IN ELECTRONIC ASSEMBLIES

Circuit boards range from simple single moulded plastic boards with copper conductors on one or both sides to multilayer boards with copper conductors, each layer being separated by a dielectric and interconnected by metal conductors. Minimum line width and spacing between lines is less than 100 µm. The board typically is made from a composite such as an epoxy with layered sheets of woven fibreglass. The dielectric material between layers of conductors is usually a polymer, for example polyimide. To maintain solder ability, the exposed copper may be coated with an inhibitor such as benzotriazole or with a solder overcoat. Components are attached to the board with solder or metal-filled conductive adhesives. Fully assembled boards may be further protected against moisture, contamination, and mechanical damage by a cover coat.

## 1. 2 SOLDER JOINT RELIABILITY AND FAILURE

Solder joints are widely used in the electronic packaging industry to produce good electrical, thermal, and mechanical connections between the package and the printed circuit board. Eighty percentage of the mechanical failure in airborne and automation electronic caused by vibration and shock. Design appropriate measure to ensure the survival equipment in the shock and vibration environment is necessary to do so. Remaining 20 percentage of mechanical failure related to thermal stresses resulting from high thermal gradients, coefficient of thermal expansion and high coefficient of elasticity.

Solder joint failure occur in several reasons:

Poor design of the solder joint

A bad solder joint treatment

Solder material

Excessive stress applied to solder joints.

In general, however, the solder joint failure are simply ranked according to the ature of stress that have caused. Most joint failure fall into three major categories:

Fatigue failure due to cyclic stress application

Due to the implementation of a long term or permanent load

The stress is due to overloading in the short term

Reflow profile also has a significant role on solder joint reliablity. because It also has a high influence micro structure of the solder joint.

Vibration failure of solder joints is often assessed for reliability using high accelerated life test, which is represented by a GRMS- time curve. For surface mount microelectronic components, an approximation of printed circuit board (PCB) model analysis can be made by assuming PCB as a bare unpopulated thin plate because the increase in stiffness of PCB due to the mounting of the components is approximately offset by the increase in total mass of the populated PCB [2]. However, this approximation can lead to errors in natural frequency prediction for different package profiles, for flip-chip-on-board (FCOB) and plastic-ball-grid-array (PBGA) assemblies [3, 4]. When the component has small profile, the approximation of PCB assembly as a bare PCB can provide satisfactory modal analysis results because the stiffness and mass contribution of small component to PCB assembly is not significant.

In this study, varying G-level random vibration tests for PCB assembly were conducted. In order to assess the reliability of PCB assembly, it is necessary to conduct the dynamic analysis. A global-local modeling approach [4-6] was used. The analyses by Basaran [7, 8], Chandaroy [9] and Zhao et al. [10] show that solder joint deformation is in the elastic range for vibration loading. The global-local or submodeling method [11-13] has been used for the board level FE simulation. In this study, four different model cases were investigated for FEA modal analysis to calculate the first order natural frequency of the FCOB assembly. A quasi-static analysis approach was conducted for the FCOB assembly to evaluate the stress strain behavior of the solder joints. A harmonic analysis was also investigated to study the dynamic response of the FCOB assembly subjected to vibration load. Fatigue life prediction results from the quasi-static analysis and harmonic analysis approaches were compared to the test results.

# 1. 3 PROJECT PURPOSE

In this modern world due to the causes of health and environmental issues the electronic manufacturing industries facing a challenging problem of necessity to produce reliable solder products in very high density with very low cost.

Solder joints are very important to the reliability of Printed Circuit Boards (PCB). This is a one of the leading factor in transmission of electrical and thermal connections. In case of every PCB even a smaller solder joints are very important.

So this project investigates the Effect of Vibration on Solder Joint Reliability in Electronics Assembly Applications. Solder joint of a Electronic assembly is very important measurement because of This model based study might help engineers effectively improve the PCB mechanical design and thus improve reliability of electronics attached to the PCB by considering realistic uncertainties and adverse vibration environments.

# CHAPTER 02

# LITERATURE REVIEW

## 2. 1 SINE ON RANDOM VIBRATION TESTING

Vibration sine on random testing is performed by superimposing a sine wave on top of a random environment. A sine on random vibration test duplicates the combined environment of a spinning helicopter blade with its distinct resonant levels and the rest of the aircraft which generates random engine and aerodynamic induced vibration. Gunfire on board an aircraft causes sine vibration while the rest of the aircraft generates random excitations. These types of tests are duplicating vibration

characterized by dominant peaks (sinusoids) superimposed on a broadband background

Another variation would be a swept sine on random test.

## 2. 2 SINUSOIDAL VIBRATION TESTING

Dynamic deflections of materials caused by vibration can cause a host of problems and malfunctions including failed electrical components, deformed seals, optical and mechanical misalignment, cracked or broken structures, excessive electrical noise, electrical shorts, chafed wiring. Because sine vibration is basically a certain fundamental frequency and the harmonics of that fundamental, in its pure state, this type of vibration is generated by a limited but significant number of sources. Expressed as amplitude versus frequency, sine vibration is the type of vibration generated in the field by sources such as engine rotational speeds, propeller and turbine blade passage frequencies, rotor blade passage and launch vehicles.

While much of " real world" vibration is random, sine vibration testing accomplishes several important goals in product qualification and testing. Much material and finished product was modeled on some type of sine vibe signature. A sine sweep of frequencies will determine whether the assumptions were correct and if the deviations are significant enough to cause design changes. In other words, sweep will establish if the anticipated frequency has been met and/or discovers the test item fundamental frequency. Similarly, a sweep will help identify the test subject resonance frequencies, which may be the points at which the item experiences particularly stressful deflections. By dwelling at those frequencies in subsequent tests, premature failures due to the properties of the material may come to light before the items sees field use. Some of the following tests include fixed frequency at higher levels of the controlling variable (displacement, velocity, acceleration), and random vibration. Per customer request, NTS will run sweeps in one direction, decreasing, increasing or bi-directionally and can change frequency logarithmically or linearly.

Another typical sinusoidal vibration test, sine burst such as the teardrop, goes rapidly to peak pulse and then decays at lower rate (to prevent damage to the unit). The burst test puts a maximum load into an article at a rapid rate and particularly stresses joints and seams to identify workmanship and design issues.

## 2. 3RANDOM VIBRATION TESTING

The legitimacy of random vibration s an effective tool of screening work man ship defects came about during manufacturing. Up until that limited hertz sine was applied during reliability testing. Pure sinusoidal vibration is composed of a single frequency at any given time. Comparisons tests revealed that to equal the effectiveness of random vibration. The test item will have to be subjected to many sine frequencies over a longer period of time, and may unintentionally fatigue the test item. Random vibrations undercover defect faster.

2. 4 Real world simulation.

Most vibration in real world is random for example a vehicle travelling over road experience random vibration from the road irregularities. A ground launched rocket vehicle experiences non stationary vibration during its flight the motor ignites the rocket travel through the atmosphere , the motor burn ends and so forth even in wing when subjected to turbulent air flow, undergoes random vibration.

Random vibration is composed of multitude of continues spectrum of frequencies. Motion varies randomly with time. It can be presented in the domain by a power spectral density function [G2/Hz].

## HIGHLY-ACCELERATED LIFE TESTING (HALT)

Exposes the product to a step-by-step cycling in environmental variables such as temperature, shock and vibration. HALT involves vibration testing in all three axes using a random mode of frequencies. Finally, HALT testing can include the simultaneous cycling of multiple environmental variables, for example, temperature cycling plus vibration testing. This multi-variable testing approach provides a closer approximation of real-world operating environments. Unlike conventional testing, the goal of HALT testing is to break the product. When the product fails, the weakest link is identified, so engineers know exactly what needs to be done to improve product quality. After a product has failed, the weak component(s) are upgraded or reinforced. The revised product is then subjected to another round of HALT testing, with the range of temperature, vibration, or shock further increased, so the product fails again. This identifies the next weakest link.

By going through several iterations like this, the product can be made quite robust. With

this informed approach, only the weak spots are identified for improvement. This type of testing provides so much information about the construction and performance of a product, that it can bequite helpful for newer engineers assigned to a product with which they are not completely familiar. HALT testing must be performed during the design phase of a product to make sure the basic design is reliable. But it is important to note that the units being tested are likely to be hand-made engineering prototypes. At Trace, we have found that HALT testing should also be performed on actual production units, to ensure that the transition from engineering design to production design has not resulted in a loss of product quality or robustness. Some engineers may consider this approach as scientifically reasonable, but financially unrealistic. However, the cost of HALT testing is much less than the cost of field failures

## HIGHLY-ACCELERATED STRESS SCREENING (HASS)

HASS testing is an on-going screening test, performed on regular production units. Here, the idea is not to damage the product, but rather to verify that actual production units continue to operate properly when subjected to the cycling of environmental variables used during the HASS test. The limits used in HASS testing are based on a skilled interpretation of the HALT testing parameters. The importance of HASS testing can be appreciated when one considers today's typical manufacturing scenario. Circuit boards are purchased from a vendor who uses materials purchased from other vendors. Components and sub-assemblies are obtained from manufacturers all over the world. Often, the final assembly of the product is performed by a subcontractor. This means that the quality of the final product is a function of the quality (or lack thereof) of all the components, materials, and processes which are a part of that final product. These components, materials, and processes can and do change over time, thereby affecting the quality and reliability of the final product. The best way to ensure that production units continue to meet reliability objectives is through HASS testing.

# RELIABILITY

Reliability is defined as the probability that a device will perform its required function under stated conditions for a specific period of time. Predicting with some degree of Confidence is very dependent on correctly defining a number of parameters. For instance, choosing the distribution that matches the data is of primary importance. If a correct distribution is not chosen, the results will not be reliable. The confidence, which depends on the sample size, must be adequate to make correct decisions. Individual component failure rates must be based on a large enough population and relevant to truly reflect present day normal usages. There are empirical considerations, such as determining the slope of the failure rate and calculating the activation energy, as well as environmental factors, such as temperature, humidity, and vibration. Lastly, there are electrical stressors such as voltage and current. Reliability engineering can be somewhat abstract in that it involves much statistics; yet it is engineering in its most practical form. Will the design perform its intended mission? Product reliability is seen as a testament to the robustness of the design as well as the integrity of the quality and manufacturing commitments of an organization.

One of the fundamentals of understanding a product’s reliability requires an understanding of the calculation of the failure rate. The traditional method of determining a product’s failure rate is through the use of accelerated vibration operating life tests performed on a sample of

devices. The failure rate obtained on the life test sample is then extrapolated to end-use conditions by means of predetermined statistical models to give an estimate of the failure rate in the field application. Although there are many other stress methods employed by electronic assembly manufacturers to fully characterize a product’s reliability, the data generated from operating life test sampling is the principal method used by the industry for estimating the failure rate of a electronic assembly in field service.

## Failure Rate (Î»)

Measure of failure per unit of time. The useful life failure rate is based on the exponential life distribution. The failure rate typically decreases slightly over early life, then stabilizes until wear-out which shows an increasing failure rate. This should occur beyond useful life.

## Failure In Time (FIT)

Measure of failure rate in 109 device hours; e. g. 1 FIT = 1 failure in 109 device hours.

## Total Device Hours (TDH)

The summation of the number of units in operation multiplied by the time of operation.

# Mean Time between failures (MTBF)

Reliability is quantified as MTBF (Mean Time Between Failures) for repairable product and MTTF (Mean Time To Failure) for non-repairable product. A correct understanding of MTBF is important. A power supply with an MTBF of 40, 000 hours does not mean that the power supply should last for an average of 40, 000 hours. According to the theory behind the statistics of confidence intervals, the statistical average becomes the true average as the number of samples increase. An MTBF of 40, 000 hours, or 1 year for 1 module, becomes 40, 000/2 for two modules and 40, 000/4 for four modules. Sometimes failure rates are measured in percent failed per million hours of operation instead of MTBF. The FIT is equivalent to one failure per billion device hours, which is equivalent to a MTBF of 1, 000, 000, 000 hours. The formula for calculating the MTBF is

Î¸ = T/R.

Î¸ = MTBF

T = total time

R = number of failures

MTTF is stands for Mean Time To Failure. To distinguish between the two, the concept of suspensions must first be understood. In reliability calculations, a suspension occurs when a destructive test or observation has been completed without observing a failure. MTBF calculations do not consider suspensions whereas MTTF does. MTTF is the number of total hours of service of all devices divided by the number of devices. It is only when all the parts fail with the same failure mode that MTBF converges to MTTF.

# Î³= T/N

Î³ = MTTF

T = total time

N = Number of units under test.

If the MTBF is known, one can calculate the failure rate as the inverse of the MTBF. The

formula for (Î») is:

where r is the number of failures.

Once a MTBF is calculated, probability can derive from following equation:

# R(t) = e-t/MTBF

# Confidence Level or Limit (CL)

Probability level at which population failure rate estimates are derived from sample life test. The upper confidence level interval is used.

# Acceleration Factor (AF)

A constant derived from experimental data which relates the times to failure at two different stresses. The AF allows extrapolation of failure rates from accelerated test conditions to use conditions.

Since reliability data can be accumulated from a number of different life tests with several different failure mechanisms, a comprehensive failure rate is desired. The failure rate calculation can be complicated if there are more than one failure mechanisms in a life test, since the failure mechanisms are thermally activated at different rates. Equation 1 accounts for these conditions and includes a statistical factor to obtain the confidence level for the resulting failure rate.

## THE BATHTUB CURVE

The life of a population of units can be divided into three distinct periods. Figure 1 shows

the reliability " bathtub curve" which models the cradle to grave instantaneous failure

rates vs. time. If we follow the slope from the start to where it begins to flatten out this

can be considered the first period. The first period is characterized by a decreasing failure

rate. It is what occurs during the early life of a population of units. The weaker units die

off leaving a population that is more rigorous. This first period is also called infant

mortality period. The next period is the flat portion of the graph. It is called the normal life. Failures occur more in a random sequence during this time. It is difficult to predict

which failure mode will manifest, but the rate of failures is predictable. Notice the

constant slope. The third period begins at the point where the slope begins to increase and

extends to the end of the graph. This is what happens when units become old and begin to

fail at an increasing rate.

## Reliability Predictions Methods

A lot of time has been spent on developing procedures for estimating reliability of electronic equipment. There are generally two categories: (1) predictions based on individual failure rates, and (2) demonstrated reliability based on operation of equipment over time. Prediction methods are based on component data from a variety of sources: failure analysis, life test data, and device physics. For some calculations (e. g. military application) MIL-HDBK-217 is used, which is considered to be the standard reliability prediction method.

A simple failure rate calculation based on a single life test would follow equation 1.

Î»€ = failure rate.

TDH = Total Device Hours = Number of units x hours under stress.

AF = Acceleration factor, see Equation 3.

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where,

Î» = failure rate in FITs (Number fails in 109 device hours)

Î² = Number of distinct possible failure mechanisms

k = Number of life tests being combined

xi = Number of failures for a given failure mechanism i = 1, 2,… Î²

TDHj = Total device hours of test time for life test j, j = 1, 2,… k

AFij = Acceleration factor for appropriate failure mechanism,

i = 1, 2,… k

M = Î2

(Î±, 2r +2) / 2

where,

Î2 = chi square factor for 2r + 2 degrees of freedom

r = total number of failures (Î£ xi)

Î± = risk associated with CL between 0 and 1.

## 2. 2 SOLDER PASTE

## 2. 1. 1 ROLE OF SOLDER PASTE IN REFLOWING

Solder paste is a combination mixture of a flux composition and a highly grinded, powdered solder metal alloy that is normally used in the electronics industry to soldering processes. And also it is call as a attachment medium between the device interconnection features and the PCB itself. The components of a solder paste are specially designed for excellent printing and reflow characteristics.

In normal case of the surface mount soldering process involves placing the substrate and a small amount of solder paste in a printed circuit board. After that the system will be heated until the solder reflows, forms an electrical connection between the solder pad and the electrical contact of electronics part. After this reflow finished it forms both an electrical and mechanical connection between the electronics components and the printed circuit board.

## 2. 1. 2 SELECTION CRITERIA OF A SOLDER PASTE

Selection of a solder paste is very important factor for reflowing process, reliability & its quality. The following factors are considerable for a good solder paste [6].

The size of the solder alloy particles which are in the solder paste

The tendency to form voids

The properties of the flux medium of the solder paste

Alpha particle emission rate

The design of the stencil to be used for printing

Thermal properties of the solder paste

Electrical properties of the solder paste

# CHAPTER 03

# EXPERIMENTS

## 3. 1 MATERIALS AND METHODOLGY

SOLDER PASTE

Basically I used solder paste in same procedure. The details of solder paste used in the experiment are given in the following table

**TYPE OF**

**SOLDER**

**PASTE**

**ALLOYS**

**CODING**

**PARTICLE**

**SIZE**

**METAL**

**LOADIND**

S1

Sn95. 5Ag4Cu0. 5

S2

Sn42Bi57Ag1

Table 3. 1. 1 types of solder paste used in experiment

For this project all above solder paste should be in a container with appropriate labelling and identification on it to distinguish it from the Tin – lead solder paste. The solder paste should be stored in a refrigerator between 35 – 45 F. and should be allowed to come room temperature for minimum four hours before doing the solder paste printing. Once it has finished the using solder paste must replace to the refrigerator since it can not be at room temperature over 24 hours. The self life of the lead free solder pastes may be reducing from the typical six month.

The above guidelines are strictly followed in this project. Because it is not only for guarantee the quality of solder paste but also a good way to reduce the errors that may affect the final results of the project.

## SOLDER PASTE PRINTING

## IMPORTANT OF SOLDER PASTE PRINTING

Surface mount technology (SMT) is used extensively in the electronics industry. Surface mount components are potentially more reliable products can be designed and manufactured using the SMT.

The solder paste stencil printing process is very critical and important step in the surface mount manufacting process. Most of all the soldering defects are due to problems dealing with the screening process. So we want to a major consideration in operation and set up steps in stencil printing process. When we are monitoring these factors carefully we can minimize the defects.

The main purpose of printing solder paste on PCB is to supply solder alloy to solder joint to correct amount. That only print must be aligned correctly and can get a perfect component placement.

## PRINTING PROCESS PARAMETERS

Some of the following parameters are very important to printing process.

## STENCIL

Stencils are using for the solder paste slip easily off the aperture edges and thereby secures a uniform print. For this process we using electro formed stencils. Because of these stencils have very shape edge and slightly conic. Generally a stencil is mading from cupper or nickel [12].

## ENVIRONMENTAL

Dust and dirt from the air that will reach the PCBs and stencils can be defects poor wet ability in the reflow soldering process. So PCBs should be stored in sealed packages and cleaned before use.

## SOLDER PASTE

Solder paste characterise must be controlled to achieve a maximum production results. Some of the factors are given below [12].

Percent of metal

Viscosity

Slump

Solder balls

Flux activity working life and shelf life

## STENCIL PRINTING PARAMETERS

Stencil printing parameters are very important factors in printing processes to achieve a best yield. The following parameters must be monitors and controlled in a printing process.

Squeegee pressure = 8kg

Squeegee speed = 20 mm/s

Separation speed = 100%

Printing gap = 0. 0 mm

These factors and limit can be adjust for our project purpose

# SOLDER PASTE PRINTING EQUIPMENT AND PROCESS

Figure 3. 2. 4. 1 DEK 260 stencil printing machine

The DEK 260 stencil printing machine is used to print solder paste on the circuit board. This DEK 260 stencil printing machine has two main functions.

Registers the position of the product screen with in the print head

Positioning the circuit board below the stencil, to ready for the print cycle.

The boards to be print are supported on magnetic tooling and held by vacuum caps arranged on the plate to guarantee the board steady during the printing on to the board. The first step of the experiment is to do the solder paste printing on to the board.

In this project unable to get metal stencil, so circuit boards are printed by hand, below procedure followed to print PCB

Put weights onto the stencil to fix it

roll the squeegee over the stencil

solder paste presses through the aperture onto PCB

separate stencil

two circuit boards are printed with solder paste for each solder paste types. Totally 4 circuit boards printed.

# SOLDER PASTE REFLOWPROCESS/PROFILE

Figure 3. 3. 1 reflow oven

To achieve a good reliable solder joint the reflow process is very important. When doing the reflow with sn-pb solder paste often performed at minimum peak temperature of about 203. It is 20k above the sn – pb liquid state temperature.

When doing the reflow process with lead free solder paste it has to be performed at a minimum peak temperature of 230. It is just 13K above the melting temperature.

It is generally accepted that lead free solders requires a higher reflow temperature up to 220 – 230.

Reflow profile will be affecting the reliability of a solder joint. Because it is a major factor that influence the formation of the intermettallic layers in a solder joint. Intermettalic layer is a critical part of a solder joint. An intermettalic bond thickness should be thin. Therefore a good reflow profile must produce solder bumps with a thin intermetallic layer.

# PREHEAT ZONE

In this zone indicates how the temperature is changing fast on the printed circuit board. The ramp-up rate is usually between 1-3 per second. If this rate exceeds there will be damage to components from thermal shock. Only In this preheat zone the solder paste begins to evaporate. So if the rise rate is too low the evaporation of flux is not incomplete. This will affect the quality of the solder joint.

## THERMAL SOAK ZONE

It is also called the flux activation zone. In this thermal soak zone it will take 60-120 seconds for removal of solder paste and activation of fluxes. Solder spattering and balling will be happen if the temperature is too high or too low. End of this thermal shock zone a thermal equilibrium will complete the entire circuit board.

## REFLOW ZONE

In this reflow zone only the maximum temperature will be reached. In this zone we have to consider about the peak temperature that is the maximum allowable temperature of entire process. It is very important to monitor this maximum temperature exceeds the peak temperature in this zone. It may cause damage to the internal dies of SMT components and a block to the growth of intermetalic bonds. we have to consider the profile time also. If time exceeds than the manufactures specification it also affect the circuit board's quality.

## 3. 3. 4 COOLING ZONE

In the reflow process the last zone is cooling zone. A proper cooling inhabits excess intermetallic formation or thermal shock to the components. Generally the cooling zone temperature range is 30 – 100.

In this project I selected the following temperature profiles. This temperature profile is stranded reflow profile for lead free soldering.

Zone 1 220

Zone 2 180

Zone 3 170

Zone 4 190

Zone5 233

Zone 6 233

Totally 4 circuit boards were printed. Choosing of good reflow profile was not involves any defects or damages in the printed circuit board.

Figure 3. 3. 4. 1a printed circuit board after reflow

## SET UP EVENT DETECTOR

The constructed PCB's were connected with event detector by ribbon data cable. Ribbon cable addressed according to `Analysis tech STD series event detectors manual' . pins 1 to 32 function as source point and pins 33 to 37 function as ground point.

To obtain closed loop circuit to monitor the behaviour of PCB components, PCB boards 1, 2, 3 and 4 connected to channel 1, 2, 33 and 34 respectively.

## Ribbon cable

After connected ribbon cable with event detector and enviromenrt chamber, channels are assigned in " WIN DATA LOG" software which supplied with event detector.

For this test following settings define for data acquisition

# INVESTICATING RELIABILITY OF SOLDER JOINT UNDER VIBRATION CHAMER

In this study, PCB's were used in Variable Frequency Vibration Test to analyse the dynamic response of PCB assembly subjected to random vibration loading. The PCB specimens were tested at different acceleration levels to assess the solder joint reliability subjected varying G-level vibration loads(G is the gravitational acceleration), respectively. Vibration tests were accomplished by using an electro dynamic Shaker