DVD-PTH-D
Through-Hole Solder Joint Workmanship Standards

Below is a copy of the narration for the DVD-PTH-D video presentation. The contents for this script were developed by a review group of industry experts and were based on the best available knowledge at the time of development. The narration may be helpful for translation and technical reference.

Introduction

This DVD training program explains the important workmanship standards for evaluating through-hole solder joints. The contents are organized into four sections: an introduction – which is common to both Class 2 and 3 training; acceptance criteria – specific to Class 2 and Class 3 products; and visual defect criteria – common to both Class 2 and 3.

The focus on this training program is on solder joint evaluation using tin-lead solder. While the criteria covered is the same for lead free, there are important visual considerations between the two types. For a comparison and explanation of these differences, please see IPC-DVD-45C, Lead Free Hand Soldering.

This introduction will explain through-hole solder joints, industry specifications for solder joint acceptance standards, classes of products and solder joint terminology. Let's begin by looking at the parts of a through-hole solder connection. The first part is the through-hole itself. A through-hole is drilled through the printed circuit board during the manufacturing process and is plated first with copper and then tin/lead. The tin/lead plating is *solderable* – since it's made from the same materials as the solder itself. This allows for a strong, reliable connection. These plated through holes are *supported* holes. This DVD does not address *unsupported* holes used on single sided circuit boards.

The next part of the through-hole solder joint is the component lead. Components are assembled onto the circuit board manually – or by automatic insertion machines. Either way the leads are *formed* – usually with a 90 degree bend – and *trimmed* to the correct length. After the lead is trimmed, it may be *clinched* or bent over to hold the component in place during the rest of the assembly process. You'll usually see two types of clinched leads: partially clinched and fully clinched. There are also straight leads that are not clinched – on components such as pin grid arrays, connectors and headers. The finished length must be long enough so that the end of the lead can still be seen after the joint has been soldered.

The last part of the connection is the solder joint. The majority of solder joints are made with *eutectic* solder, which contains 63% tin and 37% lead. Eutectic means that the solder turns liquid all at once – instead of going through a “plastic” stage. Through-hole solder joints made from the most common eutectic solder should look smooth, with a shiny or satin luster. This means that the solder cooled at the correct rate and was not moved or disturbed during cooling. There are special solders, soldering processes, fluxes and components that may produce dull, matte, gray or grainy looking solder joints that would usually be considered suspect but are normal for these materials or processes. Your company will inform you if these special circumstances apply to any assemblies you'll be evaluating.

Through-hole solder joints are almost always soldered from the side of the board where the component lead is trimmed and clinched. We’ll be referring to this as the *solder source side* of the connection. The solder source side is also called the "secondary side” or the bottom of the board. The top of the board is where the components sit – and is identified as the *solder destination side* of the connection. The top of the board is also referred to as the "primary side."

There are two industry specifications that companies in the electronics industry use to determine solder joint acceptance standards. The IPC J-STD-001 – Requirements for Soldered Electrical and Electronic Assemblies – establishes the minimum process and acceptability requirements. The IPC-A-610 – Acceptability of Electronic Assemblies – illustrates these requirements for many types of solder connections and assembly hardware.

IPC has also developed a *Through-Hole Solder Joint Evaluation Training and Reference Guide* to provide convenient reference data for solder technicians and inspectors. In addition, the same information is contained in a digital version called EWS-610. This program can be accessed over your company’s computer network. Both of these training and reference products conform to the latest revision of the IPC-A-610.

This DVD explains the solder joint acceptance requirements contained in IPC-DRM-PTH -- so it may be helpful to follow along in your DRM-PTH if you have a copy available. Any requirements not covered by the training and reference guide may also be found in the IPC-A-610 itself.

Let’s continue now by describing an acceptable solder joint. We’ll be specifying *minimum* and *maximum* dimensions and other visual attributes for all the various criteria of the solder joint. Sometimes a solder joint will meet the minimum acceptance criteria - although it may exhibit certain *cosmetic imperfections* that are *not detrimental* to the reliability of the solder joint. These types of conditions fall into a category called “Process Indicators”. The idea here is that the *process* that created these cosmetic imperfections should be changed - rather than the cosmetic imperfection. This makes a lot of sense... because when you fix the process, the incidence of imperfections will be reduced or eliminated. Solder joints that fall outside of these minimum and maximum limits will be considered *defects*. We’ll be discussing what that means in a moment.

We’ll also be showing the *target,* or ideal condition for a through-hole solder joint. Notice how the solder *feathers smoothly* onto the land… and up onto the lead. The solder fillet is curved inward - or *concave.* The solder *covers* all of the land, as well as the lead. The *texture* is smooth and shiny. The outline of the lead is visible beneath the solder. The amount of solder here is just about perfect. Although it’s desirable to have nothing but perfect solder joints for every connection on the board, we all know that there are a multitude of factors that can affect the soldering process. For example, environmental conditions of the soldering area, or contamination of the solder or component leads can result in a less than perfect solder joint.

A solder joint that barely meets the minimum acceptance requirements for a stereo would certainly not be desirable for a life-support system. That's why through-hole solder joint requirements are divided into three classes – depending on the ultimate use, the life expectancy and the operating environment of the electronic assembly.

Class 1 refers to general electronic products – which covers consumer electronics such as televisions, stereos and video games. *Class 2* includes computers, telephone systems and other commercial equipment that falls into the category of *dedicated service* electronic products. The *Class 3* category is for high performance electronic products – equipment with high reliability applications such as military, aerospace and life- support systems.

Your company may build only one class of products – or products within all three classes. It's important that you know which criteria to apply. The repercussions of applying class 1 workmanship standards to class 3 products are obvious. However, applying class three criteria to class 1 products make the class 1 products much more expensive to manufacture. If you have any questions about the type of assemblies you're working with and evaluating, feel free to ask your supervisor or trainer.

Now, let's return to the subject of solder joints that fall outside the minimum or maximum requirements. It's important to understand that you are not expected to measure every single dimension for every solder joint on the board. But what should you do when you see a solder joint that doesn't meet the minimum size requirements? Do you leave it alone or touch it up?

In some cases, especially in class three products, the entire assembly could be rejected for one solder joint that doesn't meet the requirements of the specification. In cases like this, you may have to rework the solder joint. For class 1 or 2 products the decision may not be so simple. If there is only one solder joint that is slightly less than the required minimum size, it's important to check with your supervisor or a quality assurance person to determine whether the assembly can be passed, or whether it needs to be reworked. This communication will also help insure that the source of the problem is corrected. On the other hand, when a class one or two assembly has a solder joint that is *way below* the acceptable limits – so much that the joint is clearly too small to hold up during the mechanical stresses of day-to-day operation – you would need to make a decision to rework the solder joint.

Again, the decision to rework a specific connection is different for every assembly – and every company. The acceptance requirements in the J-STD-001 provide you with information you need to help you make these important decisions. Your company's, or customer's requirements may be slightly more or less stringent than the J-Standard, and, of course, those workmanship standards will be the final criteria. But it is helpful to know what the industry standards are, to gain some perspective on the relative importance of each type of deviation. Your job is to know what the current requirements *should be* for every assembly you build.

Our last topic in this introductory section deals with terminology. Regardless of the soldering specification you use, there are standard terms used to describe the attributes of every solder joint. Perhaps the most important term in the entire soldering vocabulary is the concept of *wetting*. *Wetting* is defined as the formation of a relatively uniform, smooth, unbroken film of solder, metallurgically bonded to the basis metal.

Various degrees of wetting are characterized by the *angle of contact* between the solder and the basis metal. A smaller *contact angle*, between the two surfaces is a general indication of better wetting and a stronger bond. Larger contact angles can be an indication of reduced strength. On any type of solder joint, the target wetting angle is less than 90 degrees. A contact angle that exceeds 90 degrees usually indicates poor wetting, or excessive solder. If a solder joint has a *convex* appearance as a result of excessive solder, however, it can be difficult to tell whether the surface is properly or poorly wetted. Convex fillets caused by excess solder extending over the land can sometimes be an acceptable condition.

Another attribute of a properly wetted joint is the presence of a smooth and uniform layer of solder, both on the surfaces of the lead and on the land. The solder should *feather out smoothly* onto the *fillet*, or outline of the solder joint, and be slightly *concave*, or curved inward.

One of the more easily detected conditions is *nonwetting*. *Nonwetting* is where the solder simply does not bond to the surface of either the land or the lead. Complete nonwetting is an unacceptable condition for any class of solder joint.

*Dewetting***,** by contrast, is characterized by irregularly shaped mounds of solder that are formed when the solder *pulls back*—almost as if it had changed its mind about wetting. Dewetting is harder to identify, and may appear as a partially-wetted condition, since the surfaces can be wetted at some locations, while the base metal is covered with only a relatively thin film of solder in other places. Various degrees of dewetting or nonwetting may be acceptable, depending on the nature and class of the final product.

Class 2 Acceptance Requirements

Now that you've been introduced to the concept of acceptance requirements, product classes and soldering terminology, let's examine the *acceptance criteria* for Class 2 through-hole solder joints. The following examples will show the minimum and maximum acceptable dimensional and visual requirements for the three perspectives of a through-hole solder joint – the component side; the plated-through hole, or *barrel*; and the solder side.

Let's start by looking at the component side. The first parameter we'll examine is *land coverage*. The target solder connection will have a properly wetted fillet that covers 100% of the land and *feathers out* to a thin edge over the entire land area. It is allowable to have 0% land coverage on the component side as long as all other minimum solder coverage requirements are met on the barrel and solder side of the connection.

The other parameter for the component side of the solder joint has to do with *excess solder*. The maximum acceptable condition allows the solder to extend up into the *lead bend* area – as long as it doesn't contact the component body. Here's what it looks like when the solder actually touches the component.

Now, let's examine the acceptance requirements for the barrel of the solder joint. The first requirement we'll examine is the *vertical fill of solder* inside the plated through-hole. To evaluate this condition you must look at the solder joint from both the component and the solder sides. While we've seen that the ideal or target connection has a slightly concave, cone-shaped fillet that rises from the outer edge of the land to the component lead, the solder joints you see every day may not always live up to this ideal. One common variation of the fillet's shape is a slight dip into the through-hole – before the fillet rises onto the lead. This condition is especially common on the component side of the board as gravity can cause the solder to sag slightly into the hole as it solidifies. As long as the solder joint meets all the other requirements for acceptance, some amount of solder depression is allowed. A maximum total of 25% solder depression, on *either* the component *or* solder side, is permitted. This means that a minimum of three quarters of the barrel must be filled with solder. A 50% vertical fill is acceptable on internal layer thermal heat sink planes associated with some plated through holes.

The other parameter inside the barrel of a through-hole solder joint is the wetting of the lead and barrel. *Circumferential wetting* defines how far around the lead and barrel wall the solder wets, or connects properly. The minimum requirement calls for one half, or 180 degrees of circumferential wetting present on the component side of the lead and barrel.

Next, lets turn to the solder side of the connection. There are three acceptable criteria. The first is the wetting of the lead, land and barrel. The minimum acceptable solder joint should have a concave fillet with proper wetting for 270 degrees, or three quarters of the way around the circumference of the lead, land and barrel.

The second requirement for the solder side is contact angle. The ideal solder fillet will form a contact angle of 90 degrees or less. A contact angle of greater than 90 degrees is acceptable when the cause is the quantity of solder extending over the land. The solder joint is considered rejectable when the fillet is convex and the contact angle is greater than 90 degrees, but solder *does not* extend over the land. Another rejectable condition is when the solder clumps on the surface of the connection. Notice there is no feathered edge apparent and the contact angle is irregular.

Our last parameter for the solder side is lead visibility. The minimum requirement occurs when the fillet is slightly convex with good wetting, and the lead is *not visible* due to excess solder. You need to make sure you can see the lead in the barrel from the component side of the connection. This condition is called a *process indicator* – meaning the cause of the condition should be corrected in the soldering process.

Class 3 Acceptance Requirements

Now that you’ve been introduced to the concept of acceptance requirements, product classes and soldering terminology, let’s examine the *acceptance criteria* for Class 3 through-hole solder joints. The following examples will show the minimum and maximum acceptable dimensional and visual requirements for the three perspectives of a through-hole solder joint – the component side; the plated-through hole, or *barrel*; and the solder side.

Let’s start by looking at the component side. The first parameter we’ll examine is *land coverage*. The target solder connection will have a properly wetted fillet that covers 100% of the land and *feathers out* to a thin edge over the land area. It is allowable to have 0% land coverage on the component side as long as *all* other minimum solder coverage requirements are met on the barrel and solder side of the connection.

The other parameter for the component side of the solder joint has to do with *excess solder*. The maximum acceptable condition allows the solder to extend up into the *lead bend* area – as long as it doesn’t contact the component body. Here’s what it looks like when the solder actually touches the component.

Now, let’s examine the acceptance requirements for the barrel of the solder joint. The first requirement we’ll examine is the *vertical fill of solder* inside the plated through-hole. To evaluate this condition you must look at the solder joint from both the component and the solder sides. While we've seen that the ideal or target connection has a slightly concave, cone-shaped fillet that rises from the outer edge of the land to the component lead, the solder joints you see every day may not always live up to this ideal. One common variation of the fillet's shape is a slight *dip* into the through-hole before the fillet rises to the lead. This condition is especially common on the component side of the board as gravity can cause the solder to sag slightly into the hole as it solidifies. As long as the solder joint meets all the other requirements for acceptance, some amount of solder depression is allowed. A maximum total of 25% solder depression, on *either* the component *or* solder side, is permitted. This means that a minimum of three quarters of the barrel must be filled with solder.

The other parameter for the barrel portion of the solder joint is the wetting of the lead and barrel. *Circumferential wetting* defines how far around the lead and barrel wall the solder wets, or bonds properly. The minimum requirement calls for *three quarters*, or 270 degrees of circumferential wetting present on the *component* side of the lead and barrel.

Next, let’s turn to the solder side of the connection. There are three acceptable criteria. The first is the wetting of the lead, land and barrel. The minimum acceptable solder joint should have a concave fillet with proper wetting for 330 degrees, or approximately 90% of the way around the circumference of the lead and barrel - and a minimum of 270 degrees, or three quarters circumferential wetting over the land.

The second requirement for the solder side is contact angle. The *ideal* solder fillet will form a *contact angle* of 90 degrees or less. A contact angle of *greater* than 90 degrees is acceptable when the cause is the *quantity of solder* extending over the land. The solder joint is considered rejectable when the fillet is convex and the contact angle is greater than 90 degrees – as long as solder *does not* extend over the land. Another rejectable condition is when the solder clumps on the surface of the connection. Notice that there is no feathered edge apparent and the contact angle is irregular.

Our last parameter for the solder side is lead visibility. The minimum requirement occurs when the fillet is slightly convex with good wetting, and the lead is *not visible* due to excess solder. You need to make sure you can see the lead in the barrel from the component side of the connection. This condition is called a *process indicator* – meaning the cause of the condition should be corrected in the soldering process.

Visual Defect Criteria

Now, let’s examine the *visual defect criteria* for through-hole solder joints. We’ll look at *solder balls* first. Any solder balls that are not *entrapped* in a permanent coating, or attached to a metal contact, or violate minimum electrical clearance requirements are considered a defective condition.

Solder bridging is a connection of solder across conductors that should not be electrically joined together. This is *always* a defect – since it misdirects the electronic signal.

A *solder cavity* that does not reduce circumferential wetting of the lead and barrel; the land coverage; or the vertical fill below the minimum acceptable requirements is considered a process indicator.

A *void* is an open area caused by air trapped within the solder joint. This is an allowable condition as long as the solder joint meets all of the other dimensional requirements. Voids are process indicators.

Pinholes and *blowholes* are also examples of process indicators. Blowholes are larger than pinholes. They are created when heated gas escapes from inside the solder joint.

You can identify a *cold solder joint* by poor wetting on the land and lead. Cold solder joints are considered *defective* because the solder connection will not reliably transfer electrical signals and may reduce mechanical strength.

Occasionally the *coating* on the component body will extend into the plated-through hole during the soldering process. *Component coating in the solder joint* is a process indicator for class 2 and a defect for class 3.

You can identify *corrosion* by colored residues or a rusty appearance on metallic surfaces or hardware. Corrosion is a defective condition.

A *disturbed solder joint* is characterized by a gray, porous appearance with stress lines from movement of the solder while solidifying. This is always a defective condition because the solder connection will not be reliable.

Now, let’s look at the requirements for *exposed basis metal* on component leads, conductors or lands. If the exposed basis metal comes from nicks, scratches, dents, etc., it is considered a process indicator for both class 2 and class 3 products. If the exposed material is caused by nonwetting, however, the nonwetting criteria would apply.

This is what a *fractured or cracked* solder joint looks like. It’s possible that a cracked solder joint will not allow the electronic signal to flow. That’s why this condition is not acceptable.

The next situation we’ll examine is *lead protrusion*. Lead protrusion is measured from the top of the land, not from the surface of the circuit board. As a minimum requirement, the end of the lead must be visible in the solder joint. In terms of a maximum protrusion dimension, the lead end should extend no more than 2.5 mm for class 2 products and 1.5 mm for class 3 products – provided there is no danger of violating *electrical clearance.*

For *clinched leads*, the lead protrusion requirements are the same as we just discussed for straight leads. It is also a defect if the lead is clinched toward an electrically uncommon conductor, reducing the remaining gap below the required minimum electrical clearance.

Now, let’s look at *nonwetting*. Notice that the solder has not adhered to either the lead or the land. Complete nonwetting is a *defect* for all through-hole solder joints.

Particulate matter on an assembly is also considered a defective condition. Assemblies should be free of dirt, lint, dross and other particulate matter. Dirt or other residues might be electrically conductive and cause short circuits.

Solder projections are undesirable protrusions of solder from a solidified solder joint. Protrusions are considered defects when they violate minimum electrical clearance and height requirements – meaning they could short out to adjacent conductors – or even an adjacent assembly or the *metal chassis* when placed in the final system configuration. It's important to be aware of solder projections since they can pose a safety hazard.

Visible *residues* from *cleanable fluxes*, or any active flux residues on electrical contact surfaces are also considered defective conditions. In addition, the solder joint should be rejected if the metallic areas exhibit *crystalline white deposits*, or there is a white residue on the surface of the board on or around the soldered termination.

Solder splashes are a problem when they violate the required minimum electrical clearance. In addition, splashes not entrapped or encapsulated in some sort of coating, or not attached to a metal surface should be rejected.

Solder webbing occurs when a film or splash of solder covers any area of the assembly that should be free of solder. Solder webbing is considered a defective condition. Any solder splashes or webbing on the assembly is considered a defective condition for class 2 and class 3.

This program has explained the workmanship standards for evaluating critical acceptance criteria for through-hole solder joints. Solder joint evaluation is a very important job in electronics assembly. When the criteria are not properly understood, the results are unnecessary touch up and rework – and unreliable products. Your careful attention can make a big difference in the production of high quality electronic assemblies.