

## ULTRASONICS AS AN OPTION FOR ELECTRONICS ASSEMBLY CLEANING

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### ABSTRACT

We report results from on-going studies with ultrasonic cleaning systems that support using ultrasonic technology for cleaning electronic assemblies. Ultrasonics is an important option especially when assemblies contain hard to reach regions between or under components. Electronic assembly performance criteria have become more demanding and assembly parameters have become more challenging. Residues can limit product performance and lifetime. Cleaning to acceptable levels is difficult. Currently accepted cleaning techniques, whether in-line or batch processing, may not adequately clean flux and other residues from between or under components. Cleaning is frequently the limiting time and cost bottleneck.

Traditionally there has been a reluctance to use ultrasonics, in part because of a concern with the potential for substrate and component damage. However, as assemblies have become more densely-populated, current techniques must also be evaluated in terms of efficacy of cleaning and the potential for product damage. Many predominant cleaning methods are limited because they require line-of-sight technology. This means that assemblies must be optimally-oriented to avoid shadowing of the cleaning force. In contrast, ultrasonics is, in general, not a line-of-sight technique. It therefore can overcome limitations of spray cleaning, including meticulous maintenance and orientation of spray nozzles, slow throughput, or the potential damaging high pressures needed to get cleaning and rinsing fluids to their destination.

We are studying ultrasonic cleaning parameters including frequency, power, time, temperature and chemistries. Results demonstrate that developments in technology require rethinking of our older assumptions. With appropriate process controls, ultrasonics can significantly reduce both the potential for damage and also allow the appropriate cleaning energy and chemistry to reach the area to be cleaned.

Our findings indicate that cleaning times might be reduced from large fractions of an hour for conventional techniques to a few seconds. Cleaning resources including capital

investment, floorspace, water and energy use may also be favorably reduced.

Key words: cleaning, defluxing, ultrasonics

### INTRODUCTION

Residue can have undesirable impacts on many if not most manufactured objects; and electronics assemblies are no exception. The question of how clean is clean enough is evolving. Historically, the primary concern has been with ionic contamination introduced by solder flux. For high-value product, RMA (rosin mildly activated) fluxes were the gold standard for many years. They could be readily removed using CFC-113 or 1,1,1-trichloroethane blends. Any residue tended to be a relatively inert, amber-like substance that did not interfere with functionality. If you pulled the electronics assembly apart, you could often see the residue; but the assemblies passed required tests for ionic residue, so most people were not terribly concerned. Defluxing required good process control; but processes were fairly consistent.

Beginning in the late 1980s, in large part due to requirements to replace ozone depleting chemicals, electronics assemblers showed increased interest in “no clean” fluxes and in water soluble fluxes. Such fluxes supplanted RMA flux for the majority of applications. No clean fluxes are better-termed low residue fluxes; there is residue, but the level is low enough that cleaning (or defluxing) was not necessary for most applications. Water soluble fluxes (organic acid, OA fluxes) have a fairly active residue; but cleaning with water was sufficient for most applications. The newer fluxes, solvent cleaning (cleaning with organic, carbon based, cleaning agents) decreased dramatically. OA fluxes could be cleaned with water alone or with water and a very mild cleaning chemistry. No clean fluxes often did not require cleaning; where cleaning was needed, people selected a “cleanable” no clean and typically used water without added chemistry.

Cleaning machines were (and still are) generally in-line aqueous systems. In such systems, electronics assemblies are placed on a conveyor belt. The assemblies pass through a wash station where they are cleaned by spraying water and

cleaning chemistry on the part, then one or more rinse stations where the cleaning chemistry is removed, typically followed by a drying step.

Gradually, the situation evolved. By about 2008, there were increased concerns about achieving adequate cleaning. There are a number of factors. For one thing, miniaturization happened. Designers became ever-more creative about fitting more “stuff” in a given amount of space. In addition, while mobile phones and computers may be replaced every year or two, there has been a growth in miniature assemblies with high-reliability applications in aerospace, the military, and medical devices. Densely-populated assemblies with low standoff are difficult to clean. In general, anything below 5 mil standoff can cause cleaning issues (1,2). It is more difficult for the water and cleaning agent to gain access to parts. Water, even water with surfactants, may not “wet” sufficiently to gain access to closely-spaced components. Additives are often added to water to make the cleaning agent work better; but environmental regulatory concerns have limited effective options.

With densely populated assemblies, the recommendation is often to keep the conveyor belt to a speed of 6 inches per minute; and aqueous systems can be 20 to 30 feet long. That's slow! Inevitably, it is crunch time; operators speed up the belt; and then they are mystified as to why the parts do not pass resistivity testing. Further, we cannot always keep spraying hot water on assemblies for long periods of time. In some areas, water shortages are a concern. Some companies are adopting climate change policies that restrict energy usage. Time is money; and there are limits to how slowly it is economically feasible to run the cleaning process.

Assertions are sometimes made that there would be no cleaning/defluxing problems if the reflow process was correct. Certainly, flux residue can be minimized by using the appropriate reflow. The factors involved in optimizing activation are complex (3). Further, complex designs with large components, such as QFNs, may be more prone to result in higher residue formation and entrapment of undesirable residue. What can be achieved under controlled test conditions may not be sustainable in actual production.

Flux residue happens. We can minimize it, but we probably cannot avoid it. We are left with the need to clean. Cleaning involves chemistry, time, temperature, and physical force. We may be hitting the limits of all of these factors. If we stay with aqueous cleaning, we are faced with the inexorable limits of blends of water with other chemicals. You simply cannot change the shape of the water molecule. Further, regulatory agencies often restrict the allowable aqueous additives. Large companies may have policies that restrict allowable additives. So, let's consider time. Longer cleaning can mean more effective cleaning. We can only slow down the conveyor belt so much without compromising production. High temperatures can damage

parts and increase energy usage. How much can we continue to spray? What kinds of forces can be used before we commit blunt force trauma to the assemblies? How controllable and consistent is the spray? Remember that spray systems are inherently line of site cleaning. How precise does the fixturing need to be to assure that the spray is directed optimally? We can submerge the part so that it is surrounded by liquid. Some systems use partial immersion with agitation of the liquid; and that does improve cleaning performance. More cleaning forces may be needed. Which brings us to (gulp) ultrasonic cleaning.

## ULTRASONICS BASICS; ULTRASONICS VARIABLES

Mention ultrasonics to those in electronics assembly and responses range from polite dismay to assertions like “ultrasonics cleaning will happen over my dead body.” Some objections are based on the ultrasonic systems of at least half a century ago. Historical concerns about a tuning fork effect that could conceivably destroy connectors and other small parts are probably overblown. Ultrasonic erosion can be readily minimized by managing the frequency and power level.

Dismay (and certainly death) over the concept of ultrasonic cleaning are both counterproductive approaches.

Ultrasonic cleaning, cleaning with sound, involves a compression/rarefaction cycle that occurs when sound waves pass through liquid. During rarefaction, vapor-filled “bubbles” or “tears” in the liquid are created. The cavitation forces associated with ultrasonic cleaning are due to implosions of these vapor phase tears or bubbles that occur during compression. Ultrasonic frequency varies between 20 KHz and 500 KHz. Unlike spray systems which are line-of-site, ultrasonic forces are omnidirectional. This omnidirectional aspect has advantages for At 400 to 500 KHz, experts consider the system to utilize megasonic cleaning forces. At these high frequencies, the dominant force is acoustic streaming. Acoustic streaming is unidirectional, so it is used in such applications as wafer fabrication. At lower frequencies, cavitation dominates; as the frequency increases, acoustic streaming becomes of greater importance. At lower frequencies, the bubbles are larger; as the frequency increases, the size of the bubbles decrease. Smaller bubble size is associated with less aggressive cleaning and with fine particle removal (4).

The frequency is only one variable associated with ultrasonic cleaning. As indicated in Table 1, a number of variables impact efficacy of soil removal and the potential for substrate damage. We report ongoing studies of the impact of variables on removal of soils from complex assemblies and on the potential for near-term adoption in removal of fluxes.

**Table 1.** Some Variables Associated with Ultrasonic Cleaning

Variable	Comments
Frequency	<ul style="list-style-type: none"> <li>• Lower frequency associated with more aggressive cleaning</li> <li>• Lower frequency, large bubbles</li> <li>• Lower frequency, cavitation</li> <li>• High frequency, acoustic streaming</li> <li>• High frequency more effective for small particles</li> </ul>
Power level, amplitude	<ul style="list-style-type: none"> <li>• High power level associated with more aggressive cleaning</li> </ul>
Cleaning agent	<ul style="list-style-type: none"> <li>• Organic solvent or aqueous can be used</li> <li>• For aqueous, surfactant tends to improve cavitation</li> <li>Behavior varies widely depending on formulation</li> </ul>
Temperature	<ul style="list-style-type: none"> <li>• Hotter is not necessarily better</li> </ul>
Time	<ul style="list-style-type: none"> <li>• Generally &lt; 4 minutes should be sufficient</li> </ul>
Substrate material	<ul style="list-style-type: none"> <li>• Soft metals, plastics more prone to ultrasonic damage</li> </ul>

Over the years, ultrasonic cleaning systems have become more complex; materials of construction of newer products have evolved; and cleaning agent formulations have become more diverse. In response we've been doing studies of ultrasonic variables. The results indicate that manufacturers can achieve more effective critical cleaning practices by optimizing the combination of cleaning chemistries, time, temperature, frequency and power.

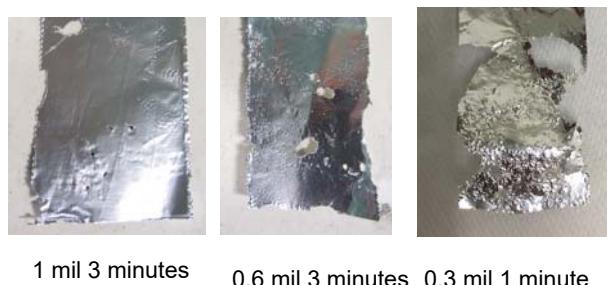
## ULTRASONIC TEST

In our studies we have looked at water or aqueous-based cleaning agents with ultrasonics. We employed three ultrasonics frequencies, 40KHz, 132 KHz and 360 kHz in Crest Ultrasonics benchtop ultrasonic tanks to test the potential for substrate damage and cleaning efficacy.

To measure the potential for substrate or component damage, we observed ultrasonic erosion of aluminum foils. Standard weight household aluminum foil (~0.0006 " thick) has historically been the most widely used indicator of ultrasonic cavitation. When cavitation occurs, foil becomes dimpled, sometimes referred to as an orange peel pattern. With excessive exposure to the ultrasonics, foil will tear and disintegrate. In addition to standard household weight foil, a Heavy Duty foil (~0.001" thick) and a very thin foil (~.0003" thick) were used for our studies.

Cleaning efficacy has been measured visually using glass microscope slides. Soils applied to the slides are graphite (particulates) and a no-clean solder flux. To emulate the conditions under low-standoff components, glass slide sandwiches were prepared, using aluminum foil strips as spacers, and with paper binder clips used to clamp the sandwich together.

Results show the dramatic effect of frequency and foil thickness on foil erosion. Figure 1 shows the effect of 40 kHz ultrasonics on the three thicknesses of foil. The heavy duty (1 mil) foil is barely dimpled and the regular weight (0.6 mil) has noticeable holes and tears after 3 minutes, but the thin foil (0.3 mil) is almost destroyed within 1 minute. At the higher frequency of 132 kHz (Figure 2), there is hardly any effect on the 0.6 mil thickness foil even at 9 minutes, and a noticeable but not very pronounced effect on the 0.3 mil foil after 3 minutes.



1 mil 3 minutes      0.6 mil 3 minutes      0.3 mil 1 minute

**Figure 1.** Aluminum foil erosion at 40 kHz



0.6 mil 9 minutes

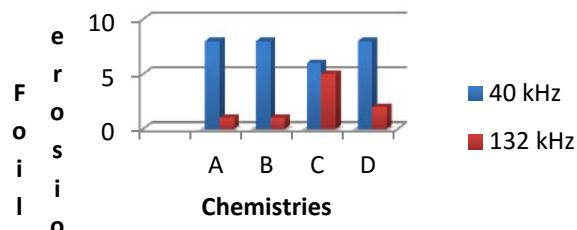


0.3 mil 3 minutes

**Figure 2.** Aluminum foil erosion at 132 kHz

Frequency is not the only parameter to affect foil erosion. We have previously demonstrated that foil erosion can be affected by other parameters, including temperature and cleaning chemistry. Figure 3 shows a comparison of different cleaning chemistries at 40 kHz and 132 kHz (5).

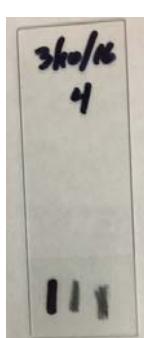
### Foil Erosion @40 kHz and 132kHz



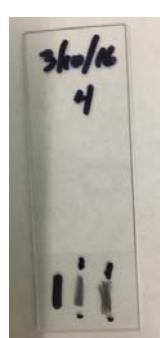
**Figure 3.** Chemistry effect on foil erosion

The impact for electronics assembly manufacturers is that by using higher frequencies, as well as varying other parameters, a balance can be obtained to achieve cleaning efficiency while reducing the risk of damage to boards, components and leads.

Studies at 360 kHz emphasized cleaning efficiency in a small gap, emulating cleaning under a low standoff component. The frosted section of a slide was marked left to right by an indelible ink pen, #2 pencil, and graphite crucible stirring rod (Figure 4a). The slide was immersed in the tank to soak with hand agitation for 20 seconds (Figure 4b). There was no noticeable removal of the markings. A 1 mil gap sandwich was constructed and the slide was again immersed in the tank for 10 seconds with ultrasonics activated (Figure 4c). Most of the graphite markings (pencil and rod) were dispersed from the slide surface.



a)Before



b)soak only 20s



c)1 mil gap, 10 s

**Figure 4.** Small particle (graphite) removal at 360 kHz

In addition to testing cleaning of small particles, graphite, a test was run to see how effectively organic flux residues can be removed by ultrasonic cleaning. A sample of Kester 925 no-clean flux was applied to a slide and baked dry (Figure 5a). Foil spacers and a cover slide completed forming a 1 mil gap sandwich, similar to that used for the graphite removal test. Ultrasonic cleaning at 360 kHz was performed for 30 seconds in a beaker containing a dilute surfactant after which the slide was observed to be visually clean (Figure 5b).



a) Dried flux on slide



b) 1 mil gap; After 30 s

**Figure 5.** Flux removal at 360 kHz

## **ULTRASONICS IS AN OPTION**

Ultrasonics should be considered as an option for cleaning of electronic assemblies, especially when there are hard to reach regions such as under low stand-off components. The availability of high frequency ultrasonics, as well as optimization of other parameters such as temperature and cleaning chemistry, minimizes the potential for erosive damage to leads, boards and components. Our tests also show that ultrasonic cleaning can be both quick and effective when the flux residue or other soils are in regions with small gaps.

Ultrasonic cleaning shows the potential for increased throughput through significantly shorter clean times, reduced equipment footprint, and lower energy and water resource consumption. Our tests are continuing and will continue to study the effects of different cleaning agents, temperature, and other parameters to achieve a balance that optimizes cleaning while minimizing potential damage.

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