ULTRASONIC CLEANING

CAN ONE SIZE FIT ALL FOR POST-LOSS ELECTRONIC EQUIPMENT RECOVERY?

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ABSTRACT
Ultrasonic cleaning presents a contamination-removal solution dating back to the 1950s. Placing items to be cleaned in a tank with a liquid medium and using high-frequency sound waves to induce cavitation, mechanically lifting contamination from surfaces. For personal lines and business personal property insurance claims, manufacturers of electronic, mechanical, and content cleaning equipment have sought to deliver a "one size fits all" solution in an effort to provide an efficient and cost-effective way to process a myriad of items with little to no disassembly. Ultrasonic cleaners can be effective and are commonly used for machinery tooling, injection molds, engine parts, as well as dental and surgical instruments, and other rigid materials. This paper reviews the details of ultrasonic methods, industry-published testing methodologies and limitations of ultrasonic cleaning of more complex electromechanical assemblies such as printed circuit boards (PCBs) as well as the components mounted on them. We evaluate the extent to which an ultrasonic "one size fits all" solution might add risk during the insurance recovery of electronics.

INTRODUCTION
Following a commercial loss involving manufacturing, medical, data center and food processing equipment, as examples, equipment owners are faced with many options that fall into the category of "recovery". Replacement of commercial equipment, even if not custom made, can take months to fabricate, ship and install.

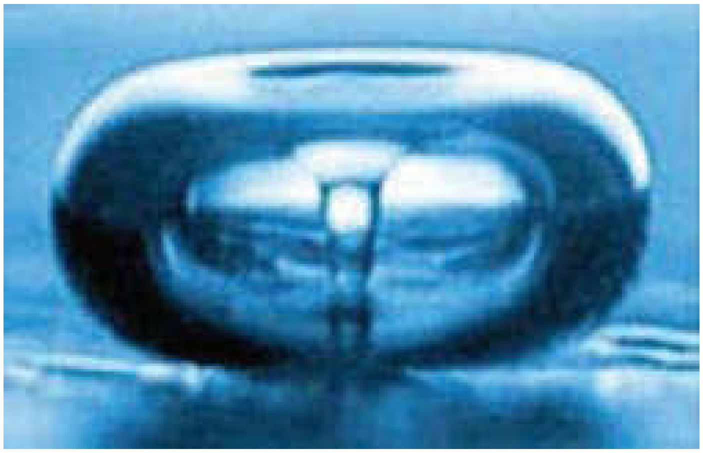
The semiconductor industry led the way in development of PCB cleaning methodologies. While adopted by military, space and industries that had a need for similar processes, every sector tailored their cleaning protocols based on quantified contaminants, composition of electronic components and minimizing adverse effects.

Grainger 50 gal. Ultrasonic Cleaner

Combustion byproducts, fire-suppression effluent and contaminated water exposure present unique challenges. Since the 1970s, post-loss equipment recovery experts offered viable solutions to restore equipment on-site and in a fraction of the time, based in large part on proven PCB techniques that posed little to no harm. Common solutions ranged from non-invasive dry techniques to aqueous based spray-in-air type processes. Ultrasonic cleaners, originally banned for military and aerospace applications, were utilized on hard non-absorbent materials such as metal tooling, parts and molds.

FIT FORM FUNCTION
Ultrasonic cleaners utilize sound waves in a liquid medium to produce cavitation bubbles. Cavitation provides the mechanical agitation that removes the contamination from the surface. Factors that affect the strength of cavitation include cleaning agent temperature, liquid surface tension and vapor pressure, as well as liquid viscosity and density. Commercial ultrasonic cleaners provide users the ability to set

precise agitation times, temperature, power and frequency. Considering all the features and available cleaning agent chemistries, operators have the ability to tailor the system to precisely fit the type of equipment being cleaned.



High speed flash photomicrograph of imploding cavity (Courtesy: National Center for Physical Acoustics, University of Mississippi)

Post-loss, analytical lab testing helps identify the composition of contaminants. Quantifying the type of contaminants plays an important role in selection of ultrasonic cleaning agent chemistry. Material compatibility, such as sensitive electronic components, must also be taken into account when selecting the right chemistry.

TECHNOLOGY BENEFITS

iUltrasonic, a manufacturer of ultrasonic cleaning systems, noted the following: From the auto shop to the dentist's office, more and more industries are using ultrasonic cleaners to remove unwanted residue and harmful contaminants from their equipment. Advances in technology have made ultrasonic cleaning safer, more efficient and more affordable every year. Ultrasonic cleaners have numerous advantages over hand-cleaning, machine washing and other cleaning methods.

Environment Impact

Until recently, the use of heavy chemical cleansers was widespread in many industries. These cleansers often contained harmful compounds, such as esters and chlorinated hydrocarbons, which can pollute groundwater supplies. The vapors from these chemicals are also highly toxic and often require workers to wear protective masks to insulate them from the dangerous fumes. An ultrasonic cleaner uses water-soluble detergents, rather than harsh chemicals, to break up residue.

Worker Safety

Not only does the ultrasonic cleaner prevent workers from inhaling harmful chemical fumes, it also helps workers avoid sharp instruments that may contain biological contaminants. In previous years, workers would hand-clean medical instruments, such as scalpels and drill bits, which could puncture the skin and expose the technician to a potential biohazard. With an ultrasonic cleaner, the worker merely needs to place the instrument in the tank, add water and detergent, and turn on the machine.

Gentle Cleaning

For more delicate items, such as jewelry or precision instruments, hand-cleaning and harsh chemicals could also damage the piece. These items require both a thorough cleaning and a delicate process. The cavitation effect produced by an ultrasonic cleaner allows the mixture of water and detergent to reach into narrow crevices and remove unwanted residue, while keeping the piece intact.

Range of Applications

Users of ultrasonic cleaners range from home hobbyists to state and federal law enforcement agencies. Home users clean their jewelry and collectible coins with ultrasonic cleaners to remove dust, grime and skin oils. Automotive shops clean their parts and tools with an ultrasonic cleaner to take away used lubricants, metal burrs and other residue that can keep a car from working at its best. Police, sheriffs and federal agents clean their weapons, handcuffs and other equipment with ultrasonic cleaners.

The sizes of these machines can vary from small desktop models all the way to larger units used to clean rifles, shotguns and other long-barreled firearms. Some cleaners use specialized detergents to remove specific contaminants, while other applications only require tap water and a minimal amount of detergent or degreaser.

Efficiency

Ultrasonic cleaner users have also found that these machines are highly efficient, much more so than hand-cleaning or other machine-based methods. The ultrasonic cleaner lowers the use of three key resources:

- Water: Ultrasonic cleaners use less water than most hand-cleaning methods or conventional equipment-washing machines.

- Electricity: Ultrasonic cleaners are more energy-efficient than many equipment-washing machines.
- Time: Ultrasonic cleaners work much more quickly and effectively than hand-cleaning or washing machines.

TECHNOLOGY CONSIDERATIONS

The decades-long availability of ultrasonic cleaning has resulted in numerous studies that addressed technology benefits and areas of concern, where perhaps additional material degradation/damage testing is required.

Example of cavitation erosion
- Cleaning Technologies Group, LLC

Cavitation Erosion

Omegasonics, a manufacturer of ultrasonic cleaning systems, noted that *"Cavitation erosion is rare, but it can occur in certain materials when they are placed in ultrasonic cleaners. Short cleaning cycles prevent this type of damage.*

Ultrasonic cleaners work on the basis of cavitation. Gas bubbles form in the cleaning liquid due to alternating high and low pressure cycles, and as the bubbles on the low-pressure side of the cycle get too big to stay intact, they implode, releasing a microscopic but intense burst of high temperature and pressure gas at a very high velocity.

Typically, these gas bubbles tend to form where surfaces are uneven - like at the enface between the part and a contaminant, and at cracks, crevices, and surface discontinuities. It's one of the true benefits of ultrasonic cleaners; they effectively clean the tight spaces that other types of cleaning systems can't reach.

Most ultrasonic cleaning cycle times are way too short to have a detrimental effect on the parts being cleaned. However, if certain types of parts are placed in ultrasonic cleaners and left there for too long, cavitation erosion will begin to occur.

Cavitation erosion is the displacement and removal of the base material. The process leaves behind pits in the surface of the part, caused by repeated explosions of the cavitation bubbles against the surface long after the cleaning process has been completed. Materials most rapidly affected by cavitation erosion are usually soft and not very resilient, like lead, aluminum, brass, and some plastics.

Cavitation erosion tends to show up in those very same places where cavitation bubbles form most frequently on a part during ultrasonic cleaning – sharp corners, cracks, crevices, and other surface discontinuities. Minute particles of the base material are literally ripped away due to the implosions. When cavitation erosion continues for a very long time, the pits created can eventually be seen by the naked eye."

Cavitation Vacuole

TM Associates, a manufacturer of ultrasonic cleaning systems, noted that *"Cavitation or the creation of a vacuole takes place in the liquid when the pressure wave of the ultrasonic passes that area. The collapse of the vacuole takes place during the peak of the wave's passage. This means that the most effective and powerful cavitation takes place around the wave peak. The higher the frequency of the ultrasonics the more evenly this energy is distributed throughout the tank, and the smaller the cavitation vacuoles are when they collapse.*

By adjusting the power and frequency of an ultrasonic system to the level where it cleans the part, without eroding the part, you can avoid damage to the part. The higher the frequency, the more evenly spread out the power. This produces more even cleaning on the part. Higher frequencies also produce smaller cavitation bubbles and can clean smaller particles.

Damage can also occur when the part is extremely fragile and it is placed in a position in the tank that suspends it so that the object is in an area of compression and the part is in an area of reareification. This is more evident in the lower frequencies (20 - 40 kHz). For this reason, most delicate parts are cleaned in a high frequency ultrasonic tank (70 - 200 kHz). By *distributing the total energy of the tank over a greater number of energy peaks, the overall effect is to create a very homogeneous power distribution and subject the part to an even level of energy."*

Vibrational Resonance

Zenith Ultrasonics, a manufacturer of precision cleaning systems, noted that *"In some cases, damage is not produced by the scrubbing action, but rather by vibrational resonance. Very thin glass, semi-conductor components, and other similar sensitive components are subject to this kind of damage. Items being ultrasonically cleaned may fracture during the cleaning process. In these cases, parts should be test cleaned in various ultrasonic frequencies to determine which operational frequency can remove the contaminant in question, while simultaneously preventing damage to the component."*

When hit, struck or disturbed, all objects have a natural frequency at which they vibrate. The vibration is considered the object's resonant frequency. Depending on the size, shape and composition of the object, resonance can produce vibrations strong enough to damage it.

Exponent, a scientific research company, published a study titled, Ultrasonic Cleaning-Induced Failures in Medical Devices. The study noted the following: *"Ultrasonic cleaning is often used as part of the manufacturing process of small medical devices such as guide wires and vascular implants. Ultrasonic cleaning at frequencies close to the natural frequency of the device can result in resonance, resulting in significant mechanical damage and possibly premature failure. This paper provides case studies of ultrasonic cleaning-induced fatigue and corresponding failures in small medical devices. Preventative measures, including analytical tools such as finite element analysis (FEA), to ensure that ultrasonic cleaning frequencies do not result in resonance and stresses sufficient to cause fatigue damage are also discussed.*

Ultrasonic cleaning has been known for years to have the potential to induce harmonic oscillation and corresponding fatigue damage in small structures used in the electronics industry. However, only limited, anecdotal evidence has been provided for ultrasonic cleaning-induced fatigue in small medical devices. While the dangers of ultrasonic cleaning may be well known within specific medical device companies, judging by the number of problems observed by the authors, this issue does not appear to be common knowledge across the entire medical device industry.

The natural frequency of a given structure is a function of its elastic moduli, geometry, and mass. Vibration amplitudes increase dramatically as the frequency of an impressed force approaches the natural frequency of the structure. A condition of resonance occurs when the impressed force frequency equals a structure's natural frequency. At and near resonance, relatively small energy input can result in large vibration amplitudes. These large deflection amplitudes at near-resonance conditions can result in fatigue crack initiation and growth.

The potential for ultrasonic cleaning to induce harmonic oscillation and subsequent fatigue damage in small structures is an issue that is not yet common knowledge throughout the medical device industry. The problem has been well established in the electronics industry, and has been proven to affect a variety of medical devices made from different alloys. Finite element analysis is capable of accurately predicting the natural frequency of a device, allowing a manufacturer to make process or even design changes that avoid resonant conditions that could lead to significant mechanical damage and premature failure. Alternative techniques that avoid ultrasonic-induced damage have been used successfully in the electronics manufacturing industries, and could be employed in the medical device industry to avoid the problems associated with ultrasonic cleaning-induced resonance and fatigue."

Quartz Based Products

IQD, a manufacturer of frequency products, published a report titled, Ultrasonic Cleaning of PCB's with Quartz Based Products, and noted the following: *"Modern ultrasonic cleaning baths may have the facility to alter the bath frequency and this is useful as it may help to reduce self-resonance by sweeping the frequency up and down thus helping to alleviate damage that may be created at one specific frequency.*

To date, little research on the use of ultrasonic cleaning of quartz components has been done. The only generally available background information was published by GEC-Marconi, Hirst Research Centre in England in 1992 and titled The Effects of Ultrasonic Cleaning on Device Degradation - Quartz Crystal Devices. The authors of the report are surprisingly optimistic in the tone of their conclusions, despite finding many failures even in their small sample size.

Failures were found to be significantly higher in low cost high volume quartz devices. However, if considering this report, it is important to recognise that quartz crystal manufacturing has changed very dramatically in the intervening years. The size, packaging and mounting structure of modern ceramic packages are not comparable to the metal can packages analysed in this report, additionally the general quality control of low cost high volume manufacturing is very different today than in 1992.

As a general comment, crystals in the MHz range (which use AT cut quartz blanks), should survive an ultrasonic cleaned process unharmed. Although the overall frequency and specification must be taken into account because higher frequencies use thinner quartz blanks which are more susceptible to breakage than thicker lower frequency devices.

However, crystals that use 'tuning-fork' technology to produce low frequencies such as the common 32.768kHz watch crystals are significantly higher risk. In their application these crystals are designed to work at very low drive levels, the internal architecture of these crystals is designed to excite resonance with very low input power levels, meaning higher power levels can cause physical damage more easily than other products. The frequencies used in ultrasonic are also much closer to the resonant frequency of the quartz, further increasing the likelihood of self-resonance.

With the above points it can be seen that the use of ultrasonic cleaning on PCB's containing quartz products is not without risks. For low frequency crystals, in the kHz range, IQD does not recommend the use of ultrasonic cleaning. For other crystal types we recommend that experimentation is undertaken to assess the risk before use in production."

Micro-Electromechanical Systems

Sparton Navigation & Exploration, a company that specializes in micro-electromechanical systems (MEMS) based inertial sensor systems, noted that *"Ultrasonic cleaning can damage the structure of MEMS devices. Sparton's line of inertial sensor systems contain MEMS accelerometers, gyroscopes, and magnetometers. When subjected to vibrations of specific frequencies the internal structure of the MEMS can become damaged. While some MEMS manufacturers do not mention this, Sparton has found that almost all MEMS structures can be damaged by the frequencies associated with ultrasonic cleaning."*

Conformal Coating & Submersion

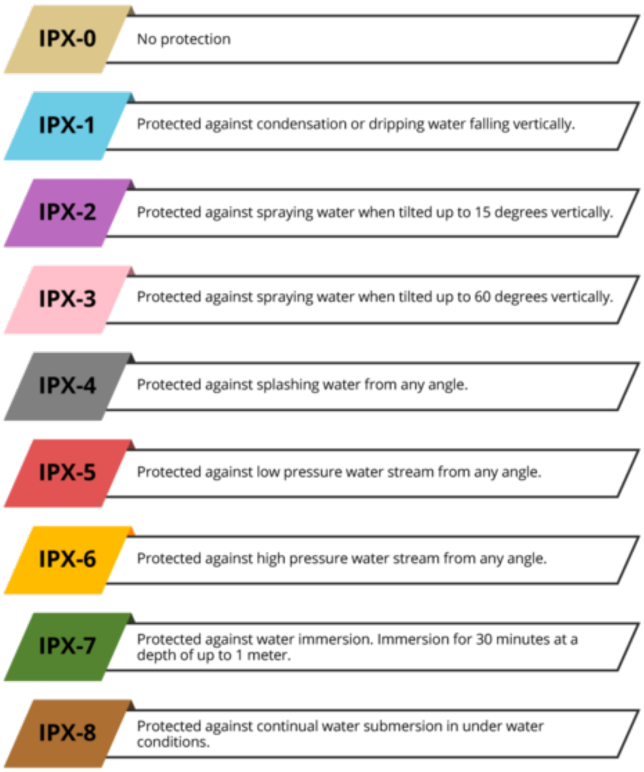
Conformal coating is a polymeric film-forming material, between 25-75μm thick with 50μm being the typical, that conforms to the circuit board topology and protects the board, as well as the electronic components, from harmful environmental conditions like elevated humidity, thermal shock and debris. By conforming to the irregular landscape of the circuit board, the coating provides increased dielectric resistance, operational integrity and reliability.

Circuit boards are populated with different types of electronic components. While some components are sealed, others are unsealed and hand-assembled after aqueous cleaning has been performed, specifically to avoid water intrusion. During a Surface Mount Technology Association (SMTA) chapter meeting, presenters Jason Keeping (Celestica) and Doug Pauls (Rockwell Collins) pointed out that electronic components that are not normally protected with a conformal coating include electromechanical components such as actuators, potentiometers, variable capacitors, photodiodes, sensors, open switches & relays, batteries as well as components sensitive to the additional capacitance of conformal coating such as RF filters.

The intended use of equipment, as well as the environment the manufacturer expects the equipment to operate in, shape the design requirements of the internal circuitry. When considering a desktop computer, as an example, some of the features that manufactures focus on involve processor speed, random access memory (RAM), graphics and the operating system. For typical home users, given computer price points, there is no financial incentive on the manufactures part to ensure that circuitry components are all sealed.

There are multiple standards that specifically address conformal coating testing and ingress protection. IPC-CC-830 Qualifications and Performance of Electrical Insulating Compound for Printed Wiring Assembly, MIL-I-46058C Insulating Compounds for Coating Printed Circuit Assemblies, IEC 61086 Coating for Loaded Printed Wire Boards, ANSI/IEC 60529 Degrees of Protection Provided by Enclosures and the IPX Waterproof Ratings.

Unless it is clearly noted by a manufacturer that circuitry was designed to operate in or withstand submersion, the circuitry needs to be evaluated and the type of electronic components considered for liquid intrusion.



IPX rating categories

IPC Ultrasonic Energy Task Group - Testing Components and Assemblies

The Institute for Interconnecting and Packaging Electronic circuits (IPC), a global association that helps manufacturers build quality electronic assemblies through proven standards, certifications, education and training, developed test methods to determine the suitability of various components to ultrasonic cleaning. These are contained in the IPC-TM-650 Test Methods Manual.

Test Method 2.6.9.1 - Test to Determine Sensitivity of Electronic Assemblies to Ultrasonic Energy. The test determines if components will survive a cleaning cycle time of 10X the anticipated cleaning cycle time or 30 minutes, whichever is greater, when the components are soldered into a printed wiring assembly.

Test Method 2.6.9.2 - Test to Determine Sensitivity of Electronic Components to Ultrasonic Energy. The test determines if components will survive the same testing conditions when placed loose in a basket.

2.6.9.2 Test Protocol to Determine Sensitivity of Components to Ultrasonic Energy

1.0 Scope

The purpose of this test method is to provide a consistent procedure to test the sensitivity of electronic components to ultrasonic energy. There has been reluctance in the electronics industry to use ultrasonic energy for printed board assembly cleaning because of the possibility of damage to wire bonds in active, hermetically sealed components or other damage that might cause latent failures. Recent work has shown that electronic components have a low potential for damage from ultrasonics (References 1-7) under conditions seen in most cleaning processes. In addition, MIL-STD-2000 Rev. A and J-STD-001 now allow for the use of ultrasonic cleaning, as does the proposal for IEC TC91 International Standards based on an updated revision of the J-STD-001.

5.1 Procedure

Note: Standard ESD handling methods should be used in handling and assembly so as not to have ESD damage misinterpreted as damage by ultrasonic exposure.

5.1.1

Perform functional electrical tests on components to be subjected to ultrasonic energy. All components should go through standard pre-screening tests to eliminate infant mortality. Note any anomalies and ignore any malfunctions in further testing.

5.1.2

Fill the test tank with de-ionized water. Turn on ultrasonics and allow a minimum of 15 minutes for the water to degas. Evidence of cavitation should be obtained by placing a piece of aluminum foil in the water for one minute and inspecting for an erosion pattern (evidence of cavitational activity). If the surface of the foil is not disrupted, continue to degas until the foil confirms ultrasonic activity.

Test components in the equipment described above. Place components randomly in basket or in a beaker. Baskets should be suspended off the bottom of the tank or contain stand off legs to keep it from setting directly on the bottom of the tank. If a beaker is to be used, it should be filled with deionized water and degassed as described in the above paragraph. The beaker should be suspended in the water filled tank and not placed on the tank bottom. Subject specimens to ultrasonics for a time period 10 times longer than the expected exposure anticipated under normal cleaning conditions or 30 minutes, whichever is longer.

5.1.3 (Optional)

Conduct any environmental stressing test(s) as specified by the reliability requirement of the product line in concern.

5.2 Evaluation Method

5.2.1
Repeat the functional electrical test in 5.1.1. Any failures should be analyzed for cause of failure. Any failure, excluding those noted in 5.1.1 or attributable to a documented defect will also be considered caused by the ultrasonics.

5.2.2
Any defect which is not assignable to a previously documented defect will also be considered caused by ultrasonics.

5.2.3
Any component exhibiting no failures or 100 percent reliability after ultrasonic testing will be considered safely resistant to ultrasonics under the conditions tested. Any component with less than 100 percent reliability will be suspect unless subsequent testing can demonstrate that it is 100 percent reliable. Unless classified or proprietary, please report test results to the Ultrasonic Energy Task Group through the IPC for compilation in the attached list.

IPC J-STD-001 - Requirements for Soldered Electrical and Electronic Assemblies, contains the following paragraph:

8.1.2.1, Ultrasonic Cleaning. Ultrasonic cleaning is permissible:

a. On bare boards or assemblies, provided only terminals or connectors without internal electronics are present.
b. On electronic assemblies with electrical components, provided the manufacturer has documentation available for review showing use of ultrasonics does not damage the mechanical or electrical performance of the product or components being cleaned.

CONCLUSION

Commercial losses involve a broad range of electrical/electronic and mechanical equipment. Machinery tooling/parts, injection molds, engine parts, dental and surgical instruments, and many other types of rigid objects, can be quickly, thoroughly and safely decontaminated with an ultrasonic cleaner.

Some circuit board manufacturers find it beneficial to qualify the use of ultrasonic cleaners. They do so by adhering to IPC test protocols, IPC-TM-650 2.6.9.1 & 2.6.9.2, either for their own production needs or to satisfy end user requirements.

Following a loss, contaminant disposition is critical to understand as some can be easily removed versus others that may be baked/hardened or infused in oil/grease. Analytically identifying the contaminants is perhaps even more important, as some areas within the facility may only exhibit operational debris, not loss related, while those that are related become part of the equation when determining the correct chemistry of the ultrasonic cleaning agent.

When considering that professional ultrasonic cleaners enable the user to set precise agitation times, cleaning agent temperature, and ultrasonic power and frequency, how would a post-loss equipment specialist determine the correct settings when different types of printed circuit boards/assemblies need to be addressed?

Perhaps Omegasonics summarized it best when they concluded that “Experimentation to clean electronics may be necessary. Due to the wide and varied geometry of electronics, there is no one universal setting suitable for everything. You may have to experiment a bit in order to find the right mix of solution, temperature and frequency to clean electronics correctly.”

Post-loss equipment specialists have a finite amount of time when considering business income loss. The liability involved when simply guessing that circuitry will survive submersion and the ultrasonic cleaning process itself, is far too great especially when addressing commercial equipment.

Therefore, when considering the electronics portion of post-loss recovery, equipment specialists have to spend time researching submersion and IPC adherence in order to determine that equipment can be addressed with an ultrasonic cleaner. Once that determination has been made, the correct tank settings need to be established for each piece. If certain electronic items qualify for ultrasonic cleaning, while others require a different recovery technique, ultrasonic cleaners cannot be considered a “one size fits all” solution in the post-loss equipment recovery industry.

REFERENCES

- IPC-TM-650 Test Methods Manual, 1/95
- IPC-CC-830 Qualification and Performance of Electrical Insulating Compounds for Printed Wiring Assemblies
- IPC J-STD-001 Requirements for Soldered Electrical and Electronic Assemblies
- MIL-I-46058C Insulating Compounds for Coating Printed Circuit Assemblies
- MIL-STD-2000 Standard Requirements for Soldered Electrical and Electronic Assemblies
- IEC 61086 Coating for Loaded Printed Wire Boards
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