Effective Use of Ultrasonic Cleaning For Pretreatment

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Ultrasonic cleaning is an effective pretreatment for a variety of surface finishing operations. It is effective for removing buffing compound and cleaning the hidden areas of parts that are not accessible to spray and simple immersion technology. The technology must be properly applied in production to achieve maximum cleaning results. This edited version of a paper from SUR/FIN® 2000 provides a background on the mechanics of the ultrasonic process and outlines methods to implement ultrasonic cleaning technology for maximum effectiveness in production.

The mechanics of the ultrasonic cleaning process are generally well understood. High-frequency sound waves are introduced into a liquid media. Each point in the liquid is subjected to alternating negative and positive pressure as the sound waves pass by. Negative pressure causes the liquid to fracture, creating what are called cavitation bubbles. As negative pressure is replaced by positive pressure under the influence of the compression portion of the sound wave, cavitation bubbles collapse in implosion, creating minute, but intense, areas of pressure and temperature. These mechanical effects, shown in Fig. 1, boost the cleaning ability of the chemistry and promote removal of small particles from critical surfaces.

Large Ultrasonic Tanks

When ultrasonic cleaning is applied in mass finishing operations, it is necessary to address concerns not typically encountered in small batch processes.

Because of the volume of parts being processed in mass finishing, the tanks used are relatively large. Applying ultrasonic energy in a large tank is not a problem with today's technology. Readily available immersible ultrasonic transducers are simply fixtured in the tank, either on the side walls or bottom. Each transducer requires an ultrasonic generator to supply it with electrical energy at the ultrasonic frequency.

Ultrasonic generators, being somewhat sensitive to dirt, moisture and corrosive fumes, are often located in an area away from the processing tanks. The generators are protected by appropriate electrical enclosures incorporating fan-forced filtered air and/or mechanical cooling.

Electrical connections from the transducers to the ultrasonic generators are made using solid or flexible stainless steel tubing (see Fig. 2).

An alternative scheme involves penetrating the tank wall directly behind each transducer with a bulkhead fitting with a gasket (see Fig. 3). This method is less convenient, because it requires the tank to be drained for transducer repair or replacement.

Ultrasonic Power

Selecting the appropriate ultrasonic power density for a given cleaning tank and process requires some skill on the part of the ultrasonic equipment supplier. Power is commonly expressed in watts of ultrasonic energy per gallon of tank volume. Although general guidelines for ultrasonic power requirements are available, the actual power requirement in any given situation can vary widely, depending on the size of the tank, the surface area of the parts, the weight of the parts, and rack design and construction. Larger tanks may require less ultrasonic power per unit of volume than smaller tanks to achieve the same cleaning result in the same application. The greater the part surface area and/or weight, the more ultrasonic energy density is required to achieve acceptable cleaning results (see Fig. 4). More energy density also will be required if part fixtures absorb ultrasonic energy or shield the parts being cleaned from the ultrasonic field.

Cavitation and Implosion

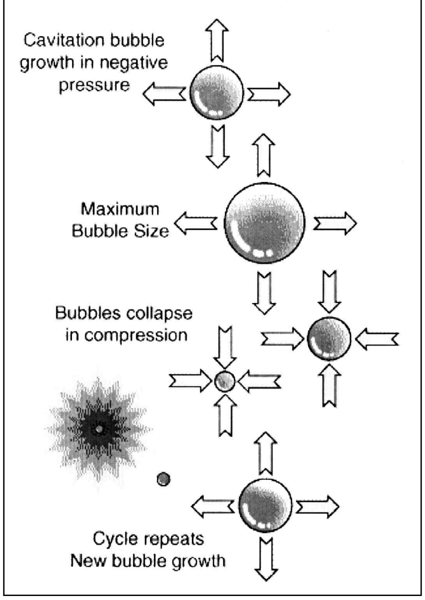

Fig. 1—Mechanical effects of ultrasonic cleaning.

Tank Construction

Tanks used for ultrasonic processing are commonly made of double-welded stainless steel for maximum strength and durability. Mild steel tanks are acceptable, but may have a shorter life. Because there is an investment in fixturing a tank for ultrasonic transducers, and because the long-term effect of ultrasonic energy can cause wear on tank surfaces, the additional investment in stainless is usually considered worthwhile.

Softer materials, such as plastic and rubber, should be avoided in tank construction for two reasons: (1) Softer materials tend to absorb ultrasonic energy, making it necessary to increase the ultrasonic power density to compensate for the absorption; and (2) there is a benefit to having sound waves reflect from the tank walls to help produce a homogeneous ultrasonic field within the tank. This effect is much less in a non-

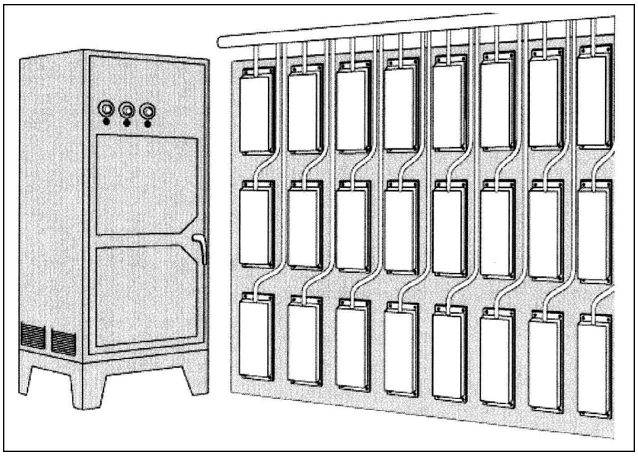

Fig. 2—Typical scheme for ultrasonic generators.

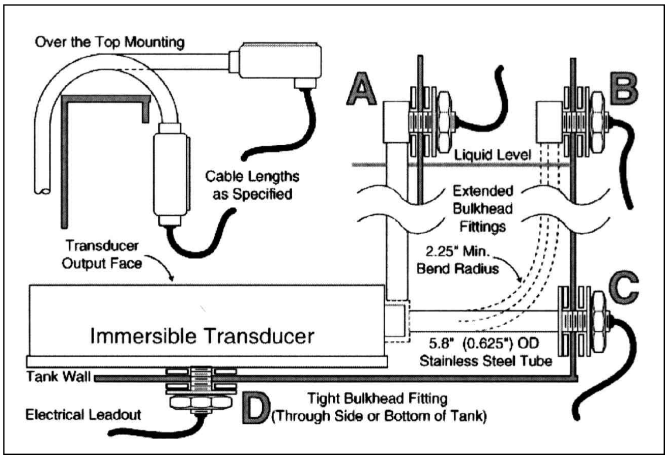

Fig. 3—Alternative power scheme for ultrasonic cleaning.

metallic tank. Also, the use of non-metallic materials in the form of heaters, heater sheaths and immersed rubber or plastic plumbing should be avoided in an ultrasonic tank.

Ultrasonic Frequency

The ultrasonic frequency spectrum ranges from slightly below 20 KHz to nearly 200 KHz. In general, frequencies near the low end are utilized in pretreatment applications in the finishing industry. Most manufacturers provide ultrasonic systems in the 20–25 KHz range as well as the 40–45 KHz range. Higher frequencies seldom find application in the metal finishing field.

Lower ultrasonic frequency will produce larger cavitation bubbles, because longer wavelength puts each growing bubble under the influence of the negative pressure portion of the sound wave for a longer period of time. The longer period gives the bubble more time to grow to a larger size. Larger cavitation bubbles collapse or implode, releasing greater energy than smaller ones. Frequencies from 20–25 KHz generally provide faster and more aggressive cleaning due to higher energy release at implosion. Frequencies from 40–45 KHz are reserved for applications on substrates susceptible to damage by high-intensity cavitation, and for cleaning and rinsing applications requiring enhanced penetration of complex surfaces.

Transducer Placement

Successful ultrasonic cleaning requires not only the proper energy density, but also uniform distribution of ultrasonic energy throughout the cleaning tank. Although ultrasonics is not a "line-of-sight" phenomenon producing sharp shadows, there are "soft" shadowing effects that can be compared to observing the shadow of a large sheet of cardboard held parallel to the surface of the earth on an overcast day. It is, therefore, important to give some consideration to the placement of ultrasonic transducers to assure that all surfaces of the parts being cleaned are exposed to the ultrasonic energy.

In most small tank applications, the preferred transducer placement is on the bottom of the tank. With bottom placement, the liquid/air interface at the upper surface of the liquid is a near-perfect reflector. This reflecting surface, combined with the reflecting properties of the tank sidewalls, serves to distribute sound waves throughout the liquid volume. Tanks that are more than twice as deep as wide at the narrow-most point may require side-mounted traducers for an even distribution of energy. In addition to the reflection phenomenon described above, the density of work in a deeper tank may cause diminished ultrasonic energy near the top of the liquid volume because of the shadowing effects of parts at the lower levels.

Low-density and "one-sided" work are often accommodated with transducers placed only on one side of a cleaning tank. High-density and "two-sided" work often require the placement of transducers on opposite tank side walls. Opposing transducers can also be staggered to further enhance the distribution of ultrasonic energy.

To minimize line length, process tanks are often made as narrow as possible in the DOT dimension. In ultrasonic tanks using side-mounted transducers, sufficient space must be left between the transducers and the work to allow the sound field to spread out and diffuse. Work placed too close to a bank of ultrasonic transducers may exhibit bands of poor cleaning in areas not directly in front of a transducer. Furthermore, parts inadvertently placed in critical positions at dimensions from one-half to three wavelengths (3/4 to 4-l/2 in.) directly in front of a transducer may exhibit cavitation burning caused by the intense sound field found at these locations. As a general rule, no part should be placed closer than six inches from the radiating face of an ultrasonic transducer.

Transducer Protection

Ultrasonic transducers are robust in their own right, but are generally not up to the abuse they can inadvertently receive in a high-speed automated tank line running heavy parts. For this reason, it is recommended that ultrasonic transducers be protected through the use of guards and/or load guides. Guards and guides are often made of bar stock and are positioned to provide minimum interference with the ultrasonic energy field. Including these devices into a tank design in process is relatively simple. It is worth the expenditure if a single incident of damage is avoided.

Rinsing

Although typically thought of as a cleaning tool, ultrasonics can also enhance rinsing. The addition of ultrasonics to rinses is particularly effective on parts having irregular surfaces, complex internal passages or, in the case of sheet metal, tight reverse bends or "hems." Ultrasonic rinsing helps remove residual cleaning chemistry that might bleed out in later finishing steps, causing rejects. It is common to realize the benefits of ultrasonic enhancement in a rinse using as little as half the ultrasonic energy density required for the initial cleaning of the same part.

In a multi-stage rinse with ultrasonics only in a limited number of tanks, the technology should be used in initial rinse(s) rather than at the end. A final ultrasonic rinse preceded by stagnant pre-rinses will only hasten contamination of the final rinse, reducing the effectiveness of the overall rinsing process.

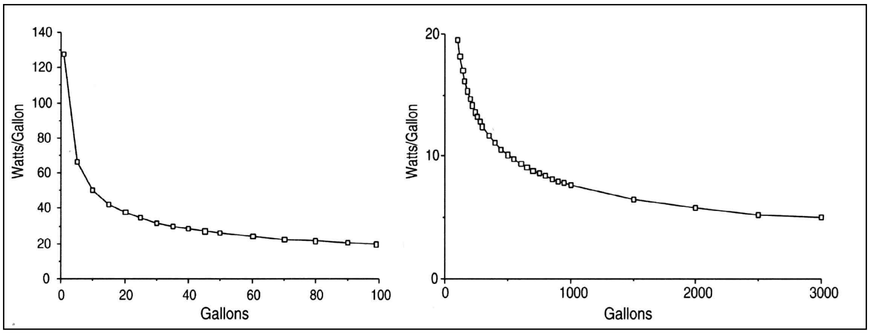

Fig. 4—Guidelines to ultrasonic density requirements for various sized tanks used in typical cleaning applications.

Parts Racking

Many finishing operations—including plating, e-coat and others—require the same attention to racking as is required for successful ultrasonic cleaning. As previously stated, parts surfaces to be cleaned must be exposed to ultrasonic energy. Because the media for ultrasonic transmission is the cleaning or rinsing liquid, all surfaces to be cleaned must be in contact with the liquid for the ultrasonic energy to be effective. Parts that are likely to trap air bubbles require special positioning to eliminate or minimize the effect.

As an alternative, parts may be repositioned after immersion to “burp” out any trapped bubbles. This is, or course, a more complex solution to the problem, but it has been utilized. Yet another alternative solution for particularly difficult parts is to provide an air relief to prevent air trapping. This requires only a very small hole that can usually be placed in an inconspicuous location. In some cases, this hole is actually filled in by the subsequent finishing operation.

In addition to being in contact with the processing liquid, parts must be exposed to an adequately intense ultrasonic field. To prevent the shadowing effect, parts must be placed with sufficient space around them to allow the ultrasonic energy to “wrap around” them. Although layers of parts can be tolerated, the position of each layer should be staggered slightly to allow the diffuse energy pattern to penetrate to all parts. In no case should parts touch one another or be allowed to stack. Not only does this prevent the ultrasonic field from reaching the surfaces that are touching, but may result in abrasion marks caused by part-against-part vibration. Finding the maximum part density allowable in some applications may require experimentation. In general, numbers of large, flat parts, such as appliance panels and printed circuit boards, are more effectively cleaned if the ultrasonic field is introduced from the edge, rather than against the flat surface. The later arrangement requires the ultrasonic energy to penetrate through a number of panels to reach those located in the center.

Rack Construction

Unfortunately, the best rack designs for many finishing operations—including plating and electrostatic coating of all kinds—are often incompatible with ultrasonics. The resists applied to racks in the form of plastisol, Teflon,® rubber and other insulating and/or protective materials act to severely dampen the ultrasonic effect. In many cases, these protective coatings are removed by extended exposure to ultrasonics, causing even greater problems.

Rack design requires some compromise, if the rack is to be compatible with both ultrasonic cleaning and subsequent finishing operations. In some cases, minimizing the thickness of coatings and positioning supports so that they do not shadow the parts is effective. Racks may also be built using thinner structural supports and cross members. The use of inexpensive expandable hangers has been successful in cases where there was no other acceptable solution. At the very least, the rack designer should be familiar with the requirements of both ultrasonics and the finishing operation, and provide a solution that meets the needs of both.

Summary

Ultrasonics has been demonstrated to be an effective pretreatment tool for finishing operations. Proper selection and installation of ultrasonic equipment is only one part of implementing an effective ultrasonic cleaning process. Consideration also must be given to other parameters, including part placement and rack design. To be most effective, ultrasonic cleaning should be followed by ultrasonic rinsing to remove all traces of cleaning chemistry prior to the finishing operation. P&SF

About the Author

John Fuchs holds a BS in industrial engineering from the University of Michigan in Ann Arbor. He has been employed by CAE Cleaning Technologies, P.O. Box 220, Jamestown, NY 14701, for more than 30 years in a number of technical capacities, and is currently director of applications technology. With extensive knowledge of ultrasonics developed through many years of experience, Fuchs has been involved in a number of developments in ultrasonic cleaning and other related technologies. He has written numerous educational articles on ultrasonics and has presented papers to many professional groups, including The Society of Manufacturing Engineers, Precision Cleaning conferences, NEPCON, NASA, Naval Weapons Center in China Lake, The Society of Vacuum Coaters, The Ultrasonic Industry Association, The Porcelain Enamel Institute and AESF. For the past several years, he has been involved in the development of advanced aqueous cleaning techniques and processes to replace CFC solvents.