OMEGASONICS™

ULTRASONIC CLEANING 101

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WHO WE ARE

OMEGASONICS

At Omegasonics, we want your business to succeed, and we have the ultrasonic cleaning technology to help you do it...

Founded in 1996 on the idea that powerful cleaning doesn't need to be expensive, time-consuming, dangerous or tough on the environment, Omegasonics is now the west coast's leading manufacturer of ultrasonic cleaning systems. We are committed to the highest quality of products, exceptional integrity and customer service, and the finest after-sales support in the industry.

THE RESULTS...

Lower cost and higher productivity: Omegasonics equipment pays for itself in less than a year. One system can save you up to $1,000 or more per month. Contact our sales team now!

WHY IT WORKS!

Our technology replaces traditional cleaning methods – time-consuming hand-scrubbing with dangerous toxic solvents – with equipment requiring only hot water and environmentally friendly soap solutions. No more storing, working with and disposing of harsh chemicals. Plus, it works better than hand cleaning.

"We want to help your business increase productivity, decrease costs and eliminate the worry associated with traditional cleaning methods. To that end, even if one of our multiple systems doesn't quite meet your needs, we will customize a machine for you. After your equipment is up and running, we are available to you 24/7, ready to help. We look forward to working with you!"

– Frank Pedeflous, President, Omegasonics

PART 1

WHAT ARE ULTRASONIC WAVES?

Ultrasonic waves are sound waves transmitted above 20,000 Hz (20 kHz or 20,000 cycles per second), or higher than the frequency detectable by humans. Sound waves are created by the vibration of an object, which causes the air molecules around it to vibrate. These vibrations cause our eardrums to vibrate, which the brain then interprets as sound. When the original vibration is very fast, so are the sound waves, and the pitch of the sound created is too high for the human ear to hear.

In the natural world, animals like dolphins and bats use these ultrasonic waves to communicate, but humans have discovered practical applications. The most commonly known is medical ultrasonography, although in the last 30 years some organizations have discovered highly effective, chemical-free cleaning applications and technology. Ultrasonic cleaners work in a very similar way to a loud speaker, except the ultrasonic waves travel at a much higher frequency and through water instead of air. A high-frequency electronic generator that creates ultrasonic waves is connected to a diaphragm, a flat or cone-shaped structure similar to the visible cone-shaped portion of a loudspeaker. The generator vibrates the diaphragm at a specific high frequency, usually between 25 and 170 kHz, inside a specially designed water tank. The ultrasonic waves created cause the water molecules to vibrate rapidly, creating alternating waves of compression and expansion within the water. During the expansion phase, or rarefaction cycle, the liquid is torn apart, creating cavitation bubbles. These bubbles are where ultrasonic cleaning technology is born.

HOW DOES ULTRASONIC TECHNOLOGY CLEAN?

Cavitation bubbles (Fig. 1) are vacuum cavities as tiny as red blood cells, or about 8 thousandths of a millimeter across. They are so small that it would take 1,250 of them lined up in a row to reach 1 cm long.

Under pressure of continuous vibration, these bubbles stretch and compress at a fast rate. Once they reach a certain size, as determined by the frequency and strength of the sound waves produced, the bubbles lose structural integrity and collapse violently. When these implosions happen near a surface, the bubbles emit high-powered streams of plasma that travel at more than 500 miles per hour and collide with, agitate and remove even very tiny particles and substances from that surface.

(Fig 1) Illustration of an Ultrasonic Cavitation Bubble

In an ultrasonic cleaning machine, this happens millions of times per second, but because cavitation bubbles are so small the process is both highly effective and very gentle. Ultrasonic technology can be used to clean metals, plastics, glass, rubber and ceramics. It effectively removes a wide variety of contaminants, even if present only in trace amounts, including dust, dirt, rust, oil, grease, soot, mold, carbon deposits, polishing compounds, wax, pigments, lime scale, bacteria, algae, fungus, fingerprints and biological soil.

These contaminants typically are removed even if they are tightly adhered to or embedded onto solid surfaces, or if they are in remote cracks or tiny crevices of an object. For this reason, items usually do not need to be disassembled before being put safely in an ultrasonic cleaning unit.

THE POWER BEHIND ULTRASONIC CLEANING

Since all ultrasound waves are generated using the same basic technology, it follows that all ultrasonic cleaning systems include the same basic components. Energy is generated via a bank of ultrasonic transducers mounted to a radiating diaphragm (Fig. 2). This transducer is then mounted to the unit's cleaning tank where it is immersed in water or an aqueous solution. It's essentially a stereo system under water. There are two types of transducers used in ultrasonic cleaning—magnetostrictive and piezoelectric. They create the same result using very different technology, therefore each has different benefits and limitations.

(Fig. 2) Two Ultrasonic Transducers: with the lid off (back), with the lid welded on (front)

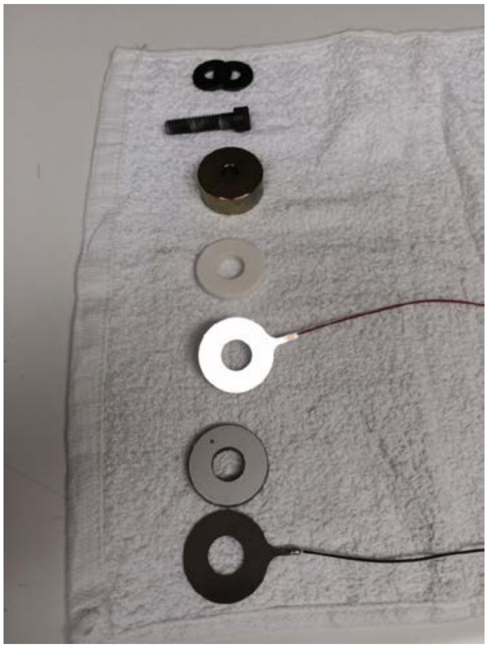
Magnetostrictive transducers work on the principle that iron-rich metals expand and contract when they are placed in a magnetic field. Thin plates of these metals are stacked up to make a core. Copper wire is then wrapped cylindrically around the core and the assembly is placed in a canister. When an electrical current is sent through the copper coil, a magnetic field is created and the core changes shape. When the electrical current is turned off, the coil returns to its original shape. This expansion and contraction causes the device's canister to resonate and generate ultrasonic waves.

MAGNETOSTRICTIVE TRANSDUCERS

Magnetostrictive transducers are remarkably durable, though its overall competitive advantages are quickly decreasing as the technology around piezoelectric transducers evolves and improves. The use of iron-based metals means there is no degradation over time; metals like nickel maintain their magnetostrictive properties on a constant level for the lifetime of the ultrasonic cleaning unit. The metal stack is welded directly to the unit's diaphragm ensuring the bond will never loosen. Also, diaphragms used with this type of transducer are usually 5 mm thick or more, eliminating the risk of cavitation erosion wear-through.

While magnetostrictive transducers have a higher mass and can drive more power into the tank, their use is limited. They can only generate a frequency between 22 and 30 kHz, so its use is restricted to cleaning applications where the parts are large, the contaminants are difficult to remove and complete removal of microscopic particles isn't required. Their energy generation process has three steps in energy conversion—electric energy to magnetic energy to mechanical energy—making it less efficient overall.

In **piezoelectric transducers (Fig. 3)**, crystals with special electrical properties called lead zirconate titanate are connected with electrical wires attached to opposite faces of the crystal. Both the crystal and wires are housed between two metal plates. **These layers are then stacked together and fastened down. (Fig. 4)** When electricity is passed through the crystal, it changes its shape. When the electricity is taken away, it returns to its original shape. This vibration causes the unit's diaphragm to vibrate and create the ultrasonic wave necessary for the cleaning process.



(Fig. 3) A Piezoelectric Transducer Unassembled

Piezoelectric transducers are less expensive to make and offer a wider variety of applications. These transducers can produce a wide variety of frequencies—between 25 and 170 kHz or more. They convert low-voltage electrical energy into mechanical energy in one step, making them cost-efficient to run frequently and for longer periods of time.

It used to be the case that the magnetostrictive transducers held a longevity advantage over its piezoelectric counterpart for two reasons: 1) When piezoelectric transducers were first developed, they used quartz crystals which lost significant power over time. Now, piezoelectric transducers use semiconductor ceramic materials that eliminate 99 percent of that strength degradation and lengthen their lifespan. 2) The adhesives available in the early days of piezoelectric transducers weren't very strong and would degrade over time. However, adhesives developed over the years by the aircraft industry are much stronger, making the difference between welding and adhesion virtually negligible.

PUTTING TRANSDUCERS TO WORK

When it comes to ultrasonic power generation, the frequency these transducers generate determines their effectiveness for any given application.

With lower frequencies, fewer cavitation bubbles are produced, but the bubbles are greater in both size and the energy released at implosion. This increases the likelihood of physical damage to items being cleaned. Softer metals like aluminum and brass may show what is called "cavitation burning." Likewise, higher frequencies generate more bubbles that are smaller in size and offer a lower level of energy and gentler cleaning action.

(Fig. 4) Piezoelectric Transducer Parts Assembled

It's important to note that when generating an ultrasonic frequency of 25 kHz, ultrasonic units must contain a matching generator that can stand up to that mass requirement of the transducer. When frequencies between 40 and 170 kHz are required, many companies will use the same transducer along with a generator designed for the specific frequency output required for the application.

25 kHz: The Heavy Weight Boxer

A 25 kHz generator is used with larger mass items, such has a large cast iron block used for injection molding, a massive steel cutting tool or large stainless steel plates. It works best when the contaminant is on the surface of the item and requires a little more punch to remove it. This frequency also works well for removing baked on materials and is often found on plating lines for pre-treatment prior to the plating process. Larger tanks often are retrofitted with 25 kHz systems for these types of jobs.

40 kHz: The Workhorse

The vast majority of ultrasonic cleaning applications require the mid-sized cavitation bubbles created by a 40 kHz generator. Approximately 90 percent of all ultrasonic cleaning applications can be addressed at this frequency. It has enough power to shake contaminants loose but is small enough to penetrate closer to the substrate. This frequency works best when items have many through-holes and/or complicated blind holes that are difficult to reach using the larger cavitation bubbles generated at lower frequencies.

Typical applications of 40 kHz generators include carburetor cleaning, removing oils and metal chips from general machine shop applications, soot removal from items damaged in fires, cleaning of ceramics used in the high technology fields, removal of biological contaminants from surgical tools and many more.

68/132/170 kHz: The Gentle Touch

Higher frequency generators are more rare, only accounting for approximately 5 percent of the ultrasonic cleaning market. These generators offer ultra-fine gentle cleaning, including removal of micron and submicron particles, and cleaning applications that require cavitation bubbles to implode closer to the substrates being cleaned. Common applications are found in the medical and optical industries, but also in semiconductor wafer fabrication, production electronics, fine instrumentation and computer memory components.

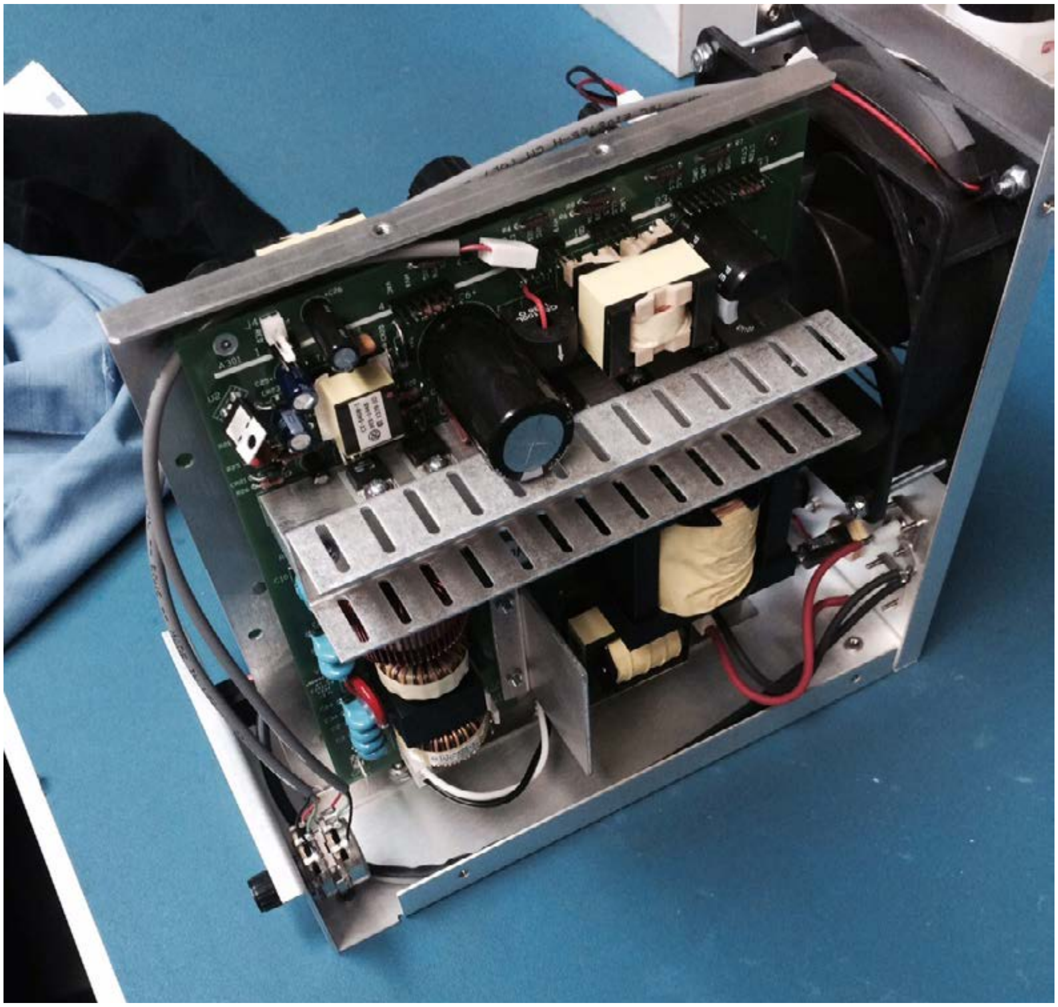
1,000 kHz (1 MHz): Megasonics

When using frequencies of 1 MHz (1 million cycles per second) or higher, ultrasonic technology becomes megasonic technology. The energy is created using the same type of generator, just at a much higher frequency. The resulting cavitation is gentler and more controlled; only the side of the part facing the cleaning unit's transducer is affected. This reduces or eliminates cavitation erosion and the risk of surface damage to the item being cleaned. Megasonic generators can be used when cleaning semiconductor wafers and industrial parts, but most frequently they are used when preparing silicon medical implants.

ANALOG VS. DIGITAL GENERATORS

It's important to note that all **ultrasonic generators (Fig. 5)** are generally analog in design. In a typical unit, all or most of its components are analog, including resistors, capacitors, transformers and inductors. The nature of the technology allows a more simple mechanical design and the use of digital technology does not enhance the effectiveness of the ultrasonic cleaning process.

Digital technology becomes useful to consider regarding circuitry and manufacturing—the machine's controls and communications. While manual controls are still common and effective on ultrasonic units, microprocessing chips can be installed and programmed to control all or part of the machine's adjustable levels, including frequency, frequency sweep modulation and waveform patterns.



(Fig. 5) Side View on an Exposed Internal Ultrasonic Generator Unit

TYPES OF ULTRASONIC CLEANERS

Ultrasonic cleaning units come in a variety of sizes, based on the intended use of the machine. Their tanks are typically made of stainless steel and are rectangular in design. Transducers are mounted, placed or welded to the tank, most often to the bottom, but units can be customized with side-mounted, hanging or bulkhead-mounted transducers.

TABLE TOP ULTRASONIC CLEANERS

These units are small enough to sit on a table, shelf or workbench and be moved easily. They are simple in design, with single tanks ranging in size from half-gallon to 8 gallons and higher frequency levels (though 40 kHz is the most prevalent), making it safe for even very delicate items. They are intended primarily for lighter duty applications, including optical parts, small gears, machined parts, bearings, surgical instruments and carburetor components.

BENCH TOP ULTRASONIC CLEANERS

These units have the small size and mobility of tabletop machines, but provide larger capacity options and more cleaning power. The typical frequency used is 40 kHz, but this style of unit also can be custom built at lower and higher frequencies. Bench top units can have tanks as large as 20 gallons, which make them more suitable for high volume. They can be used even in extreme environments, such as out at the site of a natural disaster or wildfire. Bench top tanks are designed for tough or unusual cleaning jobs, and are often used in the machining, automotive, marine and 3D printing industries.

LARGE-CAPACITY INDUSTRIAL ULTRASONIC CLEANERS

The largest ultrasonic tanks can include tanks as big as 1,000 gallons or more. These units are meant for applications requiring lower frequencies (25-40 kHz), including larger or heavy duty equipment such as over-sized manufacturing parts, automotive and marine parts and large musical instruments. Units may have multiple built-in stages, including rinse and dry stations, and are sometimes automated.

PART 5

SOLVENT-FREE CLEANING

During the 1980s the level of understanding about ozone depletion and various chemicals and gases that contributed to it grew rapidly. In 1987, leaders from many countries signed the **Montreal Protocol on Substances that Deplete the Ozone Layer**. It established legally binding controls on the national production and consumption of ozone-depleting substances (ODS) and, if it continues to be successful, will significantly phase out production and consumption of ODS before the middle of this century.

With the implementation of the Montreal Protocol over time, restrictions or bans on the chemicals often used for high-level cleaning, including solvents like 1,1,1-trichlorethane, carbon tetrachloride (tetrachloromethane) and Freon, are increasing. Organizations of all kinds need to find alternative cleaning methods that are effective without the use of harsh chemicals. Many are turning to ultrasonic technology.

Ultrasonic cleaning machines typically use water only, a water-based soap solution or a mild solvent. This largely depends on the material of the item to be cleaned or the contaminant being cleaned from it.

CLEANING SOLUTIONS

As ultrasonic cleaning technology was developed, it was discovered that if surface tension is reduced, cavitation levels increase. Cleaning solutions used with ultrasonic cleaning machines contain ingredients specially designed to increase the effectiveness of the process. These are called surfactants and they lower the surface tension of water.

General-use Soap Solutions
These solutions have a high alkaline content and are designed to remove a number of contaminants from metals, plastics and fabrics, depending on their formulation. Soap-based metal cleaners will remove oil, grease and carbon deposits. Those formulated for use with plastic and fabric items won't clean oil-based deposits from these materials.

Descalers

[Descaling detergents](#) are formulated to clean metals laden with corrosion, rust, hard mineral deposits or heat scale. They are designed to help restore parts that have been in service in hard water or high-humidity environments. These solutions are acidic in nature.

Enzyme Detergents

Enzymes are used to degrease stainless steel, aluminum, brass and titanium parts, and can be more effective than general-use soaps when removing oil and grease. They are designed to clean heavily oiled surfaces when an oil-free environment is preferred or required. They also can be used effectively to remove biological contaminants from medical, surgical, dental and optical tools. Enzymes typically consume oil residue and digest it off as carbon dioxide.

Low pH Cleaners

Low pH (Fig. 6), or acidic, cleaners come in a number of formulations and can be helpful in several ultrasonic cleaning applications. Citrus-based cleaners clean and protect metals from the effects of chemicals. Some of the stronger low pH cleaners may damage certain materials, specifically aluminum, copper and brass. Citric acid solutions are used to passivate stainless steel and titanium by removing the free iron molecules from the surface of the metal to help prevent future corrosion such as rust.

(Fig. 6) Our LpH ultrasonic cleaner solution

Specialty Detergents

Some solutions are formulated to clean specific contaminants like smoke, soot and certain odors. Although these specialty detergents will work very effectively when used in certain application, they can be harmful or ineffective when used outside of their intended use.

There are several additional considerations when determining if or how to use solutions with your ultrasonic cleaning application:

LONGEVITY

Some solutions have a longer lifespan than others, which helps decrease long-term cost, but all solutions have their pros and cons. For example, when removing oil and coolants, users must choose between using an emulsifier solution or separating detergent. An emulsifier holds oil in suspension within the fluid so it does not float to the surface of the fluid in the tank. It is more effective at removing the oil, but it doesn't last as long; once the solution is saturated with oil, it is no longer effective. A separator can remain effective for up to three months or longer. However, it cleans less effectively and, since oil rises to the surface of the tank, users risk recontamination during item removal unless filtration systems—overflow weirs or surface spargers—are added to the unit.

DISPOSAL

Most ultrasonic cleaning baths are environmentally friendly and water-based, but, depending on the solution used and the contaminant removed, various methods of waste disposal may be required. Most ultrasonic cleaning baths are 92-95 percent water, and wastewater evaporators will reduce the amount of material requiring disposal by that amount. These solutions also often can be effectively neutralized or filtered until it can be released into the sewer system safely and legally. Some companies pay waste management firms that dispose of their materials in drums.

HEAT

Solutions are often used in combination with heat, which effectively eliminates entrapped air in the water tank. For most applications, a temperature of 122-149 °F (50-65 °C) is effective. However, for some medical applications it is generally accepted that solutions should be used at temperatures below 100 °F (38 °C) to prevent protein coagulation.

TYPES OF METAL & THEIR CONTAMINANTS

Metal	Components	Potential Contaminants
aluminum, zinc	castings, open-mesh air filters, used automotive carburetor parts, valves, switch components, drawn wire	chips, lubricants and general grime
copper, brass, silver, gold, tin, lead, solder	printed circuit boards, waveguides, witch components, instrument connector pins, jewelry (before and after plating), ring bearings	chips, shop dirt, lubricants, light oxides, fingerprints, flux residues, buffing and lapping compounds
iron, steel, stainless steel	castings, stamping, machined parts, drawn wire, diesel fuel injectors	chips, lubricants, light oxides
iron, steel, stainless steel	oil-quenched, used automotive parts; fine mesh and sintered filters	carbonized oil grease, carbon smut, heavy grime deposits
iron, steel, stainless steel	bearing rings, pump parts, knife blades, drill taps, valves	chips; grinding, lapping and honing compounds; oils; waxes and abrasives
iron, steel, stainless steel	roller bearings, electronic components that are affected by water or pose dryer problems, knife blades, sintered filters	buffing and polishing compounds; miscellaneous machining, shop and other soils
magnesium	castings, machined parts	chips, lubricants, shop dirt
various metals	heat-treated tools, used automotive parts, copper-clad printed circuit boards, used fine-mesh filters	oxide coatings

(Source: Ultrasonic Cleaning, Tool and Manufacturing Engineers Handbook, Vol. 3, Materials, Finishing, and Coating, C. Wick and R.F.Veilleux, Ed., Society of Manufacturing Engineers, 1985, p. 18-20 to 18-24)

DESIGN CONSIDERATIONS

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There are important considerations when choosing or designing an ultrasonic cleaning system. All of these items help determine the tank size, frequency (generator and transducer) and other retrofits required, as well as whether a solution, with or without heat, may be effective during cleaning.

PARTS TO BE CLEANED

What the parts are, what they do, their size and shape, how intricate or delicate they are and what they are made of all come into play. Generally, smaller tanks require more watt density, or watts per-gallon of fluid. The larger the tank, the less watt density is needed. Tanks larger than 25 gallons usually will work with 25 watts RMS/Gallon or 50 watts peak.

Plastic absorbs sound, so you may need more ultrasonic power to cavitate through the parts. If items are large, you may need more power to overcome that extra mass. If heavy mass parts have most of the threaded holes on vertical surfaces, then an ultrasonic unit with **side-mount transducers** is best. If you are talking about a plating line application that is very deep with small parts hanging from a tree-style bracket, putting transducers on the bottom will perform very well on the items toward the bottom of the tank. However, these same transducers can be somewhat ineffective on the items on the top. Some applications are complex enough to warrant side- and bottom-mount transducers.

CONTAMINANT TO BE CLEANED

If the job to be done is cleaning oils, water-based coolants and light dirt, either a system with **bottom-mount transducers** or **bottom-mount direct bond transducers** will be effective because oil floats and there isn't much dirt to settle to the tank bottom. However, direct bond transducers are fixed to the tank bottom so when you look at the inside bottom of the tank, it is flat.

With **immersibles**, the **transducers (Fig. 7)** are mounted inside a housing that is 4 inches thick and bolted to the bottom of the tank. If you are cleaning heavily soiled items with a lot of dirt, grime, carbon, etc., the dirt falls to the bottom of the tank. In a direct-bond system the dirt will lie on top of the transducers and muffle the sound. This causes the cleaning performance to erode rapidly. Heavy dirt falling to the bottom of the tank with immersibles will accumulate around the transducer sides and will affect performance for a much longer period of time.

(Fig. 7) A fully assembled direct bond piezoelectric transducer

POWER CONSIDERATIONS

Typically ultrasonic generators come in **single-phase 120Volt AC** or **single-phase 240Volt**. If the facility supply is a **3 phase 240** volt or if the heating circuit necessitates so much heat that a 3 phase is required, the equipment can be built so that it is fed with **3 phase/240VAC**, but internally the generators tap off from 2 legs of the 3 phase legs. If a **3 phase 480 Volt power system** is the only voltage available, then a **step down transformer** is necessary. If a **single-phase/208VAC** is the only thing available, the 240V ultrasonic system will operate without harm, though some manufacturers' products will operate 10-17 percent below peak performance. This can be remedied with a **buck-boost transformer**, which is not terribly expensive. Generators with universal input and a unity power factor will have no degradation of the output power waveform from 120 – 240 Volt AC.

BASKET REQUIREMENTS

Basket choice is important because flat solid surfaces absorb sound and decrease the performance of the ultrasonic technology. Baskets should be made from round rod material to more efficiently reflect sound waves. Most applications make use of **immersion baskets** with 1″x1″ mesh. Smaller parts will necessitate either a tighter mesh basket or a sub-basket with a tighter mesh to fit inside the larger basket. Also, if parts are easily scuffed and cannot have metal-to-metal contact, baskets can be lined with vinyl. If parts can't touch each other, the basket will require spacers or guides to avoid parts contact.

SPECIAL FUNCTIONS

Depending on the cleaning job to be done, heat may be required. This can be controlled through either **analog or digital controls**. Ultrasonic activity heats liquid, so if a maximum temperature cannot be exceeded, the ultrasonic circuit, the heat circuit or both must shut off. Another option is a constant flow into and out of the tank of cooler flowing fluid.

With some contaminants, especially oils, **filtration systems** may be necessary. When using an emulsifier solution, oils and other particulates will float suspended in the tank solution or sink to the bottom. A pump must pull them from the main tank. If using a separator solution and only floating oils are present, an **overflow weir** is necessary to push fluid in from the surface of the bath through a set of filters in a closed loop process. A diverter valve can accommodate filtering from the overflow weir, the main tank or both simultaneously, depending upon the position of the valve.

Primary filters typically clean 10 to 50 micron to remove dirt particles before passing into a charcoal **secondary filter** to eradicate oils. Charcoal filters have a 3-micron discharge so it is optimal to pre-filter as much dirt as possible before beginning the cleaning process. In applications dealing with primarily suspended dirt, it is best to use micron filters in both cartridges.

Control systems give users the ability to control the volume or intensity of the ultrasonic action in the cleaning unit. This is sometimes necessary if wide assortments of parts are being cleaned.

Portability and maneuverability functions may be required. With smaller units, wheels or other specially designed retrofits can be added. But for larger machinery, moving the unit for cleaning, rinsing and draining typically requires a forklift, or possibly a pallet jack.

Users may require **automation**. Options such as bells, alarms, and dual output timers that automatically cycle a filtration or flush after an ultrasonic cycle will work if the application calls for it. However, basic batch machines are best left to be simple, low option units as these make them easier to work with.

LOCATION & ENVIRONMENT CONSIDERATIONS

An ultrasonic generator should never be in a room that has strong atmospheric acids, such as a plating line, which will corrode internal components. In this case, generators should be fitted with extended coax cables and be housed in a separate room. Equipment must be built to handle the overall moisture in the room where it is located. Circuit boards should be blown off occasionally, and generators also should be housed in a climate-controlled electrical housing.

MULTI-STAGE OPTIONS

Many applications require more precise cleaning and rinsing that can only be accomplished in more than one stage. The number of stages required is determined by the application, the type of filtration necessary in each stage and whether a final hot air dryer stage is necessary. Robotics also can be used to move parts baskets seamlessly from stage to stage with minimal labor.

Two-stage systems are a common design for multi-stage systems, though **three-** and **four-stage systems** are very popular. Two-stage units don't affect simplicity of use or portability. The first stage is an ultrasonic wash using a detergent followed by either a heated rinse to remove soap residue or a heated ultrasonic water rinse to ensure better final cleanliness.

Because of part complexity or the chemical make-up of the contamination, some applications may be more effective using multiple wash cycles differing in chemistries or rinse cycles. Complex industrial items with intricate multi-threaded blind holes or requiring a higher degree of final cleanliness should also go through a rinsing process, preferably heated. Depending upon the level of cleanliness needed, the secondary rinse may be helped by adding ultrasound to remove residual debris and remaining soap residue.

CLEANING & MAINTENANCE

Ultrasonic cleaning machines contain unusual technology, and they require a certain amount of care and maintenance to ensure their effectiveness, efficiency and long life. It is best to consult with a machine's manufacturer about ongoing care and any long-term maintenance and repair services available through the company.

Where the machine is to be located in any facility is an important consideration, especially if it is to be used in an industrial application. Warehouses and manufacturing facilities can include a lot of temperature variation and numerous environmental factors that can affect the ultrasonic technology.

Ideally, generators should be self-contained in the ultrasonic equipment housing to protect them from the environment and to keep coax cables from being exposed. Exposed **coax cables** are often damaged when tripped on, cut or run over by forklifts, which could result in damage to the generators.

PART 9

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