New Ultrasonic Technology – Multi-Frequency Transducers, Precise Digital Waveform Control and Compact, High Efficiency Power Supplies.

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Abstract

Recent advances in ultrasonic cleaning hardware have opened new opportunities for this useful technology in the plating industry. Ultrasonic frequency, identified as a major variable in applications requiring the removal of small particles from surfaces, continues to grow in range. Ultrasonic frequencies up to 170kHz are now readily available with higher frequency equipment already in use in some critical applications. Recognizing the benefits of lower frequencies for the removal of larger particles and the enhancement of chemical cleaning, equipment capable of generating a variety of frequencies from a single transducer bank in a controlled fashion has been developed. Precise delivery of frequency and waveform are combined to achieve the ultimate in cleaning while eliminating the possibility of exciting resonant modes of vibration in parts. Ultrasonic power supplies, once limited to 1,000 watts in a single unit are now available in 4,000 watt modules which reduce equipment size, complexity and cost in large applications.

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Introduction

In the finishing industry, ultrasonic cleaning has been found most useful in applications requiring the effective removal of contaminants such as buffing compound, lapping compound and other contaminants not easily removed using alternative means. It is especially useful in cleaning parts which can not be cleaned using normal electrocleaning processes. Its usefulness has also been demonstrated in rinse tanks where effectiveness of a rinse can be greatly enhanced by adding ultrasonic energy. In many cases, one or more rinse tanks can be eliminated or water flow reduced through the enhancement provided by ultrasonic energy.

Ultrasonics –

Briefly, ultrasonic sound waves in a liquid cause cavitation bubbles to be generated throughout the liquid volume. These microscopic bubbles form in the negative pressure portion of the sound wave and collapse or "implode" when positive pressure replaces negative pressure as the sound wave advances. The effect of cavitation bubble implosion is microagitation of the liquid in the vicinity of the cavitation bubble collapse which both mechanically dislodges particles and promotes the intermixing of liquids. Although the effect from the collapse of each cavitation bubble is very small, the forces involved are quite large and, in fact, provide temperature and pressure conditions very much like those found on the surface of the sun - - but in a very minute volume.

Historically, the options for ultrasonic energy were very limited. Most manufacturers offered units operating at discrete frequencies in the range of from 20 to 65kHz. Options included power control and, more recently, pulse or "duty cycle" modulation which was found to enhance cleaning performance. The revolution in ultrasonic cleaning systems began when a revolutionary unit was introduced in 1988 that[*] provided the capability to vary the driving frequency of the ultrasonic system in a controlled way to minimize the effect of standing waves. When it was first introduced, this new technology was, not surprisingly, relatively expensive to acquire and found application primarily in "precision" applications where its use was mandatory. The higher cost could be justified in reduced part damage and higher product yield. The introduction of sweep technology marked the beginning of digital waveform synthesis in the ultrasonic cleaning industry. Total control of the ultrasonic waveform was within reach.

Multiple Frequency Transducers –

Meanwhile, as part of the quest for effective frequency sweep, ultrasonic transducers were developed which could be operated over a wider frequency range than those relying on a sharp mechanical resonance to amplify and deliver ultrasonic energy into the cleaning liquid. Ways were also found to make ultrasonic transducers able to resonate effectively at more than one frequency. The use of a multiplicity of ultrasonic frequencies was found useful in removing particles with a wider range of sizes without causing damage to the part surface.

Digital Waveform Generators –

Ultrasonic generator technology has also seen rapid advance in recent years. In order for the new digital waveform technology to be effective, multiple transducers in large tanks must be

[*] sweep SONIC™ Systems, Ney Ultrasonics

synchronized to produce the same waveform throughout the tank. This is accomplished through the use of a master/slave arrangement with one master generator providing the driving signal to a number of modular slaves which each power one or more banks of ultrasonic transducers. Slave generators are now available which are capable of delivering up to 5,000 watts of ultrasonic power from a single source. Simultaneous operation of a number of such sources makes the size range of ultrasonic tanks nearly unlimited.

"All very interesting," you may say, "but how does all of this relate to the use of ultrasonics in the finishing industry?" - - The use of ultrasonic cleaning has been promoted to the metal finishers for years. There have been a number of successes but also a few failures. Failures constitute situations where parts could not be effectively cleaned and those where parts were damaged by the cleaning process. Other "failures" were applications where the use of ultrasonics could not be cost justified. The advances referenced above and their extensions offer new opportunity for the wider application of ultrasonic cleaning in the metal finishing industry.

Removal of Smaller Particles Using Higher Frequency Ultrasonics

Contaminants on surfaces to be finished are often very complex. They consist of both soluble and particulate residues that in some cases may trace all the way back to the very first steps of manufacture. Soluble contaminants may include, among other things, drawing lubricants, machining lubricants, mold release agents and other materials left as a result of processing, handling and storage. Soluble materials are generally dissolved or emulsified by the cleaning chemistry. In the case of soluble contaminants, the major role of ultrasonics is to supply mechanical energy to assure that there is sufficient interface interaction between the chemistry and the contaminant being removed.

Contaminants also, however, often include particles. Major sources of particles include any machining operation, abrasives, and residues of buffing and lapping compounds. Particles commonly range in size from a fraction of an inch in any dimension down to one micron or less. Particles are a challenge to remove because they are held in place by adhesive, cohesive, and/or ionic forces. Successful removal of a particle consists of breaking any bond holding it in place and moving it far enough from the surface to prevent re-attachment. Large particles are relatively easy to remove. Once any bonding agent is eliminated, the particle will fall free from the surface as its own weight overcomes any attractive forces holding it in place. As particle size becomes smaller, successful particle removal becomes more reliant on the delivery of sufficient mechanical force to accomplish the task. Two things working against the delivery of mechanical energy to very small particles are the size of the cavitation bubbles and the thickness of the boundary layer in an ultrasonic field at relatively low frequencies. Smaller particles are removed more efficiently by higher ultrasonic frequencies due to the smaller bubble size and the thinning of the boundary or "stagnant" layer immediately adjacent to the substrate.

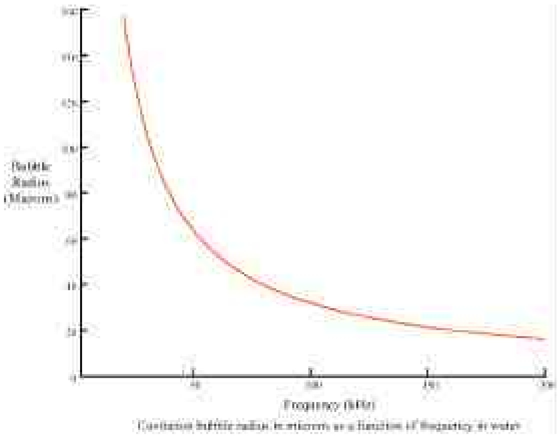

Figure 1 – Bubble size decreases as ultrasonic frequency increases

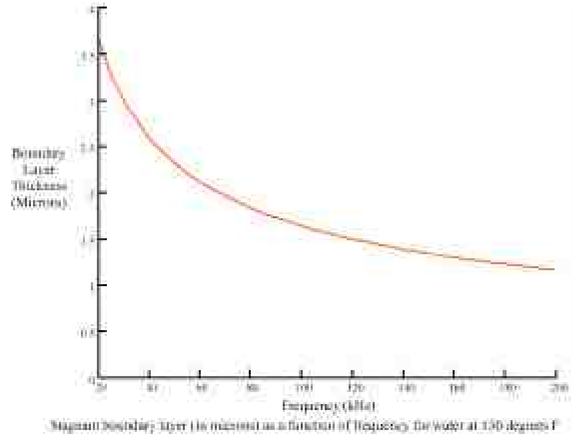

Figure 2 – The boundary or "stagnant" layer decreases in thickness as frequency is increased

As ultrasonic frequency is increased, cavitation bubble size is reduced. Smaller cavitation bubbles, although they do not deliver as much energy, can form and implode in very close proximity to small particles and with an advantageous force angle. A force angle parallel to the substrate is more likely to break a particle free than a force angle normal to the substrate.

Multiple Frequency –

Although it is easy to make a case for the use of higher frequencies to remove very small particles, the fact remains that the smaller cavitation bubbles formed at the higher frequencies do not deliver as much energy per event as do the larger bubbles produced at lower frequencies. Some removal mechanisms are threshold dependent and will not occur at all unless a specific energy threshold is reached. Interface displacement between a soluble contaminant and a solvent, for example, may occur very slowly (or not at all) with the low energy peak delivered by the implosion of very small cavitation bubbles. To get the benefit of both low and high frequency ultrasonic energy, the use of both is indicated. This can be accomplished using multi-frequency equipment that is now available.

Elimination of Part Damage Mechanisms

It was mentioned earlier that part damage has been one of the obstacles to the application of ultrasonic cleaning in the finishing industry. Part damage manifests itself in two primary ways. The first is cavitation pitting or "burning" which results from the intense energy generated by the implosion of cavitation bubbles. The second is part failure due to fatigue as a result of sympathetic vibration of the part at a resonant frequency.

Cavitation Burning –

When cavitation bubbles implode, very high pressures and temperatures are generated in a "jet" which emerges from the site of the implosion and travels preferentially in the direction of any adjacent surface. On soft materials including aluminum, brass and copper, the surface of the part may be etched by the combined effect of a large number of cavitation bubble implosions. The effect of cavitation burning is most evident on highly buffed surfaces which, of course, are often the surfaces requiring the highest level of cleanliness. It doesn't take much of a defect to be highly visible when it is reflected from a mirror-like buffed surface.

In order to reduce the intensity of the cavitation implosion to eliminate cavitation burning it is necessary to change either the properties of the cavitating liquid or the properties of the ultrasonic wave generating the cavitation bubbles. Although cavitation erosion has been successfully eliminated in many cases through careful selection of chemistry and operating temperature, the manipulation of the ultrasonic wave to reduce the size of the cavitation bubbles and, therefore, their implosion intensity proves a much more effective and controllable alternative.

Power Control –

The size of the cavitation bubbles produced in an ultrasonic field is somewhat dependant on the amplitude of the sound wave that generates them. Control of the sound wave amplitude is not a new innovation and still serves as one of the alternative means in reducing cavitation burning.

Increasing Frequency –

Increasing the ultrasonic frequency results in a larger population of smaller cavitation bubbles which, individually, implode with less intensity although the aggregate energy delivered may be maintained. Increasing frequency, then, is another way to eliminate the cavitation burning effect. Smaller cavitation bubbles do not individually achieve the threshold energy level required to initiate the cavitation burning effect.

When the ultrasonic frequency is increased, however, the cleaning effect may suffer as a result. Removal of some contaminants is, like cavitation burning, dependent on a certain threshold level of energy being achieved. This was the fate of some sensitive applications when only discrete frequency ultrasonic sources were available. Fortunately, these effects are also at least somewhat time dependent. In short, exposure at a specific frequency for a controlled period of time may provide effective cleaning without initiating cavitation burning.

Digital waveform synthesis allows very precise delivery of ultrasonic energy at a variety of ultrasonic frequencies, power levels and times facilitating cleaning without cavitation burning.

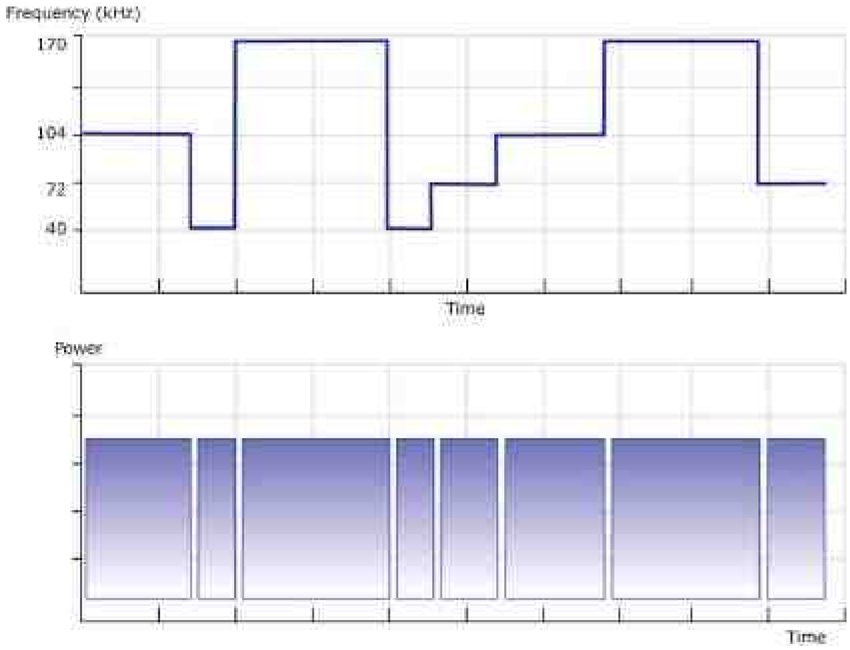

Figure 3 – Precise control of ultrasonic frequency and time prevents part damage due to cavitation erosion.

Part Resonance –

Nearly any part geometry will exhibit resonance at one or more frequency within the mechanical vibration spectrum ranging from below 1 hertz up to the physical limits of mechanical vibration. Although it is unlikely that larger parts will resonate at the primary ultrasonic frequencies normally used for cleaning, there have been cases where parts have been excited at lower frequencies which result from the introduction of fixed period sweep and duty cycle modulation on the ultrasonic frequency waveform. In the case of sweep, a high energy peak of power is generated at a frequency double the sweep rate as the transducer is excited by its preferred driving frequency twice during each sweep cycle. In the case of duty cycle modulation, a high peak power is introduced into the cleaning system each time the primary frequency is switched on. These frequencies are well within the range of frequencies where one would expect to see resonance in typical parts processed by the metal finishing industry.

When a geometry resonates, a runaway vibration is initiated which may eventually exceed the elastic or fatigue limit of the material thereby causing permanent deformation or a fracture . Parts that are especially susceptible to damage due to resonance are those with large flat surfaces, finger-like protrusions, and/or thin cross sections. Automotive trim pieces, wheels, and decorative hardware, for example, are good candidates for damage due to this effect.

In order to eliminate damage due to part resonance, it is necessary to remove any source of regular, recurring vibration. This can be done by randomizing both the sweep and amplitude modulation rates. When applied with random periods, sweep and amplitude modulation can not act to excite parts into resonance.

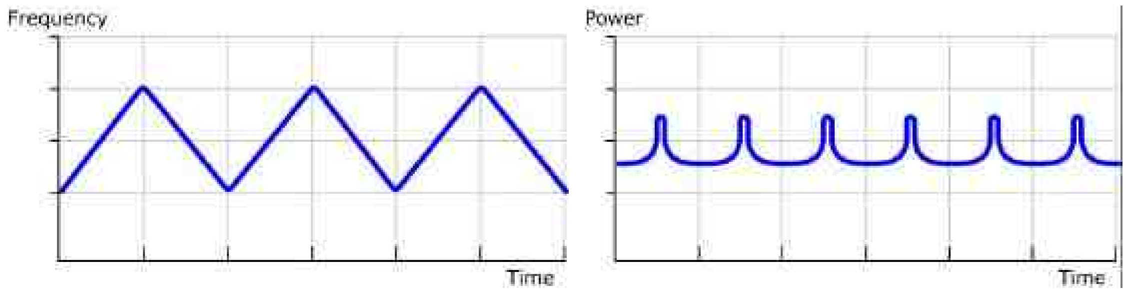

Figure 4 – A constant sweep frequency results in regular power peaks at twice the sweep frequency. These regular power pulses may excite sensitive parts into mechanical resonance.

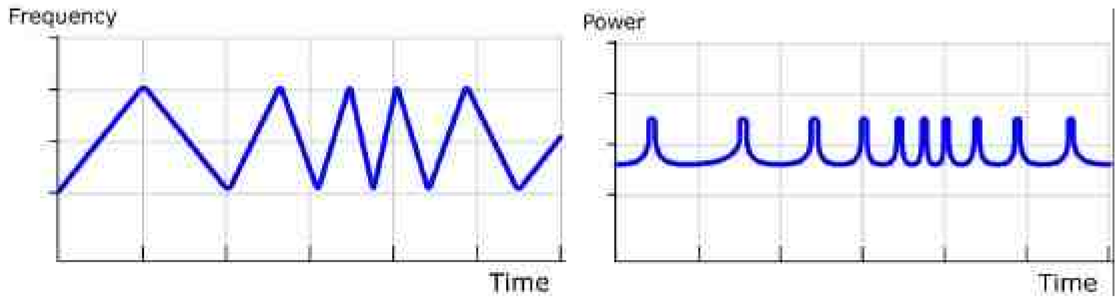

Figure 5 – Randomizing the sweep frequency eliminates regular power peaks thereby eliminating the possibility of damage due to part resonance.

Larger System Capability –

Large process tanks require powerful ultrasonic systems capable of delivering several, if not tens of thousands, of watts of ultrasonic power. In the past, large systems have been provided through the use of many, modular generator/transducer packages. The modular generator systems occupied considerable valuable floor space. Individual ultrasonic generators are now available that can each provide several thousand watts of power from a single chassis. This power may distributed to several discrete transducers which are positioned in the cleaning tank to provide the energy distribution required for maximum cleaning effect. Large systems can now be powered from a small cabinet on the same order of size as a typical rectifier package. In order to provide the digital waveform control discussed above, it is necessary to synchronize all of the ultrasonic transducers in each process tank. This synchronization is facilitated by the use of fewer, more powerful generators all driven from a single master control module. In addition to being smaller, these systems are easier to install and less costly than modular generators and the associated electrical enclosures and controls they require.

Summary –

Ultrasonic cleaning hardware is changing to meet the needs of the metal finishing industry. Equipment presently available is state-of-the-art, robust and overcomes earlier obstacles at an affordable price.