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Intelligent Ultrasonics for the Disk Drive Industry, Renuka Rodrigo, PH.D. and Timothy Piazza, PH.D., September 2000

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Maximize cleaning performance, minimize damage with breakthrough “Designer Waveform” technology.

Ultrasonics has been a mainstay in the cleaning of disk drive media and disk drive components for many years. Historically, the application of conventional ultrasonics has provided the appropriate cleanliness levels but has opened the process up to the possibility of damage in both disk media and components from cavitation erosion and sympathetic resonance.

Recently, as head fly heights have progressively decreased (currently on the order of tens of nm), cleanliness specifications have increased and tolerable defect size has decreased. This fact has contributed to new developments in ultrasonics along two important lines: higher/multiple operational frequencies and the development of “Designer Waveforms”1

These developments work hand in hand toward increased particle removal efficiencies, well into the submicron range, and the elimination of damage. This article will discuss these two developments, their physical underpinnings and their effect on particle removal and damage elimination.

Physics of Cavitation

Ultrasonic cleaning is, at its heart, characterized by the creation and subsequent collapse of microscopic bubbles within a liquid. This phenomenon is known as cavitation. Cavitation is one of nature’s most efficient and dramatic amplifiers of energy density currently known. During sonication a tank of liquid at room temperature, with <100 W/gal. of ultrasonic energy, is populated by a high-density field of cavitation events. Each bubble collapse is accompanied by the local generation of temperatures on the order of thousands of ÞK and pressures exceeding hundreds of atmospheres. Though this collapse has been recognized for almost a century, physicists have yet to construct a complete description of it.

It is the oscillation and subsequent implosion of cavitation bubbles that affects the bulk of the cleaning associated with ultrasound. As such, manipulation of this event alters the character of the cleaning accomplished by ultrasonics. Though much of the final implosion event is shrouded in mystery, the bubble dynamics prior to this is quite well understood.

For the purposes of cleaning, the important parameters are the amount of energy released in a cavitation event, and the density of cavitation events. These parameters have a simple relation based upon bubble size. As the bubble radius increases, the energy released at implosion also increases. With a constant power input into a liquid, this means that the larger the typical bubble, the fewer total number of bubbles there will be per unit of time. An equivalent way of saying this is to say that bubble radius is proportional to implosion energy and inversely proportional to bubble density. Armed with this knowledge, we can customize cleaning by modifying bubble radius, and thus the energy in each event, as well as the number density of events.

The most effective way of doing this is by changing the frequency of insonation. Low frequencies allow bubbles plenty of time to grow large, while high frequencies give cavitation bubbles only little time to evolve. Controlling the energy in each cavitation implosion is important to prevent pitting or craters on the surface of the substrate being cleaned.

From a cleaning perspective, there is much research on particle removal efficiencies (PRE) at different frequencies. It is observed that low frequency ultrasound has superior PRE for large particles, and that high frequency ultrasound is best suited for submicron particle removal. Thus, in an optimized single process, one would employ low frequency ultrasonics (few, high energy events) to remove large particles and /or gross contamination, and high frequency ultrasonics (many small low energy events) to remove submicron particles. This constitutes the ideal cleaning process, in which a part can be exposed to relatively low frequency ultrasound, i.e. 40 or 72 kHz, for short amounts of time and then to high frequency ultrasound, i.e. 104 or 170 kHz for long times. Such a process would avoid the damage often associated with low frequency ultrasonics but run the gamut from large to submicron sized particles, in excellent particle removal efficiency. The most recent technological advances in ultrasonic systems allow such a processing scheme to be realized. There is a new class of liquid cleaning and processing equipment in which there is one transducer array and one generator that produces ultrasound at the primary resonance, or one of a number of overtones, of that transducer array for some given period of time. After this programmed time the frequency then discontinuously jumps, as specified by the process engineer, to a different overtone of the transducer array for some other specified time before discontinuously jumping to a third overtone, and so on.

Designer Waveforms

Since Ney Ultrasonics' introduction of sweep frequency to the ultrasonic cleaning industry in 1988, much has been learned about the way the characteristics of a cavitating fluid can be modified by altering the driving signal of a transducer. We call this approach "Designer Waveforms." Intelligent ultrasonics no longer focuses on a generator or on a transducer in isolation. Instead, a more holistic view is needed, one that focuses on the entire cleaning process. The relevant questions to be asked are,

• How does the generator impart energy to the transducers?

• How do the transducers impart that energy to the cleaning solution?

• What degrees of freedom are excited in the cleaning system?

The cleaning system is composed of both the cleaning solution and the part or parts being cleaned. When this is understood, the designer of intelligent ultrasonics knows that the way ultrasonic energy excites a part can be at least as important as how it excites the cleaning solution. One can then identify potential damage modes and ensure that they are eliminated.

There are many ways to alter the characteristics of ultrasonic waves in a liquid contained in a tank. The ultrasonic waves can be frequency modulated (FM) by varying the output frequency of the ultrasonic generator. The ultrasonic waves can be amplitude modulated (AM) by changing the amplitude of the generator output and/or by tailoring the impedance vs. frequency characteristics of the transducer array.

“Drive signal AM” refers to the time variation of the magnitude of the output of an ultrasonic generator. This can occur in multiple forms. The first, and most obvious, is that of square wave modulation. In this variation the output of an ultrasonic generator is kept constant during the duty cycle. This means that the output has a square wave shape. This is an interesting waveform for applications that are particularly sensitive or prone to cavitation damage. Square wave AM has a peak power that is equal to the average power delivered to the transducers during the duty cycle; this eliminates any spikes in the power delivered to the transducers. The second form of AM is characterized by a peak power that does not equal the average power. An example of this would be a sine wave or quarter sine wave modulated output. In both of these examples the peak power is significantly higher than the average power. Such an example of AM, particularly the quarter sine wave modulation with its high peak to average ratio, is particularly well suited for hard-to-cavitate fluids and rugged substrates.

When a typical Langevin type transducer is swept through a band of frequencies, the output power is not constant for each frequency. Generally, the output power of the generator peaks near the center of the bandwidth. When sweeping up in frequency, a peak pulse of power is put into the tank at the center of the sweep range. When sweeping down in frequency, another peak pulse of power is put into the tank at the center of this sweep range. This process continues producing equally spaced power pulses at a rate equal to two times the sweep rate. (See Figures 2 and 3 that show a conventional sweep rate graph and a graph of power into the liquid, each referring to the same time scale.)

Sweeping frequency, the most primitive type of FM, has had a major impact on the ultrasonic cleaning industry. When applied correctly, it improves the performance of an ultrasonic cleaner and generally reduces the damage to delicate parts caused by conventional ultrasonics. Figure 2 shows a graph of frequency vs. time for a typical sweeping frequency 104 kHz ultrasonic generator with a 4 kHz bandwidth and a 500 Hz sweep rate. Figure 3 demonstrates the periodic pulses of power that such a sweep scheme delivers to an ultrasonic system. These pulses peak when the sweeping frequency passes through the actual resonant frequency of the transducer array, i.e., the frequency where the response of the array is maximal.

One FM improvement to the conventional fixed frequency sweep rate is a non-constant sweep rate. This can be accomplished by making the sweep rate random, by changing the sweep rate as a function of time or, specifically, by linearly sweeping the sweep rate. This third variation, linearly sweeping the sweep rate, is referred to as dual-sweep. The main reason for a non-constant sweep rate is to eliminate any single frequency sweep rate from the system because a part being cleaned can be excited into resonance by two times the frequency of the single frequency sweep rate. Many delicate parts will fracture when excited into resonance.

If a delicate part has a resonant frequency at or near two times the sweep rate, the large amplitudes that the part goes through when it is resonated by the repetitive peak power pulses is likely to cause damage to the part. With an understanding that the resonance phenomenon is caused by repeatedly pumping energy into a part at its resonant frequency, it should now be obvious that a non-constant sweep rate will vary the spacing between the power pulses. Therefore, there is no fixed frequency at which the power pulses are supplied to the liquid and therefore, no repetitive single frequency to excite the part being cleaned into resonance.

By way of example, a leading manufacturer of suspension assemblies for hard disk drives was experiencing fatigue failure in the gimbal area during conventional ultrasonic cleaning. High-speed photography of the suspensions during cleaning revealed violent high amplitude vibrations induced in the suspensions to be the cause of these fatigue failures. These vibrations were at a frequency significantly below that of sonication, and it was concluded that a beat frequency was responsible for the damaged parts. A Designer Waveform was needed. On a test group, the introduction of a higher frequency and a generator featuring dual sweep technology (Figure 4 and 5) brought the incidence of failure from 39% at 30 min. of sonication to precisely 0%. At an extreme, the same equipment brought the incidence of failure from 93% at 300 min. of sonication again to precisely 0%. This was done with no penalty in part cleanliness.

Another Designer Wave form variation on conventional sweeping frequency is to monotonically sweep the frequency from high frequency to low frequency. This causes an ever-expanding wavelength in the tank. Figure 6 shows a frequency-vs.-time graph of a monotonically “up-sweeping” system. The ever-expanding ultrasonic wave characteristic of up-sweep puts an extra upward force on contamination in the liquid. Using bottom-mounted transducers on a tank with overflow weirs, this extra upward force helps the system purge itself of contamination.

Conclusion

The action of ultrasonic cleaning is a complex process affected by multiple variables. Indeed, any design that can be referred to as “Intelligent Ultrasonics” must consider the entire system, not simply its component parts in isolation. The most dramatic ways by which ultrasonic activity can be controlled and modified are through frequency selection and the so-called “Designer Waveforms.” Frequency selection at last allows the user control over the actual energy of each cavitation event. This is important for both the minimization of damage to sensitive substrates as well as for the optimization of particle removal. With the understanding that an ultrasonic system is composed of both the sonicated fluid as well as the immersed part, the Designer Waveforms approach strives to eliminate all possible damage modes that can be introduced into that system. Real world examples serve to illustrate that the way energy is transmitted to a fluid and to a part will determine whether that part is damaged during the cleaning process as well as dramatically change the cleaning performance of an ultrasonic system. Breakthrough technologies, such as multiple frequencies, sweep, dual-sweep, and up-sweep, promise to refine the current state of the art and offer cleaning performance and damage elimination never before realized from ultrasonic technology.

Reference

1 “ Designer Waveforms,” W. Puskas and T. Piazza, Ph.D., Proceedings, CleanTech 2000, Witter Publishing/Witter Expositions.

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