　　　　　Fundamentals of Ultrasonic Cleaning Technology and its Applications

　Automated ultrasonic deburring cleaning and polishing with cavitation technology

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1. What is ultrasonic cleaning technology?

A major reason for the 30-year stagnation of ultrasonic cleaning technology is a misunderstanding of the basic understanding of what ultrasonic cleaning is. Ultrasonic cleaning systems have made rapid progress in accordance with advances in peripheral technologies and user demands. Ultrasonic cleaning systems have rapidly progressed in accordance with advances in peripheral technologies and user demand, such as conveyor technology, instrumentation technology, and sheet metal welding technology. However, there has been no significant change in the basic content of ultrasonic cleaning technology, with a few exceptions. It cannot be said that there is a great difference between Japanese and Chinese ultrasonic cleaning technologies. Even if the appearance and transport technology change, ultrasonic cleaning technology will not be able to meet the demands of the times unless there is a fundamental innovation in ultrasonic cleaning technology.　In order to fully utilize the innovative ultrasonic cleaning technology that responds to the new era, it is first necessary to have a deep understanding of what ultrasonic cleaning is, why it removes contamination, and why it does not, and to dispel misunderstandings about its principles.

Ultrasonic cleaning is a cleaning method that emits powerful ultrasonic waves into a liquid and utilizes the impact force generated when cavities are created and extinguished. If cavities are not generated, it cannot be called ultrasonic cleaning. In other words, ultrasonic cleaning is a technology that uses cavities generated by ultrasonic waves for cleaning. Therefore, the basic requirement for understanding and effectively using ultrasonic cleaning is to correctly understand cavities and the phenomena of cavity generation and annihilation (cavitation).

A powerful sound wave of 20 KHz or higher, i.e., ultrasonic waves, is irradiated into the liquid. When the sound pressure changes above a certain level in the liquid, so-called cavities are generated. Cavities are composed of many vacuum nuclei (microcavities), and their overall size varies depending on the frequency and the magnitude of the sound pressure change, but at the practical level, the size ranges from about 100 microns to a few dozen millimeters. The shape also varies, and can be roughly divided into a gas nebula type **[Photo 1] and a** globular nebula type **[Photo 2]**. In order to distinguish cavities from cavities generated by sound pressure changes other than ultrasound, I call them cavities (microvacuum nuclei). Cavities (microvacuum nuclei) are repeatedly generated and annihilated as follows.

2. principle of ultrasonic deburring and cleaning - summary

When using 25 kHz ultrasound, the cavity [a group of microvacuum nuclei] reaches its maximum shape in approximately 5,000ths of a second after the onset and disappears in the next 5,000ths of a second. This is repeated 25,000 times per second. In the case of a spherical nebula cavity with a diameter of 10 mm, this means that a liquid volume of 10 mm in diameter moves away from the center of the cavity at high speed in 1/50000 of a second. I call the shock force generated at this time a positive shock wave. In the next 5000th of a second, the cavity disappears. This means that the liquid outside the vacuum core with a diameter of 10 mm reaches the cavity center in 1/5000th of a second. The shock wave generated at this time is called a negative shock wave.

When measured accurately, the speed of cavity generation and annihilation are not the same; annihilation is about 20% faster. In other words, the negative shock wave is larger.

Therefore, since the total impact energy of the cavity is due to the high-speed movement of the liquid, its kinetic energy is proportional to its mass and to the square of its velocity, which in this case can be said to be proportional to the third power of its diameter if the travel time is the same. Of course, it is not that simple, since one cavity is a collection of smaller vacuum nuclei, but it is clear that the size of the cavity has a significant effect on the magnitude of the positive and negative impact forces.

The ultrasonic deburring and cleaning technology removes burrs from their roots by stress fracture through the repetition of positive and negative shock waves - pushing and pulling - 25,000 times per second by a spherical nebula-shaped cavity attached to the burr. **[Figures 1-7]**

3. Importance of Cavitation Control

Since 1993, the author has referred to the early ultrasonic cleaners as the first generation of ultrasonic cleaners, which seemed to think that ultrasonic cleaning was possible if the cleaning object was placed above the ultrasonic transducer. Then, in response to the importance of cavities in ultrasonic cleaning, ultrasonic cleaners that attempt to control the cavities in the ultrasonic cleaning tank according to the purpose are called second-generation ultrasonic cleaners. Here, we will briefly discuss cavity control in second-generation ultrasonic cleaners. This is the basis of all design of ultrasonic cleaning systems and their application technology, and it is impossible to design a new era of ultrasonic cleaning without understanding and practicing this concept.

1. Control of cavitation generation position

In an ultrasonic cleaning tank (the same applies to ultrasonic spray), it is an extremely important basic technology to determine where and how cavitation is generated in a stable manner. The position and shape of the cavitation distribution are determined by the frequency, type of liquid, temperature, depth of liquid, placement of transducers, direction of liquid flow, temperature distribution, etc., as well as the type of material to be cleaned.　The basic distribution of cavitation can be horizontal, vertical, grid, even, or cylindrical, etc., depending on the purpose. The ultrasonic cleaning engineer and the user must clarify the purpose of each ultrasonic bath, and share the distribution of cavitation in each bath and the method of checking it. If the liquid depth is unstable or not theoretically supported, it can be assumed that the basics of cleaning design have not been established.

(2) Control of cavitation generation density

　Cavities in ultrasonic cleaning do not occur on a surface. They occur at points. There is a distance between cavities, and multiple cavities do not occur attached to each other. In general degreasing cleaning, however, the spaces between cavities cause defects in so-called precision cleaning. Therefore, efforts are made to increase cavity density in various ways. Or, efforts are made to increase the distance traveled by the cavities. We are accumulating detailed efforts in such areas as ultrasonic waveforms, oscillation efficiency, liquid injection efficiency, output per unit area, devising ways to attach vibrating elements, reducing the amount of liquid, and so on.

(3) Cavitation impact force control

If the positive and negative impact forces of the cavities are too weak, the cleaning cannot be done; if they are too strong, the object to be cleaned will be damaged, resulting in defective products. Naturally, if the impact force of the cavity cannot be controlled, it is impossible to design ultrasonic cleaning.　Recently, ultrasonic cleaning objects have become more and more precise and delicate, and the range of cavity selection has become narrower. However, if you have a better understanding of cavities in ultrasonic cleaning, you will have a better understanding of how to control the impact force. In general, the impact force of a cavity is proportional to the pressure of the liquid and inversely proportional to the frequency, vapor pressure of the liquid, and amount of dissolved air.　Since the cavity impact force is proportional to the mass of liquid that the cavity removes (attracts) in a unit of time, once the principle is understood, it is clear what to control.

Cavitation control is an important basic technology in ultrasonic cleaning equipment. It is impossible to introduce a new technology for ultrasonic cleaning without neglecting these, that is, without neglecting cavity control.

3. Third-generation ultrasonic cleaning technology

Let me now discuss ultrasonic cleaning, the backbone of the new technology. The principle is important, and the applications are unlimited, depending on the object. This is the basic technology that was first discovered and put to practical use by the author in the world during the CFC era, and has been refined and developed into ultra-strong cleaning, ultrasonic burr, ultrasonic polishing, and ultrasonic high-speed etching today. （Without precise cavity control, this cleaning technology will not produce the required performance, and in some cases will lead to the destruction of the ultrasonic transducer and a significant reduction in cleaning power. However, we believe that without this technology, innovation in cleaning technology for the new era would be impossible.

This method of controlling the content of gas dissolved in the liquid to maximize and utilize the impact force of cavities generated by ultrasound is called the third-generation cleaning technology Cavitation Enhancement System.

(1) Cavitation enhancement system

Ultrasonic cleaning equipment that controls the dissolved amount of air in a liquid according to the purpose, based on the premise of an ultrasonic tank that precisely controls cavitation, is called ultrasonic cleaning equipment with a cavitation enhancement system (third-generation ultrasonic cleaning equipment).　The ultrasonic cleaner with a cavitation enhancement system (third-generation ultrasonic cleaner) is called an ultrasonic cleaner with a cavitation enhancement system (third-generation ultrasonic cleaner). The ultrasonic cleaning technology of the future is inconceivable without controlling the dissolved oxygen content (hereinafter, for the sake of measurement technology, we will substitute dissolved oxygen). When the dissolved oxygen content is more than a few ppm, in other words, in the case of general water and water-based ultrasonic cleaning, **gas nebula cavities** are generated. In the case of **gas nebula cavities**, the speed of movement of the liquid at the time of cavity formation and annihilation is slow, and as a result, the impact force is extremely weak.　　In addition, the cavities themselves move only a short distance (within a few millimeters), causing severe cleaning irregularities.

(To avoid misunderstanding, the visible microbubbles generated by ultrasonic waves under atmospheric pressure have nothing to do with cavities, but are merely air bubbles that deter and absorb ultrasonic energy. They are simply ultrasonic gas aeration, hardly ultrasonic cleaning.)

Ultrasonic cleaners that utilize gas nebula type cavities are not suitable for the ultrasonic cleaning systems that will compete for precision in the future.　Therefore, ultrasonic cleaners of the future should use **spherical nebula cavities**. In the era of modern precision processing technology, it is necessary for us to master ultrasonic cleaning technology that uses this **spherical nebula cavity** stably and efficiently by controlling the amount of dissolved oxygen in the liquid, as well as the cavity enhancement system technology.

(2) Globular nebula-shaped cavity

In ultrasonic cleaning in the range of 20 KHz to 10 MHz, it is an absolute prerequisite to control dissolved oxygen to a low level and to use spherical cavities in order to achieve efficient precision cleaning.　Spherical cavities absorb and discharge a large amount of liquid per unit time, and the cavities themselves move at a high speed. Therefore, the cleaning power is the highest under the same conditions, and the diffusion effect (dirt transport effect by cavities) is also the highest.　The air entering from the liquid surface, the gas contained in the liquid itself, and the air on the surface of the object to be cleaned should be removed from the ultrasonic cleaning area, and the air content of the liquid around the object to be cleaned and between the object and the vibrating plate should be kept stable at less than half of its saturation level.　This is exactly the same if the ultrasonic irradiation utilizes a cavity, no matter what medium or what flow path it goes through.　How much oxygen (air) content is appropriate depends on the frequency of the ultrasound, the type and temperature of the liquid, and above all, the purpose of the cleaning. In order to use this technology stably and efficiently, it is not enough to simply degas the liquid, but it is necessary to strictly observe the aforementioned cavitation control. In Japan, many attempts have been made since the presentation of this technology by the author, and as a result, it must be considered that a similar product cannot be made yet, because of the lack of technology to comply with the cavitation control.

4, Applied technology - ultrasonic deburring, ultrasonic polishing

　　　The application of cavities (micro vacuum nuclei), which can reach 10 mm in diameter, does not stop at simply powerful unmatched ultrasonic cleaning. They are used in the manufacturing processes of automobile parts, electronic parts, medical parts, etc. as a deburring cleaning device after machining and precision molding of metals, plastics, ceramics, and their composite materials. Of course, deburring of tool cutting edges is an important market for **ultrasonic deburring and cleaning equipment [Photo 3].**

As can be seen from the principle, the target of ultrasonic deburring can be any material. Basically, it can be applied to almost all materials, including metals, plastics, ceramics, and their composite materials, although there are some degree of difficulty. In addition, it is not restricted by shape, the location of burr generation is multi-directional, and tolerance holes on the inner surface can also be targeted.

If the thickness at the base of the burr is approximately 0.1 mm, there is a high possibility that it can be removed. However, there are no practical examples of burrs made of soft materials such as rubber or silicone.

Deburring cleaning time ranges from less than 30 seconds to about 30 minutes. The deburring time is determined by the thickness of the root of the burr and other factors.

The number of pieces processed can be from one to tens of thousands at a time or continuously. **［Photo 6 (4)**

　This powerful ultrasound is also causing innovation in the world of barrel polishing. **Ultrasonic barrel finishing [photo 4]**. Instead of barrel finishing using media, there are reported cases of ultrasonic deburring, polishing, cleaning, and drying of 3,000 to 25,000 pieces at a time using only water and ultrasonic waves, without using media, such as bearing retainers and precision pressed parts for watches.