FUNDAMENTALS

OF

ULTRASONIC CLEANING

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HESSONIC

HIGH ENERGY SOUND SUPERSONICS

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INTRODUCTION

Ultrasonic cleaning offers several advantages over conventional methods. Ultrasonic waves generate and evenly distribute cavitation implosions in a liquid medium. The released energies reach and penetrate deep into crevices, blind holes, and areas that are inaccessible by other cleaning methods. The removal of contaminants is consistent and uniform regardless the complexity and geometry of the part being cleaned.

ADDITIONAL FEATURES:

1) SPEED, cleaning usually completed in 1 to 3 minutes
2) LABOR, Tremendous labors savings over conventional cleaning methods.
3) CHEMICAL, use lower concentration and milder chemicals to complete cleaning task. Does no have to be a low foaming chemical as required in most spray, agitation cleaners.

NOTE:

This paper is written in two parts. Part one contains information for basic knowledge on ultrasonic theory and chemistry. An asterisk (*) with a number will be found throughout part one on certain topics, these asterisks (*) with matching numbers will also be found in part two and will give additional information on the specific topic for those who require more in depth detail.

WHAT DOES ULTRASONIC MEAN

Before we go into the theory of ultrasonics lets first get a better understanding of what me mean by ultrasonic. A sound wave (may also be expressed as an acoustical pulse or pressure wave), which is beyond the range audible to human hearing, is the point at which ultrasonic begins. Since 18,000 Hertz (18,000 cycles) per second is the approximate upper limit or the human hearing range it is considered the point at which ultrasonic begins. Most like to refer to the ultrasonic range as a sound wave equal to or greater than 20 KHz or 20 Kilo Hertz, Kilo meaning thousand and Hertz (after H.R.Hertz) meaning cycle per second. Ultrasonic cleaning indicates it uses sound waves at or above the 18/20 KHz range.

PART ONE

Every ultrasonic cleaning system consists of three components.

1) ULTRASONIC GENERATOR
   The function of the ultrasonic generator is to utilize the available electrical power, usually 120 or 240 volt 60/50 Hertz, and convert it into a higher voltage and faster cycle to activate the transducer, usually 2000 volts at 40,000 Hertz for a 40KHz cleaning system.
2) TRANSDUCER
   The function of the transducer is to take a signal in one form (electrical) and convert it into a signal of another form (a sound wave, which also may be expressed as a acoustics pulse or pressure wave). A good example would be a microphone and speaker. We speak into a microphone and produce a sound wave or acoustic pulse that is then converted by the microphone transducer into an electrical signal. This electrical signal is transmitted to a speaker transducer that converts this electrical signal back into a sound wave.
   The function of the transducer used in ultrasonic cleaning is to convert the electrical pulses from the generator into a sound wave or pressure wave. When this sound wave/pressure wave is driven through a liquid with appropriate amplitude it will cause the formation of a cavitation vapor/vacuum cavity, which is the scrubbing force found in ultrasonic cleaning systems.
3) TANK OR VESSEL
   The transducer must be bonded to the sides or bottom or immersed into (using an immersible Transducer) a tank or vessel filled with a liquid to remove the high intensity pressure wave from the Transducer. Ultrasonic cleaning transducers cannot be operated dry or series damage may result to both the generator and the transducer. (*2)

TRANSDUCERS (*1)

Ultrasonic transducers may be made from a number of materials. The most common piezoelectric material used is a ceramic called lead zerconate titanate. During the manufacturing process the ceramic is subjected to a high electrical potential causing the ceramic to develop dipoles (*2) and become polarized (to have a positive and negative side). This polarization will give the ceramic a unique feature. When the transducer ceramic is put into service and has an electrical potential applied to it from an ultrasonic generator it will swell and change dimension. When the electrical potential is removed the ceramic will return to its original state and will continue to expand and contract or resonate (like a tuning fork) until it self dampens and stops. Each time the transducer expands it emits a sound wave or pressure wave. Both the resonant frequency that the transducer was manufactured for, and the output frequency of the generator determine the frequency of this pressure wave.

The generator must be designed to emit an electrical pulse at precise intervals so as to compliment the movement of the transducer, not to hinder its movement; this is referred to as automatic tuning.

TRANSDUCER BONDING (*3)

Two types of transducer bonding are used to secure the transducers to the cleaning tank or immersible, one being epoxy (aircraft quality) and the other being brazed. The most common bonding practice used today is epoxy do to the large surface contact area and lightweight of the piezoelectric transducer sandwich. (*1)

With the epoxy bonding technique the transducer may be designed with electrical isolation from the tank or cleaning system (no high voltage potential will be grounded through the tank or cleaning system).

The epoxy adhesion is more than sufficient for bonding the piezoelectric transducer to the tank wall or bottom and gives uniform attachment on surfaces that are not perfectly flat or level. Epoxy bonding is so reliable that most manufacturers will guarantee the bond for 10 years or longer.

The second type is braze bonding. This technique was first used to bond the heavy electromagnetic (magnetrostrictive) transducers (*1) do to their heavy weight and small surface contact area. This bonding technique was carried over to some piezoelectric transducers with no real advantage over epoxy bonding because the bonding strength was not required and there may be a reduction in cleaning performance do to the higher-pressure readings. (*3). Brazing also indicates the transducer sandwich mounting surface is steel not aluminum. The acoustical velocity (mm/microseconds) in steel is 5.79 as compared to aluminum at 6.45. This indicates a significant energy loss by using steel in place of aluminum. Also a brazed transducer cannot be easily isolated from being grounded to the tank.

ULTRASONIC GENERATORS (*4) * SEE DRAWING A

Ultrasonic generators differ in the waveforms they emit and their output ratings. Three forms of output may be used, full wave, half wave, and continuous wave. When discussing generator output power always refer to the average output power, not the peak output those without electrical knowledge may be easily misled so again request average power output.

The manufacturer or supplier of the cleaning system should have a frequency/watt meter available to verify the output frequency and output wattage of the generator. Checking the input power to the ultrasonic generator is of little value when you are interested in the output power, don't be fooled.

To protect the generator from electrical fluctuations and spikes the generator output may be de tuned by as much as 10% but never any more. The frequency/watt meter is the best way to check output frequency and wattage.

1) Virtually all-Industrial ultrasonic generators have automatic frequency tuning.
2) Generators with constant power output hold power output when input voltage changes.
3) Generators should have a power intensity control to control output power.
4) It is advisable to have sweep frequency (*7)
5) It is advisable to have a control to adjust the sweep repetition rate.

ULTRASONIC POWER (*5)

For water at ambient temperature the minimum amount of energy needed to achieve cavitation was estimated to be 0.3 to 0.5 watts per square centimeter for the transducer-radiating surface operating at 40 KHz. What this means is we must supply adequate power to the transducer to initiate cavitation. Cavitation, the scrubbing force in ultrasonic cleaning will be covered at a later time.

Take a given tank filled with a liquid and introduce a pressure wave derived from 100 watts of generator output power, the pressure wave travels through the liquid uneventfully. Now increase the generator to 200 watts output power and once again the pressure wave travels through the liquid uneventfully. Now increase the generator output power to 300 watts. Now as the pressure wave travels through the liquid it has enough amplitude to reduce the local pressure below the point of vaporization and form a cavitation bubble, this is referred to as the threshold of cavitation. Now increase the generator output to 500 watts and one might conclude we increase the power in each cavitation bubble, but this is not the case. After initiating cavitation as we increase power to the ultrasonic tank we increase the number of cavitation bubbles (Referred to as events) we do not affect the energy in the cavitation events. The operating frequency determines the size of the cavitation event and among other factors the energy released.

FREQUENCY (*5)

- The lower the operating frequency the larger the implosion bubble.
- The higher the operating frequency the smaller the implosion bubble.

As we lower the operating frequency the implosion bubble becomes larger and releases more energy when they implode but we also lower the number or amount of events. As we increase the operating frequency we reduce the size of the implosion bubble releasing less energy when they implode but we also increase the number or amount of events.
The maximum size of the cavitation event is proportional to the applied frequency. At equal power inputs to a 25 KHz tank, a 40 KHz tank, and a 68 KHz tank the 40 KHz tank will have 60% higher number of events than the 25KHz tank, and the 68 KHz tank will have 70% higher number of events than the 40 KHz tank. As we increase the frequency we increase the amount of cleaning events and cleaning is more homogeneous but less power is released in each event so cleaning ability may be reduced.

20 KHz to 25 KHz

At 25 KHz and lower there will be fewer events than the higher frequencies but these events will store and release considerably more energy when they implode resulting in more aggressive scrubbing. The cautions to be noted are there is increased potential for damage to the part being cleaned and do to the longer wave length one may notice less homogeneous cleaning results.
Ultrasonic cleaners operating at these lower frequencies will emit stray frequencies or sub harmonics that will be more noticeable and audible to the personal operating the cleaner and in some cases be quite irritating. Frequencies operating at 20 KHz and lower may require the operating personal to wear some type of ear protection do to the potential unknown hazards that this low frequency may have. .
The lower frequencies do to the high intensity of the implosion event will show more rapid signs of cavitation erosion on the transducer-radiating surface. Cavitation erosion is the under cutting and removal of metal from the stainless steel radiating surface.

40 KHz

At 40 KHz the softer implosion forces are usually adequate for most cleaning applications, has better overall cleaning uniformity do to the higher number of cavitation events and there is less chance of damaging the product being cleaned by the imploding bubble.
At 40 KHz the stray frequencies or sub harmonics are further from the hearing range and have little noticeable noise output. Do to the softer implosion force less cavitation erosion will result on the transducer-radiating surface, (also referred to as the transducer diaphragm). 40 KHz is the most wildly used frequency for ultrasonic cleaning.

60 KHz to 80 KHz

At 60 KHz to 80 KHz the implosion forces are much weaker than the lower frequencies and will not have sufficient implosion forces for adequate cleaning in the majority of applications. Do to the shorter wavelength and higher number of cavitation events increase uniformity in cleaning will be noted. With the softer implosion force there is virtually no cavitation erosion and being so far from the human hearing range noise from stray frequencies of sub harmonics are of no concern.
NOTE: Even with the low cavitation implosion forces these higher frequencies can out performs the lower frequencies in certain applications. (*6)

400 KHz to 800 KHz and higher

At 400 KHz to 800 KHz and higher cavitation events have virtually no cleaning ability do to their weak cavitation implosion force. Any cleaning achieved at these frequencies is do to liquid movement or fluid dynamics produced by the pressure wave traveling through the liquid. These high frequencies, as the lower 60 KHz to 80 KHz frequencies, do not lend themselves to most ultrasonic cleaning applications but are used by electronic component manufacturers on special cleaning applications (*6)

MULTI FREQUENCY / SWEEP FREQUENCY (*7) * see drawing B

Multi frequency suggests more than one frequency being introduced into the cleaning tank. A given transducer is manufactured to operate at a fixed frequency (resonant frequency) the transducer must be operated at its resonant frequency or within plus or minus 1 to 2 KHz from its resonant frequency. If a transducer is driven at more than 2 KHz from its manufactured frequency a reduction in output power will result. If transducers of different frequency and bonded to a tank only the transducers driven at or close to their resonant frequency will be operating at maximum efficiency, the remaining transducer will have poor power output and could over heat do to the miss matched frequency.

Sweep frequency suggests changing the generator output through a frequency band by sweeping from a lower frequency to a higher frequency. This sweep must be no more than plus/minus 1 to 2 KHz from the fundamental frequency of the transducers. By exciting the transducers in this manner pressure waves of different frequencies will be introduced into the liquid causing better overall cleaning and less dead spots or standing waves

STANDING WAVES (*7)

Within the cleaning bath fixed points of maximum and minimum amplitude of one completed cycle can be found. The point of maximum amplitude is called the antinode; the point of minimum amplitude is called node. Cavitation takes place primarily at the antinode point and virtually none at the node point. By changing the frequency we shorten or lengthen the wavelength and so change the antinode/node locations helping to eliminate the dead spots (standing waves) within the bath giving better overall cleaning results. Sweeping the frequency is the best way to reduce the negative results of a standing wave.

CAVITATION * see drawing C & E

What is cavitation? Now that we have some knowledge about ultrasonic cleaning and that the ultrasonic generator and transducer are required to produce cavitation in an ultrasonic cleaning bath and that it is the scrubbing force found in ultrasonic cleaning, how is it formed?

To develop a cavitation event we must transmit a high intensity pressure wave from the transducer into a liquid with enough amplitude so as to tear the liquid apart in the rarefaction half cycle and drop the pressure within the liquid below its point of vaporization. When this has been achieved we will develop millions of minute vacuum bubbles called cavitation events. Every half cycle we develop these vacuum bubbles which store their developing energy and then collapse or implode in the compression half cycle releasing their energy. This causes the shear forces they release to break the bonds holding a particle to the item being cleaned. At 40 KHz this cleaning cycle will repeat itself 40,000 times a second.

Cavitation development and amount of energy released relies on a number of factors such as

1) Ultrasonic power.
2) Density.

3) Vapor pressure.
4) Temperature
5) Condition of the liquid (Will be covered in the liquid properties for ultrasonic cleaning section.)

The imploding cavitation bubble conducts the majority of the cleaning by the development of shearing forces but is aided by what is known as micro streaming within the liquid the maximum size of the cavitation bubble is proportional to the applied frequency. As we lower the frequency the larger the imploding bubble will grow. The larger the imploding bubble the greater the implosion force. As we lower the frequency we also lower the number of cavitation events. As we increase the frequency we decrease the size of the cavitation bubble and weaken or soften the implosion force. As we increase the frequency we also increase the number the number of cavitation events

At 40 KHz there are 60 % more cavitation implosions than at 25 KHz
At 68 KHz there are 70 % more cavitation implosions than at 40 KHz. * See drawing C

The characteristic size of a cavitation bubble in water under normal atmospheric pressure is roughly given by F x R = 300, with the frequency being F in Hertz and the equilibrium bubble radius R in (cm). For F= 30 KHz R will be 100UM.
All the above relates to what size cavitation implosion bubble do we want to do our cleaning task without damage to the Item being cleaned, and receive the best overall cleaning results in the shortest time frame.

LIQUID PROPERTIES BEST SUITED FOR ULTRASONIC CLEANING.

VISCOSITY (*8)
In an ultrasonic cleaning bath viscosity should be low to promote cavitation. A thick viscous, syrup type solution would not lend itself to good cavitation, the higher the viscosity the more energy is needed for transmission of the ultrasonic pressure wave.

DENSITY
Density should be high to create intense cavitation events although high-density liquids require additional energy to initiate cavitation. If density is to high cavitation may not be initiated. If cavitation is initiated The imploding cavitation bubble would have tremendous amounts of energy to be released.

In an aqueous cleaning system the viscosity and density are both in a good range for ultrasonic cleaning and should be of little concern.

VAPOR PRESSURE

A vapor pressure of medium value is most suitable for ultrasonic cleaning. Remember we have to go below the point of vaporization of the liquid to initiate cavitation. If the vapor pressure of the liquid is low it will take more power to reach the point of vaporization and in some cases the required power may not be available, so cavitation will never be initiated. Under these conditions if enough power was available the cavitation bubble will store and release extremely high levels of energy.
High vapor pressure will develop cavitation bubbles with ease do to the fact it will be easier to go below the point of vaporization so little power is required, this means less power will be stored and less energy will released. Water in an average temperature range and a middle range for vapor pressure is favorable for most ultrasonic cleaning applications.

SURFACE TENSION

Like vapor pressure the surface tension should be moderate.
With high surface tension the cavitation bubbles have less elasticity so are very hard to develop. Under these conditions of we have enough power to initiate cavitation development tremendous amounts of energy will be stored and released.
With low surface tension the bubbles have more elasticity so are easy to develop. Because of the ease of development the cavitation bubbles will require lower power levels to initiate cavitation development and so will store and release lower implosion forces.
Tap water without additives is hard to cavitate do to high surface tension. If we add a small amount of wetting agent to reduce the surface tension (make the water wetter) we will have noticeable more cavitation activity. If we add to many wetting agents we can lower the surface tension to a point that we will begin losing cavitation intensity. Most chemicals formulated for use in an ultrasonic cleaning bath have the required wetting agents.
NOTE: We must also wet the product being cleaned to achieve proper cleaning. Without a wetting agent to lower the surface tension in water proper contact between the product and the water cannot be achieved.

SCENARIO

Trying to develop a cavitation bubble in water with high surface tension is like trying to blow up a balloon for the first time. You have to exert a tremendous force to initiate expansion. If expansion is accomplished a tremendous amount of energy will be stored, If ample power is not available no cavitation will be developed. (Now add a wetting agent to reduce surface tension) Now compare this to a balloon that has been blown up numerous times, it takes less exertion to initiate expansion so the balloon will blow up quite easily so less energy will be stored, but cavitation will be easy to initiate to begin the cleaning process. Surface tension not only affects the cavitation intensity but also allows the Item being cleaned to have better water contact for improved cleaning. Expression- makes the water wetter.

LIQUID TEMPERATURE

The liquid temperature affects the cavitation quantity, intensity and chemical cleaning action. The cooler the liquid the more difficult to go below the point of vaporization to begin the cavitation development process, this is do to the differential between the low temperature and the boiling point of the liquid. The applied energy must be sufficient to drop the pressure within the liquid below its vapor pressure point. If the liquid is to cold and the applied energy is insufficient under these conditions no cavitation cavities will be developed. If we increase the input power enough to initiate cavitation tremendous amounts of energy will be stored and released when the cavitation bubble implodes in the compression half cycle.
If we increase the liquid temperature it makes it easier to go below the point of vaporization so we initiate cavitation with less energy. The number of cavitation events will increase as the temperature is increased but the energy being stored in the cavitation bubble will decrease. As we approach the boiling point cavitation intensity steadily diminishes and cease or becomes ineffective for most cleaning applications at the boiling point of the liquid.
The liquid temperature will also affect the chemical cleaning ability. Some chemicals work best at elevated temperatures; while others will break down so require lower temperatures. If the temperature is to low the chemical may have trouble dissolving or dispersing. As we increase the liquid temperature most chemicals get more aggressive but we lower the cavitation implosion force. We have to find a temperature / cavitation Balance that is right for the application.

SCENARIO

Picture a seesaw with cavitation intensity on one side and temperature on the other side. As we lower the temperature side we raise the cavitation intensity side. As we raise the temperature side we lower the cavitation intensity side.
The temperature of an ultrasonic bath may vary from 80 degrees Fahrenheit (27 Celsius) or lower to 180 degrees Fahrenheit (82 Celsius) or higher depending on the application. 140 degrees Fahrenheit (60 Celsius) are the average temperature for most ultrasonic cleaning applications.

DEGASSING

Before cavitation can become effective in an ultrasonic bath dissolved gases trapped in the liquid must be removed. If not removed the cavitation vacuum bubbles being formed will fill with this gas cushioning the implosion force In some cases the cavitation bubble will sequentially grow with each cycle and when large enough float to the liquid surface without performing any cleaning task.
Unwanted gases may also be introduced into the liquid in a number of ways, all of which should be avoided if possible.
RHEOLOGICAL PROPERTIES TO BE AVOIDED

1) Pumping the solution at to fast a rate and returning above the liquid
2) Introducing the product being cleaned into the bath to rapidly.
3) Moving the product around to fast while in the bath
4) Repeatedly introducing and removing the product from the bath.
5) Continuously pumping the liquid. to a secondary tank and back

DEGASSING SUGGESTIONS

1) Switch the generator to a half wave mode
2) Shutting the generator off and on at 3 second intervals, 3 on, 3 off etc.
3) Elevate the liquid temperature
4) Fill the tank the night before and let stand until the next day.
5) Once the water is degassed and left inactive subsequent use will require little or no degassing.

WATER CONDITONS

Most alkaline detergents can soften water with up to 10 grains of hardness. If the available water is harder than this consider using a water softener.
Distilled or highly polished water is not recommended for most ultrasonic cleaning applications do to the lack of nuclei in the water from which the vacuum bubble is formed. By adding a soap or detergent to the water will help this condition to some degree but using (not so clean) water will help insure you of having the needed nuclei.

ALKALINE DETERGENTS (8*)

Before a proper chemical can be selected we must first be familiar with the soil or soils to be removed and the sensitivity of the item being cleaned in regards to temperature limitations and metal /material /coating compatibility.
Three common types of contamination are classified as ORGANIC, INORGANIC, and PARTICULAR.

ORGANIC contamination such as oil, greases, waxes and adhesives are solvent soluble.

INORGANIC contamination is insoluble in solvents and requires water-based solutions.

PARTICULAR contamination is usually insoluble.

WATER is the best universal cleaner for both organic and inorganic soils when treated with the proper cleaning chemical. In most cases particular contamination is best removed with water and ultrasonics rather than solvents. The cavitation intensity in water can be 10 to 100 times greater the cavitation intensity in most solvents.

The major active ingredients in alkaline detergents are
1) SAPONIFIERS
2) WETTING AGENTS
3) DEFLOCCULANTS
4) SEQUESTERING or CHELATING AGENTS
5) BUFFERING AGENTS
6) INHIBITORS

The proper selection of ingredients must be tailored to the contamination being removed for best cleaning results.

ACIDIC DETERGENTS SEE DRAWING F

Acidic solutions are seldom used in ultrasonic cleaning systems. If the contamination is not suitable for alkaline detergent cleaning acids may be used if the stainless steel tank (usually 316L) is compatible with the acid at the concentration being used.
If the acid is not compatible with the tank stainless consider using a tank or insert made from a different grade of stainless or consider quartz, glass, tantalum, titanium, PVC, polypropylene, or a compatible plastic. * See drawing E
The least desirable would be the plastics do to the dampening effects of the plastics when used as an insert tank. An insert tank approach is also the most common way to use different chemicals for different cleaning applications without draining the main ultrasonic cleaning bath.

After the contamination has been identified a detergent may be formulated with consideration of not damaging or attacking the item being cleaned and the temperature limitations of both the item being cleaned and the detergent. Remember the hotter the solution the more aggressive the detergent will usually be but the ultrasonic cavitation intensity will be lowered. As we reduce the liquid temperature we increase the cavitation implosion force, we have to find that balance best suited for the application. One of the most important ingredients required for the best cleaning results in an ultrasonic cleaner is the wetting agent. When the surface tension is to high cavitation development will be difficult, and cavitation erosion may be more rapid on the radiating surface. If we don't properly wet the part being cleaned we cannot expect to properly wet the contamination for removal.
Ultrasonic cleaning can also be a great asset when used in a final rinse to aid detergent removal.
Ultrasonic cleaning systems cannot be fully effective as a cleaner without the aid of chemicals or a wetting age

SUMMARY

ULTRASONIC GENERATORS
1. Refer to the average output power only, not peak power
2. Verify output power and frequency
3. Request a power intensity control on the generator.
4. Request sweep frequency, verify if true sweep and not a temporary wobble at the start of the cycle.
5. Request an adjustable sweep repetition control.
6 Check longevity of ultrasonic manufacturer.

TRANSDUCERS
1. Piezoelectric ceramic transducer.
2. Epoxy bond.
3 Operating frequency

FREQUENCY

1 18 KHz to 25 KHz (most aggressive)
2 40 KHz (most highly used frequency for general cleaning applications)
3 60 KHz to 80 KHz (best for removing sub micron particles. Common use in electronic manufacturing)

400KHz to 800KHz and higher (same as 60 KHz to 80 KHz)

LIQUID PROPERTIES

1 Liquid temperature.
2 Viscosity
3 Density
4 Vapor pressure

Surface tension, wetness of water, best around 30 dyn/cm

ALKALINE DETERGENTS

First identify the contamination and classify. Formulate a detergent as required with consideration to temperature limitations. Proper wetting agents as required to satisfy the ultrasonic needs and to properly wet the product being cleaned.

CAVITATION

1 The lower the frequency the more aggressive the cavitation implosion.
2 The lower the frequency the fewer cavitation events
3 The higher the frequency the softer the cavitation implosion.
4 The higher the frequency the more cavitation events.
5 The cooler the liquid temperature the harder to initiate effective cavitation.
6 The hotter the liquid temperature the easier to initiate effective cavitation.
7 Wetting agents affect both the quantity and the quality of the cavitation event.
8 Three steps for cavitation are nucleation, growth and violent collapse or implosion.

STANDING WAVES

Dead spots within the cleaning bath which is evident in all ultrasonic cleaners. To reduce the effects use sweep frequency. The product may also be slowly moved up and down in the liquid for at least one wavelength during the cleaning process to insure that the part is fully and equally exposed to the antinodes.

EROSION

The undercutting and removal of metal from the radiating surface, more evident at the lower frequencies. By adding titanium nitride coating to the radiating surface erosion will be greatly reduced.

ULTRASONIC POWER

1 Must have adequate power to initiate and maintain cavitation under most work conditions.
2 If we try to introduce too much ultrasonic power into a tank a barrier will form at the liquid/radiating surface interface that will block additional input power and will cause advanced cavitation erosion.
3 If we do not have adequate ultrasonic power initiating cavitation will be difficult, maintaining cavitation will be difficult, and cleaning at best will be marginal. A low power level will also greatly reduce the cleaning applications the tank will be able to perform.
4 When considering purchasing a special ultrasonic cleaning system for a specific cleaning application FIRST Contact someone who is knowledgeable in ultrasonic design.
  SECOND. Send a sample of the item to be cleaned to their testing lab for evaluation. THIRD. Request information on tank design best suited for the application.

  DEGASSING

  Removal of unwanted gas from the liquid. Must be completed before cavitation can be fully Effective.

END OF PART ONE

PART TWO

TRANSDUCERS (*1)

Transducers are available in two varieties, MAGNETOSTRICTIVE and ELECTROISTRICTIVE. The magnetostrictive type transducers contain ferromagnetic nickel laminations surrounded by electrical coils. During operation a varying magnetic field causes the laminations to alternately expand and contract generating a sound wave or pressure wave that is driven into the liquid of an ultrasonic tank. Magnetrostrictive transducers are a low frequency transducer and cannot operate practically at frequencies higher than approximately 20 KHz. Magnetostrictive transducers can lose up to 50 % of their applied energy in the form of heat making it difficult to maintain a low temperature in the ultrasonic bath. Magnetostrictive transducers are a low voltage, high current device that requires polarization. Do to the low operating frequency sub harmonics from the fundamental frequency are at a high amplitude in the human hearing range and usually will require ear protection by operating personal or other precautions will have to be taken.

Electrostrictive (piezoelectric) transducers have ceramic crystals, which similarly expand, and contract (vibrate) in a varying electrical field. First quartz was used, then barium titanate. The draw back with the quartz was the high cost. The draw back with the barium titanate was the low operating temperature of 160 degrees Fahrenheit (70 Celsius) maximum, or the transducer would become de polarized and destroyed. The new lead zerconate titanate ceramic transducer element can withstand temperatures in excess of 250 degrees Fahrenheit (120 Celsius). These piezoelectric transducers are a high voltage low current device and are far more efficient in energy conversion (in excess of 90 %). The piezoelectric ceramic can be manufactured to virtually any operating frequency making in the most widely used material used for ultrasonic applications. The transducer ceramic crystal is compressed into a "sandwich " consisting of a steel back plate and a steel or aluminum face plate for protecting the fragile ceramic, to aid in mounting to the tank wall, and to adjust the fundamental frequency by compression forces of the sandwich assembly. The advantages of ceramic technology in stacking ultrasonic transducers within the sandwich are overwhelming. Silicon carbide, second only to diamonds in hardness and acoustically the best ceramic in the world to transmit a sound wave should be used to enhance the transmission of ultrasonic sound wave from the transducer sandwich assembly.

TRANSDUCER CONSTRUCTION (*2) SEE DRAWING G

During the manufacturing process the lead zerconate titanate ceramic is subjected to a very high electrical field causing the formation of dipoles within the ceramic. A dipole is a small infinitesimal group of molecules bonded together within the ceramic. These dipoles display a unique feature when polarized. The dipoles will now have a polarity of opposite potential on the opposing sides. When an electrical potential from the ultrasonic generator is applied to the transducer, positive-to-positive and negative-to-negative the dipoles will compress or shrink. When the electrical potential from the ultrasonic generator is reversed and applied to the transducer, positive to negative and positive to negative the dipoles will expand or grow in length. * See drawing F

These dipoles are located throughout the ceramic crystal with all their positive polarities facing in one direction and all their negative polarities facing in the opposite direction. When an electrical potential is applied to the polarized ceramic crystal all the dipoles work in unison causing the ceramic disc to expand or contract. Each time the crystal expands it emits a movement of molecules in the form of a sound wave or pressure wave.

With a better understanding of the dipole and how in works should be evident how a transducer functions. The transducer will take a signal in one form (electrical) and convert it into a signal of another form, (Mechanical movement) to produce a sound wave or pressure wave. This is the principal of electrical to mechanical conversion.

If a transducer is subjected to extremely high temperatures (above the curing temperature of the ceramic) The dipoles could slip out of alignment and the transducer will become de polarized and will no longer function properly. If an ultrasonic cleaning transducer is run dry (no water in tank) permanent damage can result. Without a liquid coupling to disperse the high intensity sound wave the transducer may chip or fragment causing a frequency change. Never test a dry ultrasonic cleaner by a quick buzz of power, with a quick two second buzz on a 40 KHz tank the transducer has just operated (without water) 80,000 times, this is not a recommended procedure!

TRANSDUCER BONDING (*3)

A recent comparison by a Silicon Valley, Ca. Computer disc drive giant showed 25 to 30 % higher pressure readings when comparing a leading manufacturers epoxy bonded transducer to a vacuum brazed transducer from another leading manufacturer.
Additional test was conducted using a Hewlett-Packard Co. digital signal analyzer, which also indicated 29 % superiority for the epoxy-bonded transducer.

ULTRASONIC GENERATORS (*4) SEE DRAWING A

Ultrasonic generators are the power source for providing electrical power to the transducer at the voltage required for operation. Each generator is designed to drive a designated number of transducers. A 500-watt generator is normally connected to 12 transducer elements or 6 pairs, supplying each with approximately 40 watts of power. The crystals are capable of accepting additional power but this would cause significantly more cavitation erosion on the radiating surface, especially at the lower frequencies. Also by driving more power to the transducers fewer would be required, causing poor transducer distribution on the radiating surface.
Generators differ in the waveforms they emit. The three waveforms are full wave, half wave, and continuous wave, of these, full and half wave are most common.
FULL WAVE
Peak power is twice the avenge power.
HALF WAVE.
Peak power is four times the average power
CONTINUOUS WAVE
Peak power and average power are the same.

Always refer to the generator average output power when discussing power.

All Industrial ultrasonic generators have FCC suppression filters. The FCC filter prevents the modulated RF signal from entering the electrical supply line.

Generators with constant output power will self adjust to compensate for voltage fluctuations.

Generators with an electronic feedback loop changes the generator output power whenever the tank is loaded or the liquid level is changed and in most cases leads to erratic cleaning.

*NOTE: Ultrasonic generators and transducers from one manufacturer cannot be mixed with generators and transducers from another manufacturer. When selecting ultrasonic cleaning equipment longevity of the manufacturer should be your number one priority. What good is a 10-year guarantee on the transducer if the Company has only been in business for a few years? Anyone can give a guarantee but only a few will honor it. If a small manufacturer is forcer into a recall because of a defective part this manufacturer will suddenly disappear leaving you with a very expensive non-working and non-repairable ultrasonic cleaning system. If a manufacturer has been in business for 30 or 40 years be assured of getting service far into the future.

ULTRASONIC POWER (*5)

To determine if we have adequate ultrasonic power in a tank we must know both the wattage per square inch of the transducer-radiating surface and the cubic volume measurement of the liquid being ultrasonically activated.

1) If the ultrasonic tank bottom measures 10 inch by 14 inch this would give us a radiating surface of 140 square inch. If this tank were driven by a 500-watt generator the watt density would be 3.6 watts per square inch (500-divided by140) on the radiating surface.
2) If we fill this 10 by 14-inch tank to a depth of 10 inch we will now have 1400 cubic inches of liquid (6.1 gallons).

   If a 500-watt generator drives this tank the volume density would be .36 watts per Cubic inch of liquid. This would be considered a standard intensity ultrasonic tank.

   If we now install a 1000 watt generator to drive this tank the watt density per square inch on the Radiating surface would be 7.2 watts per square inch on the radiating surface and .72 watts per cubic inch of liquid; this would be considered a high intensity ultrasonic tank.

   Now lets take this 10-inch by 14 ultrasonic tank and increase is volume by filling it to up to a depth of 36 inches.(22 gallon). If this tank is once again connected to a 500-watt generator the watt density is again 3.6watts per square inch, but the watt density per cubic inch has dropped from .36 watts per cubic inch to (.099) watts per cubic inch. This is a reduction from 1/3 watt per cubic inch to 1/10 watt per cubic inch of liquid. The generator may have enough power to initiate cavitation in the first or second wavelength but will loose amplitude as it travels through this much liquid and will have trouble initiating and maintaining cavitation in the remainder of the tank.

   Do to the low ultrasonic power level the only way to help satisfy this condition is to elevate the tank temperature. At the elevated temperature of 180 degrees Fahrenheit the tank will eventually degas and cavitation will be initiated. The precaution that must be taken with this tank is that the high temperature must be retained and the load being cleaned must be kept small or the tank will stall and cavitation will be lost.

Ultrasonic power may be rated as <u>low intensity, medium intensity, standard intensity,</u> and <u>high intensity.</u>
It should be obvious that we can not expect to use the same ultrasonic power level as used in the blind cleaner, (usually in the area of 1500 watts for 25 to 30 gallons) and expect to install this same amount of power into a tank containing 95 or 100 gallons and expect to achieve effective ultrasonic cleaning. If a person is not familiar with ultrasonic activity and power levels one may be deceived into thinking their tank is:

1) **WORKING THE WAY IT SHOULD**
2) **THE CLEANING TASK IS TO DIFFERCULT**
3) **THE LOAD IS TO LARGE FOR THE TANK**
4) **I MUST BE USING THE WRONG CHEMICAL**

As the capacity of an ultrasonic tank increases, the increase in ultrasonic power is <u>not linear.</u> If we drive a 10-gallon tank with 750 watts of power we do not have to drive a 90-gallon tank with 6750 watts of power to archive the same cleaning results.

If we change the configuration of a tank but retain the same volume the ultrasonic power requirements may also change. A tank with dimensions of 24 inch x 24 inch x 9 inch deep (22 gallon) may only require 750 watts of ultrasonic power where a tank with dimensions of 12 inch x 12 inch x 36 inch deep (22 gallon) may require 1500 watts of ultrasonic power to achieve the same cleaning results.
When interested in purchasing a special ultrasonic cleaning tank go to a qualified ultrasonic design engineer for specifications.
If you have a special cleaning application it is recommended that you send a sample to a qualified ultrasonic cleaning lab for evaluation and tank design specifications.

FREQUENCY (*6)

The lower frequencies are more widely used when the product being cleaned is not susceptible to damage by the aggressive cavitation. This aggressive nature of the lower frequencies is best suited for removal of insoluble particles in the middle to upper micron range, and for removal of tenacious deposits.
Ultrasonic intensity is an integral function of the frequency and amplitude of the radiating wave.

1. A 20 KHz radiating wave will be approximately twice the intensity of a 40 KHz wave for a given average power output.
2. The diameter range of a 20 KHz cavitation bubbles is 50/200 micron.
3. The diameter range of a 25 KHz cavitation bubbles is 35/150 micron.
4. At 20 KHz the impact range is 35/70- K Pascal with a streaming velocity of 400 km/hr.
5. At 20 KHz the node, antinode points are one half-wave length or two inches apart.

40 KHz is the most widely used frequency for most ultrasonic cleaning applications. At 40 KHz the node, antinode points are one half wavelength or one inch apart.

60 KHz to 80 KHz is more commonly used in the electronic Industry. Removal efficiency of a one micron and sub micron particle is increased with the higher frequencies. At 65 KHz the removal efficient on a one-micron particle is 95 % compared to 88 % for 40 KHz. The size of a one-micron particle is one thousandth of a millimeter or one millionth of a meter, much to small to see with the human eye without magnification. Under most general ultrasonic cleaning applications these small micron and sub micron particles are of little concern so the lower frequencies are favored. The higher frequencies are favored for use in the electronic Industry for cleaning hybrids; substrates, surface mounts, and disc drive components. This Industry is very concerned with these small micron and sub micron particles and being very susceptible to damage welcome the weak cavitation implosion force of the higher frequencies.

At the higher frequencies of 400 KHz to 800 KHz and higher the removal efficiency of a one micron particle is virtually the same as the 60 KHz and 80 KHz frequencies. These frequencies are also used exclusively by the electronic and optical Industries.

One might expect that the lower frequencies, with their more aggressive cavitation implosion forces to have a greater detachment effect for all particles no matter what their micron size.
Small particles are harder to remove do to both their force of attraction and their ability for lodging into small areas. The weight of the particle is also a major factor in detachment. Although the force between a particle and an adjacent surface decreases with particle size it becomes more difficult to remove a solid particle from a solid surface because of the value of the ratio Fa/W where Fa is the force of attraction and W is the weight of the particle. The value of Fa/W increases rapidly as the diameter of the particle decreases.
Even highly polished surfaces have some valleys and irregular areas where small micron and sub micron particles can lodge. The low frequency of 20 KHz has a cavitation bubble range size of 50 to 200 microns in diameter. These cavitation bubbles have little chance of penetrating into these small irregular areas to remove small micron particles. The higher frequencies of 60 KHz and 80 KHz with its smaller range of cavitation bubbles and higher number of cavitation events have a better chance of penetrating these areas and removing more of the particles.
On items being cleaned characteristic viscous and thermal boundary layers exist. At 30 KHz the viscous boundary layer thickness is 4.4 millionths of a meter, the thermal boundary layer is 1.1 millionths of a meter.
At the lower frequencies the acoustic field does not perpetrate these boundary layers significantly so small micron and sub micron particles do not always feel the effects of the acoustic field
The boundary layer thickness is inversely proportional to the square root of the frequency.
The best means of penetrating this boundary layer is to increase the operating frequency. At 900 KHz the viscous boundary layer is to 0.8 millionths of a meter thus increasing the removal efficiency of small micron and sub micron particles.

SWEEP FREQUENCY (*7) * see drawing D

Caution should be taken when talking about sweep frequency, Some refer to a sweep frequency when in fact it is nothing more than a unpredictable frequency "wobble" during the first 5 to 10 % of the modulated cycle. This occurs because at the beginning of the cycle the voltage is to low to lock onto the fundamental frequency so is in a searching or wandering mode until the voltage reaches operational levels. At about 10 % into the modulated cycle the circuit locks on to the fundamental frequency for the balance of the cycle. During the first 10 % of the modulated cycle the energy level accounts for less than 2 % of the total energy delivered during a single modulated cycle.

THIS PHENOMENON IS EVEDENT IN ALL ULTRASONIC SYSTEMS, THIS IS NOT A SWEEP FREQUENCY.

A true sweep frequency is when the ultrasonic is operating at its fundamental frequency, lets say 40 KHz and then changes its output to 39 KHz, then back to 40 KHz, then to 41 KHz, then back to 40 KHz and so on through the full modulated cycle. This generator would have a sweep of plus or minus 1 KHz around the fundamental frequency of 40 KHz.

An additional feature that aids in cleaning is an adjustable sweep repetition rate control. Under non-adjustable conditions the sweep will be set at a fixed repetition rate of 100 to 125 sweeps per second. With the adjustable sweep the repetition rate may be changed from 30 sweeps per second to 250 sweeps per second. The changing of the sweep repetition rate is very valuable in reducing damage to certain sensitive parts being cleaned.

ALKALINE DETERGENTS (*8)

The most common aqueous cleaning media, alkaline detergents are widely used to remove a wide verity of contaminants from metals to plastics to glass. Some alkaline detergents may be used at high temperatures while others are temperature limited.

These cleaning agents utilize alkaline salts as sodium hydroxide, sodium metasilicate, orthosilicate or trisilicate, sodium carbonate, sodium tetraborate, trisodium phosphate, tetrasodium pyrophosphate, or sodium polyphosphates.

Rather than dissolving soils like solvents alkaline detergents displace and suspend them, emulsify them, or react with them to form water-soluble soaps. Selection of a specific cleaner should be based on work piece materials, soil composition, cleanliness standards and water conditions (especially hardness)

The major active ingredients in alkaline detergents are **saponifiers, wetting agents, deflocculants, water softeners, buffering agents** and **inhibitors.**

SAPONIFIERS

Saponifiers are strong alkalines, which convert oils and greases into water-soluble soaps.

WETTING AGENTS

Wetting agents are surface-active synthetic detergents, which lower the surface tension of the cleaning solution. Simply immersing a solid item into a liquid doesn't mean that the item is sufficiently wetted for cleaning. In order to penetrate the surface of a contaminate layer the liquid must have a lower surface tension than that of the contaminant. EXPRESSION (make the water wetter).

The normal difference in surface tension between water and oil may be illustrated when a drop of water is placed on top of an oily surface and the water will bead up and remain there. If a wetting agent is added to this water droplet to reduce the surface tension to that of the oil film the droplet will spread out over the oil and will cause the water to penetrate and displace the oil, sending the oil droplets to the surface of the water.

DEFLOCCULANTS

Deflocculants are sub-microscopic colloidal particles that are added to a cleaning solution. The deflocculants do not dissolve in the water, but remain suspended and exhibit constant Brownian movement. Deflocculants aid cleaning through attraction of oppositely charged fine soil particles clinging to part surfaces. When their attraction is greater than the surface charge attraction the particles leave the surface and become suspended, with little tendency for redeposition.

WATER SOFTENERS

Water softeners are sequestering or chelating agents that combine with metallic ions to form water-soluble Nonionic structures. Most alkaline detergents can softer water up to 10 grains of hardness. If available water is harder than this the use of deionized water is recommended.

SEQUESTERING or CHELATING AGENTS.

Sequestering or chelating agents are similar in action except sequestering agents are limited to maximum temperatures of 180 degrees F (82 C). They are composed of polyphosphates, usually sodium tripolyphosphate, tetraphosphate or hexametaphosphate.

CHELATING AGENTS

Chelating agents are generally organic sodium salts of one of various acids. Unlike the polyphosphates they do not break down or lose potency at high temperatures. Moreover they enable alkaline cleaners to solubilize metallic compounds such s rust, scale, iron, and zinc phosphate conversion coatings, and drawing compounds.

BUFFERING AGENTS

Buffering agents or buffer salts maintain the optimum pH range for maximum detergency of soaps and other surface-active agents. Each cleaning solution has a particular pH range of greater effectiveness. Buffering agents are designed to keep the solution within this range despite contamination by acidic or alkaline soils during cleaning.

INHIBITORS

Inhibitors are silicates or chromates added to highly alkaline detergents to allow their use with non-ferrous metals such as aluminum, copper, lead, zinc and tin. They are not required when working pieces are composed of ferrous metals of titanium and magnesium alloys. During cleaning inhibitors deposit a thin protective film on the bare metal surfaces as soon as soils are removed to protect attack, pitting or tarnishing.

END

Any questions, comments, suggestions or request for cleaning application laboratory tests please direct to:

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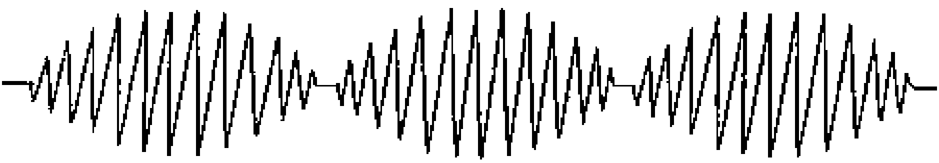
DRAWING A

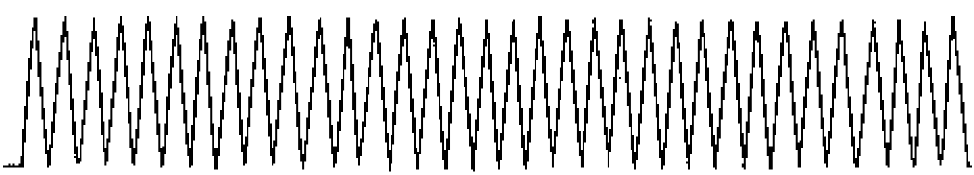
FORMS OF ULTRASONIC GENERATOR OUTPUTS

* FULL WAVE



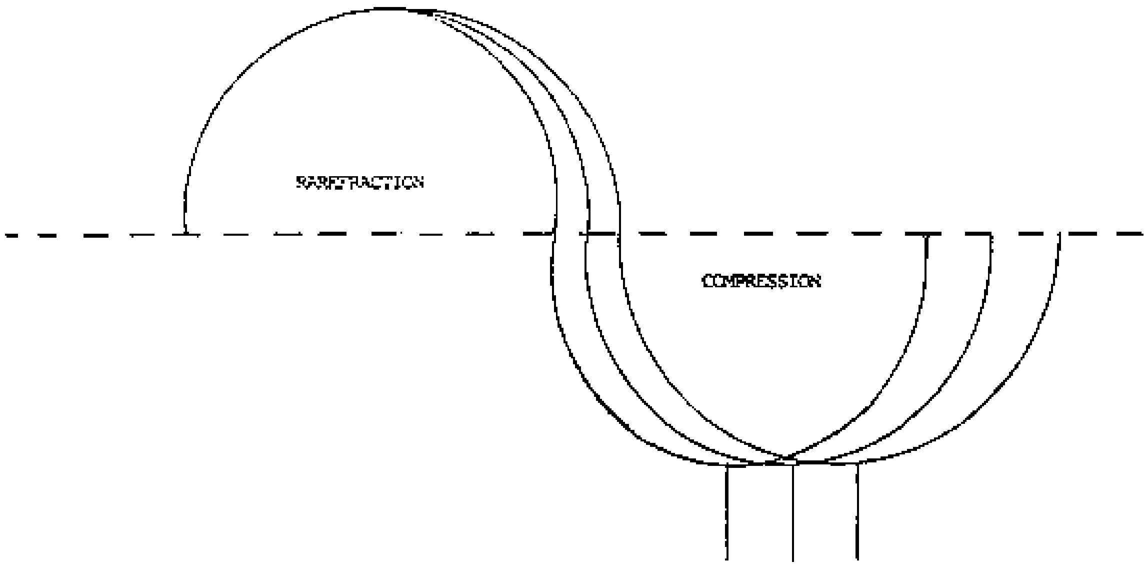
* HALF WAVE

* CONTINUOUS WAVE



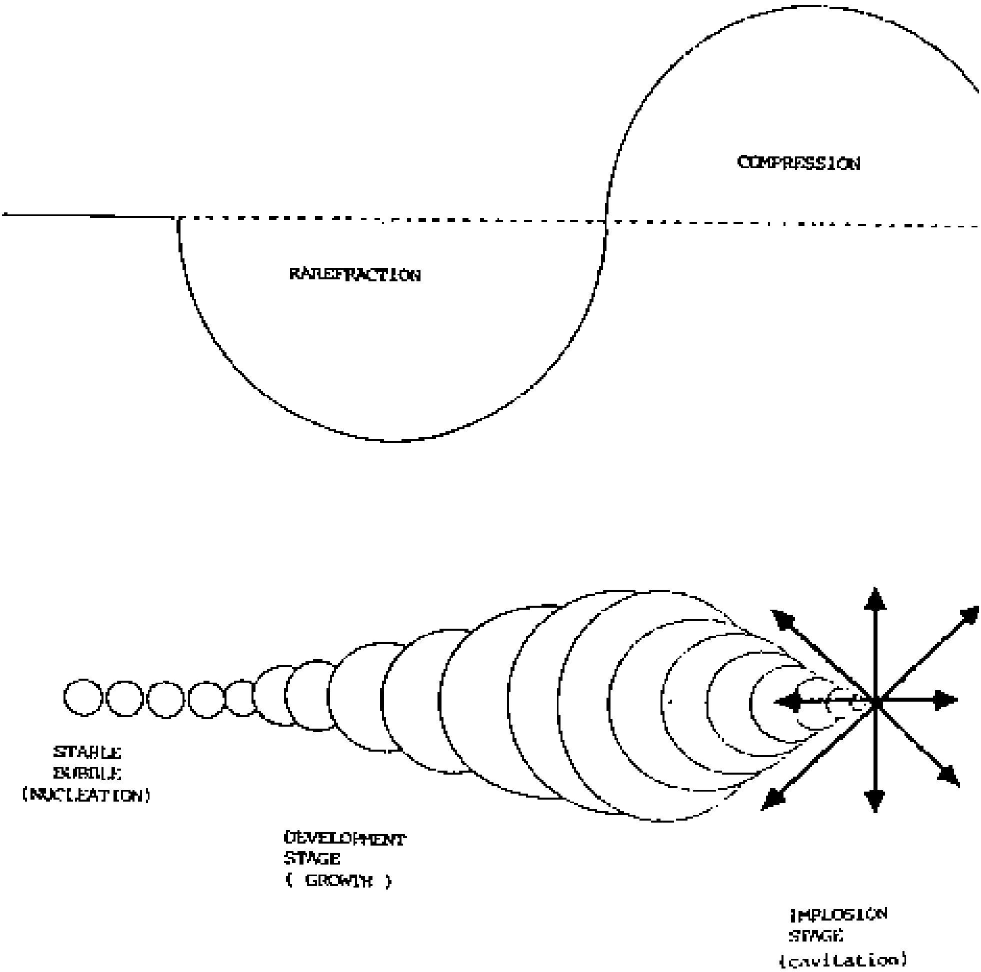
DRAWING B

"SWEEP FREQUENCY"



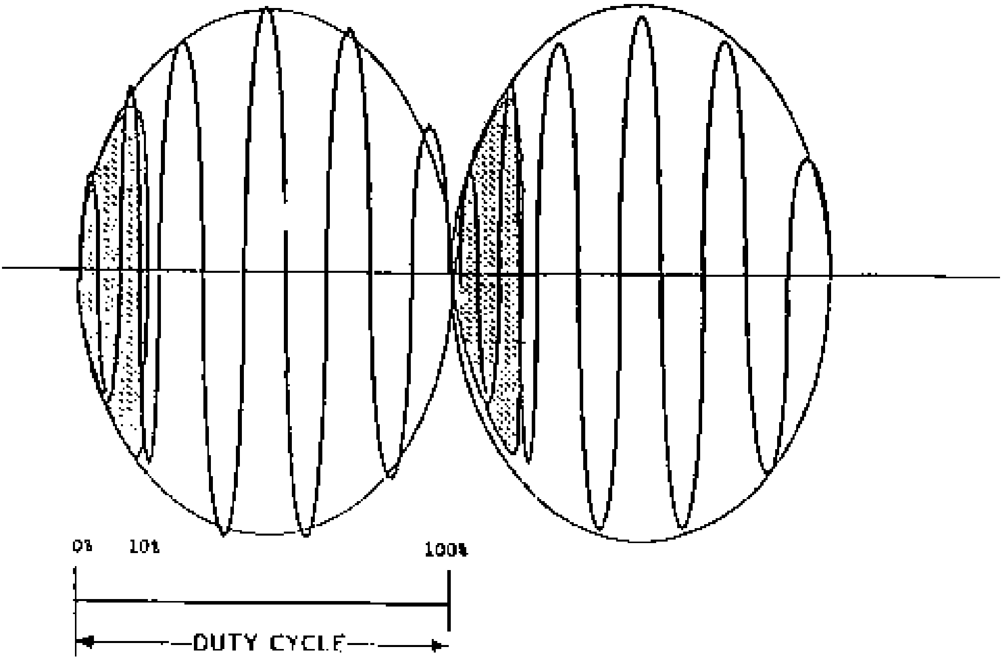
BY CHANGING THE GENERATOR OUTPUT FREQUENCY (WITHIN LIMITS) WE CHANGE THE LOCATION OF THE NODE, ANTINODE HELPING TO ELIMINATE DEAD SPOTS (STANDING WAVES)

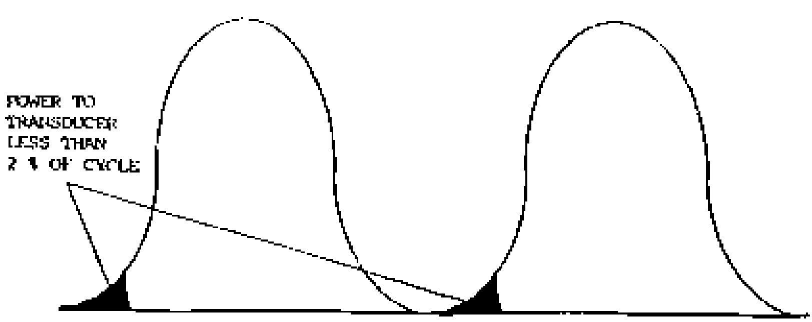
DRAWING C


COMPRESSION
RAREFRACTION
STABLE
BUBBLE
(NUCLEATION)
DEVELOPMENT
STAGE
(GROWTH)
IMPLOSION
STAGE
(cavitation)

DRAWING D

* THIS IS NOT SWEEP FREQUENCY

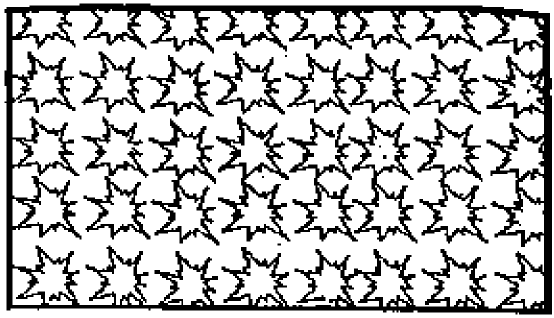




DRAWING E

68 kHz

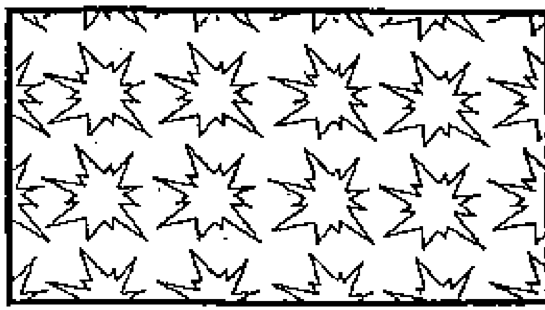
70% more implosions than 40 kHz



Cavitations at 68 kHz

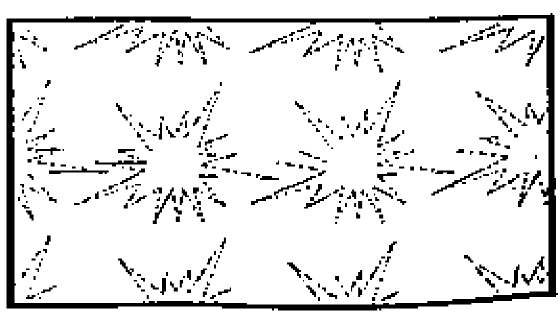
40 kHz

60% more implosions than 25 kHz



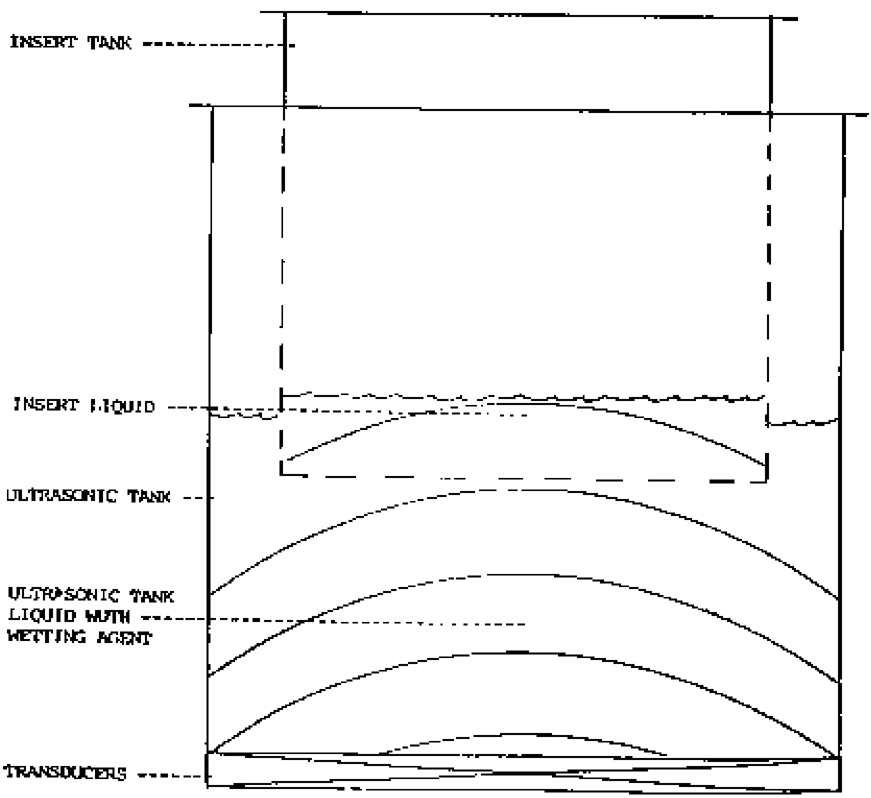
Cavitations at 40 kHz

25 kHz

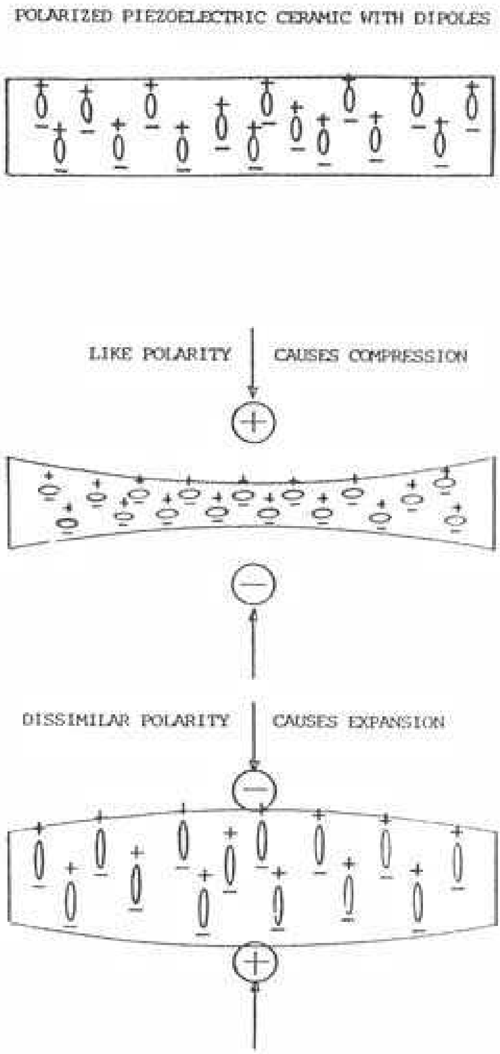


Cavitations at 25 kHz

USE OF AN INSERT TANK TO CAVITATE A SECONDARY SOLUTION



DRAWING G



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