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Precision Cleaning Systems

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Basic Facts on Ultrasonic Cleaning
Process Description
The Ultrasonic Cleaning Process

Basics

An ultrasonic cleaner is simply a metal tank [stainless steel] that has pizeo ceramic transducers bonded to the bottom or side. These transducers have a unique property of changing size almost instantly when excited by an electrical signal. When excited the transducer increases in size and causes the tank bottom or side to move. This creates a compression wave in the liquid of the tank.

By using an electrical generator that puts out a high frequency signal [20 to 250 kHz] the transducer rapidly induces compression and rarefaction waves in the liquid.
During the rarefaction cycle the liquid is torn apart. This creates a vacuum cavity within the liquid. These cavities will grow larger and smaller as the compression waves are continued. When the cavity reaches a certain size [based on the frequency and the wattage of the signal] the cavity can no longer retain its shape. The cavity collapses violently and creates a temperature of 5,000 degrees centigrade and a jet of plasma that impacts against whatever object is in the tank. There are millions of these bubbles created and collapsing every second in an ultrasonic tank
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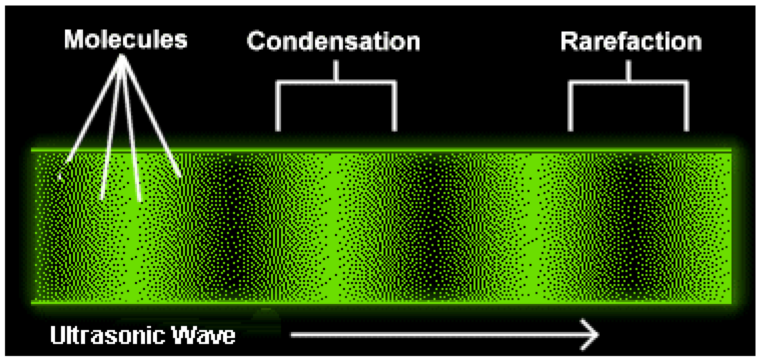
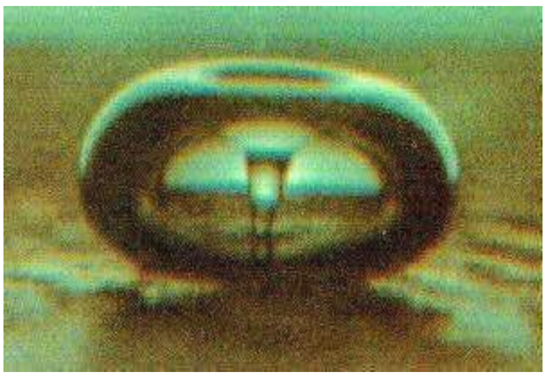


Compression & Reareification Waves in an ultrasonic Tank

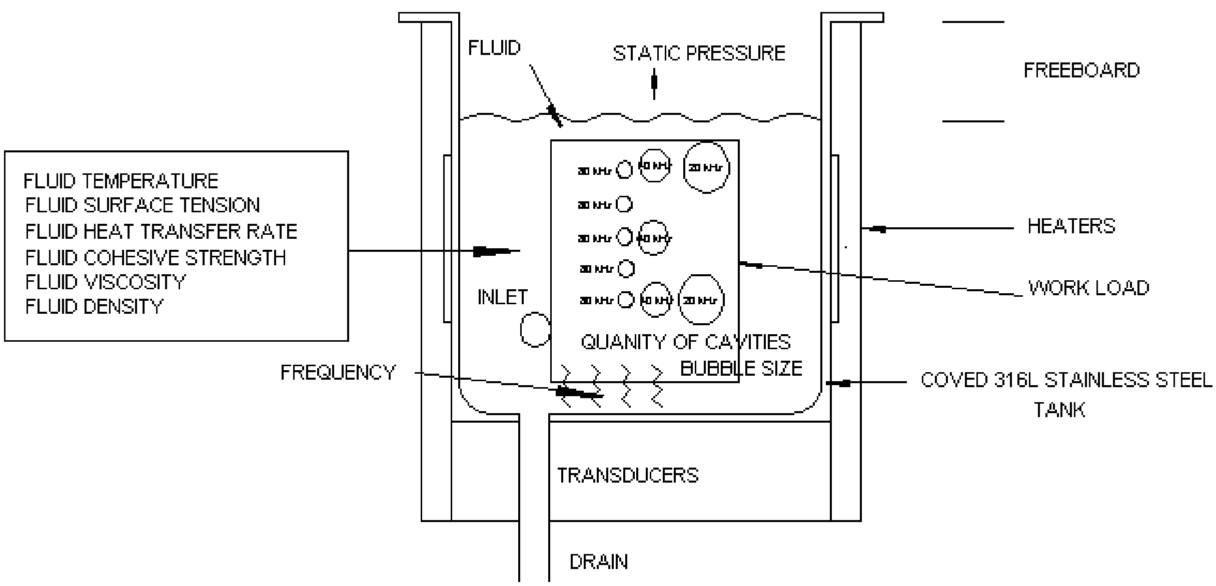
It is these collapses that clean the part. The jet will explode the dirt or any other material off the surface of the part. By adding soap or other chemical to the water in an ultrasonic tank, you can increase the effectiveness of the cleaning operation. Heat also improves Ultrasonic Cleaning by eliminating entrapped air in the water. The best temperature to clean with is 80% of the boiling temperature of the solution. You should always use a basket to hold the parts you are cleaning. Never put parts directly on the bottom of an ultrasonic cleaner.



Factors In Ultrasonic Cleaning:

1. Fluid Temperature:
The higher the temperature of the cleaning fluid the less energy required to induce cavitation.
2. Fluid Surface Tension:
The lower the surface tension, the less energy required to induce cavitation. The most common way of lowering the surface tension of a fluid is to add a surfactant. [Soap]
3. Fluid Heat Transfer Rate:
The Heat transfer rate of the fluid is a factor in the cleaning. The higher the transfer rate the more the cleaning effect
4. Fluid Cohesive Strength:
The cohesive strength [molecular strength of the fluid] determines the point at witch cavitation takes place. The higher the strength the more energy required to induce cavitation.

5. Fluid Viscosity:
   High viscosity fluids are harder to induce cavitation and do not flow and cover a part as easily as a low viscosity fluid. Usually a high viscosity fluid requires more heat and more ultrasonics to be effective as a cleaning agent.
6. Fluid Density:
   The higher the density of the fluid the more ultrasonic energy required to induce cavitation in the fluid.
7. Static Pressure
   The higher the static pressure on the fluid the more energy required to induce cavitation in the fluid.
8. Freeboard:
   Freeboard is the term used to represent the distance from the fluid level to the top of the tank. It should be about 2".
9. Frequency:
   Frequency is the rate of expansion and contraction of the transducers. It is measured in kHz. Ultrasonic Cleaning frequencies range from 20 kHz to 250 kHz. Above 250 kHz cavitation does not take place.
10. Cavitation or Bubble Size:
    Bubble Size is based on the Frequency. The higher the frequency the smaller and more evenly distributed the cavitation.
11. Work Load:
    The workload [or parts] should never exceed 50% by volume of the tank capacity.



Frequency

The Peak to peak distance generated in an ultrasonic tank is dependent on the frequency of the generator. Lower frequencies generate longer peak-to-peak distances than the higher frequencies. It is important to remember that an ultrasonic wave is a standing frequency and not a sine wave. Since it is not a sine wave there are areas in the tank that receive less ultrasonic energy due to the fact that cavitation takes place more strongly around the compression areas of the wave. Lower frequencies such as 20 kHz will generate more uneven areas of cleaning but will concentrate power in these areas and will clean heaver deposits of soil.
explosion

The higher the frequency, the smaller the final size cavitation vacuoles. This generates a more even cleaning and coverage of the product. A higher frequency distributes the ultrasonic power more evenly in the ultrasonic tank. Changing the frequency does not change the overall power of the ultrasonics.
20 kHz is 1.5" peak to peak
40 kHz is .75" peak to peak
68 kHz is .44" peak to peak
80 kHz is .37" peak to Peak

120 kHz is .25” peak to peak
170 kHz is .17” peak to peak
190 kHz is .15” peak to peak

Wave Form

Ultrasonic generators can be designed to generate sine, square or saw tooth waves. Most ultrasonic generators generate sine waves with square waves the next most popular type. [Sine waves are the most popular type of generator] Square waves will tend to shock or damage very delicate parts. Saw tooth waves just don’t work well in cleaning.

Cavitation

Cavitation or the creation of a vacuole takes place in the liquid when the pressure wave of the ultrasonic passes that area. The collapse of the vacuole takes place during the peak of the wave’s passage. This means that the most effective and powerful cavitation takes place around the wave peak. The higher the frequency of the ultrasonics the more evenly this energy is distributed throughout the tank, and the smaller the cavitation vacuoles is when they collapse. This means that the higher frequency will clean in smaller areas on the work.

Full or ½ Waves

Some ultrasonic generators have a degassing stage that will chop the wave, this is to allow the entrapped gasses that are being driven out of the solution to leave the tank. A continuous wave will trap the bubbles in between the peaks of the wave. This entrapped gas diminishes the collapse effect of the cavitation. An ultrasonic tank is not an effective cleaner until it is degassed.

Power

The power of an ultrasonic generator is the total watts delivered to the transducers. If it is a 500-watt generator the power of the tank is somewhat less than 500 watts at any frequency. The power is more evenly distributed throughout the tank the higher the frequency. The power rating of the generator is also subject to losses from the transducers, tank design, solution, chemistry and the type of product being cleaned.
Wall Watts is the power the entire system draws, generator, fans lights, transducers.
Average Watts is the actual watts in the tank itself after it has started.
Peak Watts is the power required to start the transducer, and is usually twice the average watts for a brief period on start up.
Generator Power is the power output in watts of the generator, the actual tank power will be less.
Tank Power is the actual power in the ultrasonic tank liquid. It can be measured with a L-2000 probe
Frequency Distribution of power is how the power is distributed in the tank; the higher frequencies will have more even power distribution.

Power Intensity

Power Intensity is the control that will limit the amount of power that reaches the transducer. The curve of a power intensity control is not a straight line function, due to the fact that the transducer will require a higher tickler charge to start but will continue to operate at a lower setting. The power intensity control is used to set the amount of power so that the system will clean the part but will not damage it.

Sweep Frequency

Any transducer can be run at more than one frequency. A transducer has several nodal points where it is effective i.e., a 40 kHz can be designed to run at 40, 68, and 170 kHz with only a slight loss of efficiency at the secondary frequencies. [Determining the secondary frequencies is depended on the actual design of the transducer and the resonant masses applied to the transducer.]

Sweep Frequency will move the resonant point of the transducer 10 to 20 kHz either side of its base. It will not move it much more than that since until you get to the next nodal point on the transducer it will not resonate with any respectable power. The sweep frequency control in most systems does not allow you to choose the amount of sweep but only the times per second that the frequency is swept.

Sweep frequency is more effective at 170 kHz and above since the wave forms peaks are closer together and benefit more from the sweep. Cavities are more uniformly generated

Cavitation

The Pressure generated by the compression and rearification of the solution creates cavities in the liquid. The collapse of the cavities creates the shock wave that actually does the cleaning. The size of the cavity is dependent on the frequency. The lower the frequency the larger the cavity is before it collapses. Note cavities may go though several rarefaction and compression cycles before they are large enough to collapse. When they do collapse they tend to send the jet of plasma in the direction of the closest surface [your parts] Since the temperature in the jet can reach 5,000 deg. C and the shock wave is traveling at 700Mph it creates quite an effect on the surface of the part. This can cause cavitation erosion if the correct power level and frequency are not used.

The cavities are not generated uniformly throughout the liquid. Cavities are generated at and around the peaks of the wave. This is why most generators have a sweep frequency control

The ultrasonic power is usually stated in watts average. [Startup on peak watts could be double the average power]. The watts average refers to the output of the generator, not the output of the transducers or the actual power in the tank. It is the power that determines the ability of a tank to clean; the frequency determines what it cleans best.

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Degassing

Any liquid will retain an amount of dissolved Oxygen, when ultrasonic energy is applied to the liquid and the cavities are formed the dissolved oxygen will tend to migrate to these areas of lower pressure. The oxygen in the cavities will prevent their collapse and reduces the power of the ultrasonics. The 2 ways that you can degas a liquid is 1 heating the liquid to 80% of its boiling rate, 2 allowing the ultrasonics to run for about 10-15 minutes before use.

Transducers

The design of the transducer and the frequency has a lot to do with the even coverage of the ultrasonics within the tank. Most ultrasonic transducers today are a compound type of transducer that has a forward mass and a rear resonant mass. This allows the transducer to be bolt mounted to the bottom of the tank and to be tuned by compression of the stack. They are also held in place by epoxy to assure a good acoustical connection.

There is more than one type of transducer used in ultrasonic cleaning systems and it is important to know the type of transducer that is in your system as it will affect the performance of the tank. The types are

1. Piezo disk type: These are small [1.5” to 2” dia ¼” thick] transducers that are used on light duty tabletop tanks. They are made for light duty use and do not have the power to clean industrial or high end products. They are adequate for jobs such as dental tools, lab glassware and other light cleaning jobs.
2. Compound Piezo Transducers are the most common transducers used today and are used in most high end cleaning systems. They may be made to operate at more than one frequency.
3. Magneto-Strictive Transducers are used in very low frequency systems, they are mostly obsolete today

Surprisingly, we do not want every transducer to be exactly at the stated frequency; by having them slightly offset we can generate secondary frequencies that help reduce the stratification of energy within the tank. By mounting two or more transducers on a rectangular bar we can generate secondary frequencies that reduce stratification within the tank.

Tank Design

The ultrasonic tank design is also important. The shape and loading of the tank will have a lot to do with the propagation of the ultrasonics in the tank. The most important area of the tank is the diaphragm area where the transducers are mounted. There has to be the right amount of flex and stiffness to provide an even transmission of the frequency. The hardness of the steel also helps transmit ultrasonics better. A hard surface such as provided by electro-polishing the tank improves the reflection of ultrasonics within the tank creating a more homogeneous mix.

Parts Placement Fixtures

Parts in an ultrasonic tank should be placed at least 1 to 2 inches below the surface of the liquid. A rack or parts fixture should be used. The distance between the parts is not so much based on the frequency used as it is on the ability of the cleaning solution to be circulated between the parts. The ultrasonics will act as a pump and move the fluid in the tank past the parts. [This is one of the reasons that sono-chemisty works] The ultrasonic action destroys the barrier layer next to the part and pumps fresh cleaning solution to the surface of the part. In addition the ultrasonics forces the solution under the contaminant on the part and causes it to loosen. Ideally the parts should be placed ¼" apart in a tank to allow circulation of the cleaning fluid.

Since an ultrasonic tank is much like a speaker filled with liquid parts should never be placed on the bottom of the tank. This will change the propagation of the ultrasonic waves and will also place the parts in blind areas where the ultrasonics is not combined. [Each individual transducer projects a cone shaped ultrasonic path up into the tank. about 2" from the bottom of the tank is the lower limit for parts placement.

Work fixtures should be open and as light as possible. They are ideally made from electro polished stainless steel rod. The may be coated with other materials to prevent some solvents from degrading them. This is one of the most important parts of a cleaning system.

Filtration

The ability of a solution to clean is based on its volume in relation to the parts being cleaned. The larger the volume ratio of the cleaning solution is to the part, the more contaminates it can hold. There is a finite limit to any cleaning solutions ability to hold contaminants. This is why most systems have a re circulation filter system installed in the cleaning tank. This will keep the cleaning fluid cleaner; there is however a finite life of a cleaning bath based on no filterable contaminants and on the maximum holding power of the detergent.

Chemistry

The chemistry in the cleaning solution helps make the water wetter for better penetration and will change the electrical charge of the contaminate so that it does not hold to the part as tightly. DI Water is the most common basis for any cleaning solution. DI water in itself is a good cleaning agent since it is so hungry for ions. It will tend to extract the ions from contaminates and loosen the particles on the surface of the part.

The effect of the chemistry on the solution also extends to the ability of the transducers to propagate ultrasonics. Some chemistry will inhibit the formation of cavities within the solution. Some will aid the formation by reducing the surface tension of the solution and its vapor pressure.

Solvents should always be used with great care. The ultrasonic process will cause light solvents to give off a very fine mist. This mist is highly flammable. This type of cleaning solution should only be used in special ultrasonic tanks designed for this purpose. Consult the manufacturer for how to use solvents in an ultrasonic cleaning solution. **Do Not Use Flammable Solvents in any Ultrasonic Tank unless it is specifically designed for this purpose.**

DI Water

It is always desirable to use DI water as the basis for your cleaning solution. DI water has no minerals or other ions in it and as a result looks for those ions the only place available that is usually your product and contaminates on it. This greatly enhances the cleaning power of your solution. It is also very good for rinsing since it will strip off the detergent better than regular water and it leaves no residue so spotting is eliminated.

Heat

Heat will help the chemical action of any solution by adding energy; this also makes it easier to cavitate the solution. It reduces the surface tension and the vapor pressure and also increases the molecular movement within the solution.

Most chemistries work better with heat. Care should be taken not to overheat a cleaning agent so that it starts to break down.

Base Line Performance Mark

Get a base line for performance for your new tank; Even if you can't afford a probe to test and record the ultrasonic tank performance you can do a simple aluminum foil test to determine your tanks initial performance and keep this record in a book to compare to future records. To perform this test you will need some aluminum foil

1. Prepare an aluminum foil sample. Obtain a roll of standard lightweight household aluminum foil. Measuring approximately one inch greater than the depth of the tank by approximately the width of the tank. Use a scissors to cut the foil. Do not tear the foil to separate it. Smooth the foil using a soft cloth on a smooth table top or desk so that the surface of the foil is shiny. Wrap one end of the foil [top] around a rod or wire so that it can be suspended in the liquid.
2. Set the power intensity setting to full [if your tank has this control
3. Allow the tank to come up to operating temperature. [Record this in your log.]
   Turn the ultrasonic cleaner on for a minimum of five minutes using the timer function to assure proper degassing of the cleaning solution.
4. Turn the ultrasonic cleaner on for a minimum of five minutes using the timer function or a watch to assure proper degassing of the cleaning solution
5. Reset the timer for 60 seconds. Lower the foil sample, which was prepared in step 1 into the tank. Position it vertically; the foil long dimension should be positioned with the long tank dimension. The foil should extend downward to the tank bottom but not touching the bottom.
6. Use a piece of tape to hold the rod in position as steady as possible. Turn on the ultrasonic cleaner for exactly 60 seconds.
7. Turn off the ultrasonic cleaner. [This will occur automatically if you have a digital timer.] Remove the foil and allow drying in the air. Be careful not to wrinkle the foil.
8. The first time you perform the test, immediately after the initial purchase or after a servicing has been performed. The following observations and actions should be made.
   A. The foil surfaces, actually submerged into the solution, should be uniformly peppered, that is worked with a tiny pebbling effect over the entire surface.
   B. Areas greater than ½" square having no pebbling should indicate that there is a possible problem with this unit. The unit should be immediately retested using new foil, to substantiate the failure. The unit along with its latest foil record should be returned to your service center for service, if both foil samples agree.
   C. If the foil sample is correct, then it should be retained in your cleaner file for future comparative purposes.

In subsequent testing you should not only make the observations listed in step 8 above, but also you should compare the new foil with the previous foil retained in step 8 above. The foil records form a characteristic picture of your particular ultrasonic cleaner. If these foil records differ, materially, contact you service center.

While the aluminum foil test will show approximately how the tank is performing, it is much better to use an instrument specifically designed to show the power in the ultrasonic tank. This way you can test not only the tank and individual transducers, you can also test the efficiency of the work holder.

The Basic Process

Initial Set Up of the Ultrasonic Cleaning System

Location:

There are several tips and rules to follow when using an ultrasonic cleaner for getting the best performance possible. Locate the cleaner in an area where you have plenty of room to stage your parts prior to cleaning and where you have room to stack the clean parts after cleaning. If you are going to rinse your parts after cleaning locate the unit close to the rinse area. Do not block the generator airflow as this will overheat the generator and cause a loss of cleaning action and damage the electronics. If your generator is separate from the tank make sure that it won't get wet when you are cleaning parts.

Locate the cleaner in an area where there is a source for water, and a drain. Wipe the inside of the tank with a damp cloth, or chem. Wipe to remove any dust or other material in the tank. Make sure the drain is closed.

Set Up:

Fill the tank with Water [or DI water] to about 1 inch from the top, add a measured amount of detergent as recommended by the detergent manufacturer and set the heat for the temperature that you will be using in your cleaning process:

Allow the tank to reach operational temperature and record the length of the heat up time. This can be used for comparison later if there is any heat up problems. Measure the temperature of the liquid in the tank and compare it to the set point temperature on the tank. [There is usually some difference due to the fact that most small tanks do not have an internal thermocouple but use an outside thermocouple or thermostat on the outside tank wall.] Record the difference in set point and actual temperature.

Work Fixtures and Parts Loading
Always use a work fixture or basket that is suspended from the lip of the tank; never use a basket or parts fixture that sits on the bottom. This will distort the ultrasonics and the vibration will eventually damage the bottom of the tank. Do not use plastic work fixtures. Plastic work fixtures will absorb ultrasonics and block it's cleaning action. The work fixture should be designed to hold the specific part that you are cleaning. The best material for work fixtures is electro polished stainless steel rod. The fixture may be coated to withstand some aggressive types of chemistry. Very small parts can be cleaned in a beaker that is held in a special beaker holder

Prepare the parts to be cleaned by rinsing off any excess dirt or oils, this will make the solution in your tank last longer and work better.

Load the parts with space between the parts to allow the cleaning solution to reach all areas of the parts. Make sure all parts are located so that there is about 2" fluid below the parts and about 2" fluid above the parts when they are placed in the tank. This will assure the parts have enough fluid to be completely cleaned. Do not overload the tank with parts.

Place the basket in the ultrasonic tank set the power intensity to full and turn on the ultrasonics for about 3 min. After the ultrasonics has stopped remove the parts and rinse in clean water or DI water. Observe the parts visually for dirt and or cavitation erosion damage that may be caused by the ultrasonics. If there is no damage, and the parts are clean proceed with cleaning. If you see cavitation damage, reduce the power and lengthen the cleaning time. By manipulating the 2 factors of time and power you will arrive at a setting that will clean your parts without damage.

Rinse
After the ultrasonic detergent clean, rinse the parts in DI water spray, this removes most of the detergent layer on the parts. For ultra clean parts you should rinse the part in an ultrasonic overflow rinse tank. This tank may be equipped with a resistivity rinse controller that will tell you how clean your part is.

Dry
The parts may be dried in air, usually in a class 100 laminar flow hood or in a HEPA oven dry system that uses filtered dry hot air as the drying agent. A lower temperature such as 120 to 179 deg. F is recommended for most parts. It does not "flash dry" the parts.

Maintaining the Cleaning Process

1. Keep the Detergent tank clean and free of any dirt or parts on the bottom of the tank.
2. Get a base line evaluation of the tank when you start your process.
3. Record the parameters of your cleaning process
    a. Tank Temperature [detergent and rinse]
    b. Water quality
    c. Cycle time [Detergent and rinse]
    d. Type and amount of detergent
    e. Power level of ultrasonic tank
    f. Method of loading and inserting parts into the tank
    g. Dry temperature and time

Ultrasonic Power Meters and how they work
Most ultrasonic power meters work on the same principal at that of a sonar receiver. They are a transducer that receives the sound waves generated in the tank by both the compression and rearification waves of the ultrasonics. The amount of power generated is directly proportional to the amount of cavitations in an area.

The design of the probe will affect the overall reading. The design of the probe should be similar to an acoustical receiver in a submarine in that it picks up the power in the liquid at a specific spot or area in the liquid.

The amount of power that is picked up is dependent on the size of the probe and the design of the acoustical transducers. The receiving transducers are the same material as the ones on the ultrasonic tank bottom but they are a different shape designed to receive signals in a specific area.

Most ultrasonic probes just show a power level. The ultrasonics generate a certain amount of voltage in the receiver and display it as either Root Mean Square or Watts [dependent on the circuit in the probe electronics package] A problem with digital displays are that they are too sensitive and must be dampened to a certain extent. If the signal is over dampened it is not representative of the wave as the power level and cavitation is changing by the mili second.

As the frequency is increased less and less power is generated at any one spot in a tank and the meter has a harder time picking up the frequency. Most hand Held meters have an amplification circuit in them to increase the signal strength. If this is not done correctly it will also distort the signal.

The probe design was also a problem; large sensors were not adequate to get in tight places. Designing smaller probes required new types of sensors; we worked with a company to design a system similar to the ones used in submarines.

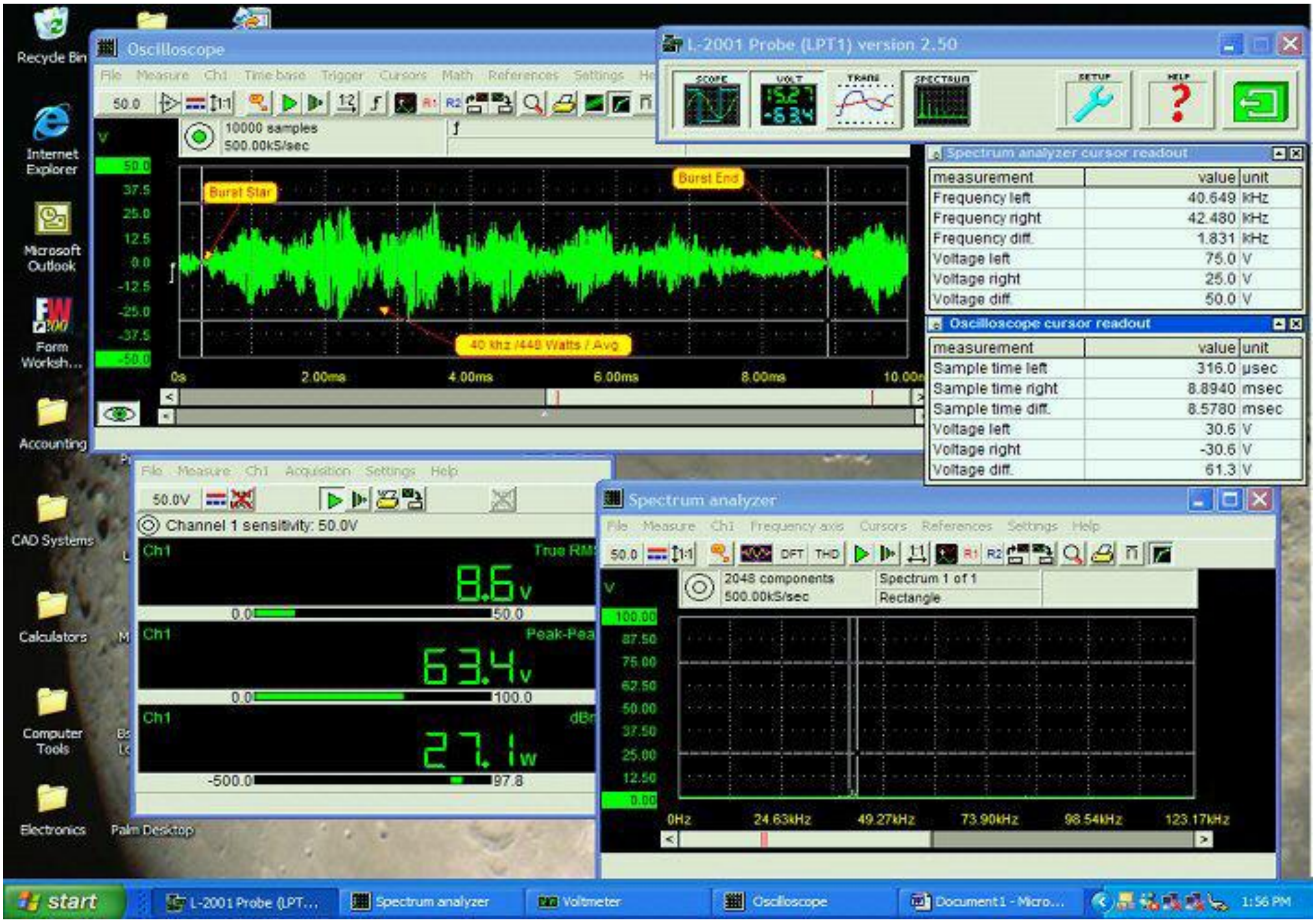
We initially started out with a hand held meter type so that we could design better tanks, and found that it was adequate for determining power levels in spot areas in the tank for frequencies up to 120 kHz above that it was hard to read the signal. It did not tell us the frequency or the secondary frequencies that were generated in the tank

Over the years we developed a software package in conjunction with a firm that designs computer sonar instrumentation that tells us all the things we want to know so that we can design tanks and cleaning systems that work.

We needed to know the following

A. The actual frequency generated within a tank [and its power] and the secondary frequencies.
B. The voltage [RMS] or wattage at any spot in the tank
C. The wave form
D. A way to record the data for later analysis so that we could compare performance work fixtures within and with other tanks.

What we developed is the L-2001 probe system. This was developed as an internal instrument for our own use but we have since made it a product.



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