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(See Pages 37 & 39)

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ULTRASONICS — and its uses

The magic of "silent sound" is being widely used in our industry, hospitals, aircraft, submarines, and missiles.

By **ROBERT L. ROD**
President, Acoustica Associates, Inc.

ABOUT THE AUTHOR

Our author, 38-year-old president of Acoustica Associates, Inc., has built the company in just a few years into the nation's largest exclusive producer and designer of ultrasonic equipment. Into his company's eight plants at Mineola, New York, Hartford, Conn., and Los Angeles, he has brought 350 employees, mostly skilled engineers, to help and expand his ideas.

Rod studied electrical engineering at Georgia Tech, took his degree in 1942, joined the Signal Corps, and was sent to England to study radar. After the war, he worked on radar at RCA for five years, then briefly for Melpar, Inc., and for Bogue Electric for four years as Director of Research. With his associates, he has expanded Acoustica from its first order of $1200 four years ago into a company whose sales are expected to reach $5,000,000 this year. Rod is proud that Acoustica is the only company with under 500 employees ever selected by the U. S. Air Force to be a prime contractor in the "Atlas" Intercontinental Ballistic Missile program.

SOMEWHERE in the stillness of outer space a giant missile intrudes. And, within its complex apparatus, "silent sound" waves, too high in frequency to be audible to human ears, pulse from a tiny device. They help assure the successful flight of the missile toward its appointed goal.

"Forceps . . . scalpel . . ." the surgeon commands during an operation and the instruments, after use, pile up quickly. Soon, the mound of blood-soaked surgical instruments, with bits of tissue adhering to crevices, are loaded into what looks like a home dishwasher where sound waves, unheard, pass through the batch, and in a few minutes, they are spotless, shining like new, surgically clean.

In a spotless, dust-free lab of a giant electronic manufacturing plant, an engineer dips a basket of delicate transistors and other miniature electronic parts into a hissing bath of water. It seems to be boiling but the water is not hot; it is being "irritated" by sound waves. The tiny parts emerge clean.

A new science has emerged almost overnight from a laboratory curiosity of yesterday to a powerful tool of industrial production today, and even more amazingly as an integral key in our nation's defense. This new science of ultrasonics has a short history. From underwater sonar of World War II and the silent whistle that dogs alone can hear, ultrasonics has emerged in the last decade into big, cleaning, processing, and machining systems; liquid level measuring uses; and other applications all over the world, including Soviet Russia, according to reports.

Principles of Ultrasonics

It is difficult for the average person to imagine that audible sound, much less the inaudible variety, possesses real physical power. Audible sound waves we hear often are very powerful, but ultra-sound offers an opportunity to use even higher power without creating disturbing noise. Scientists have just scratched the surface of ultrasonic power and its useful functions.

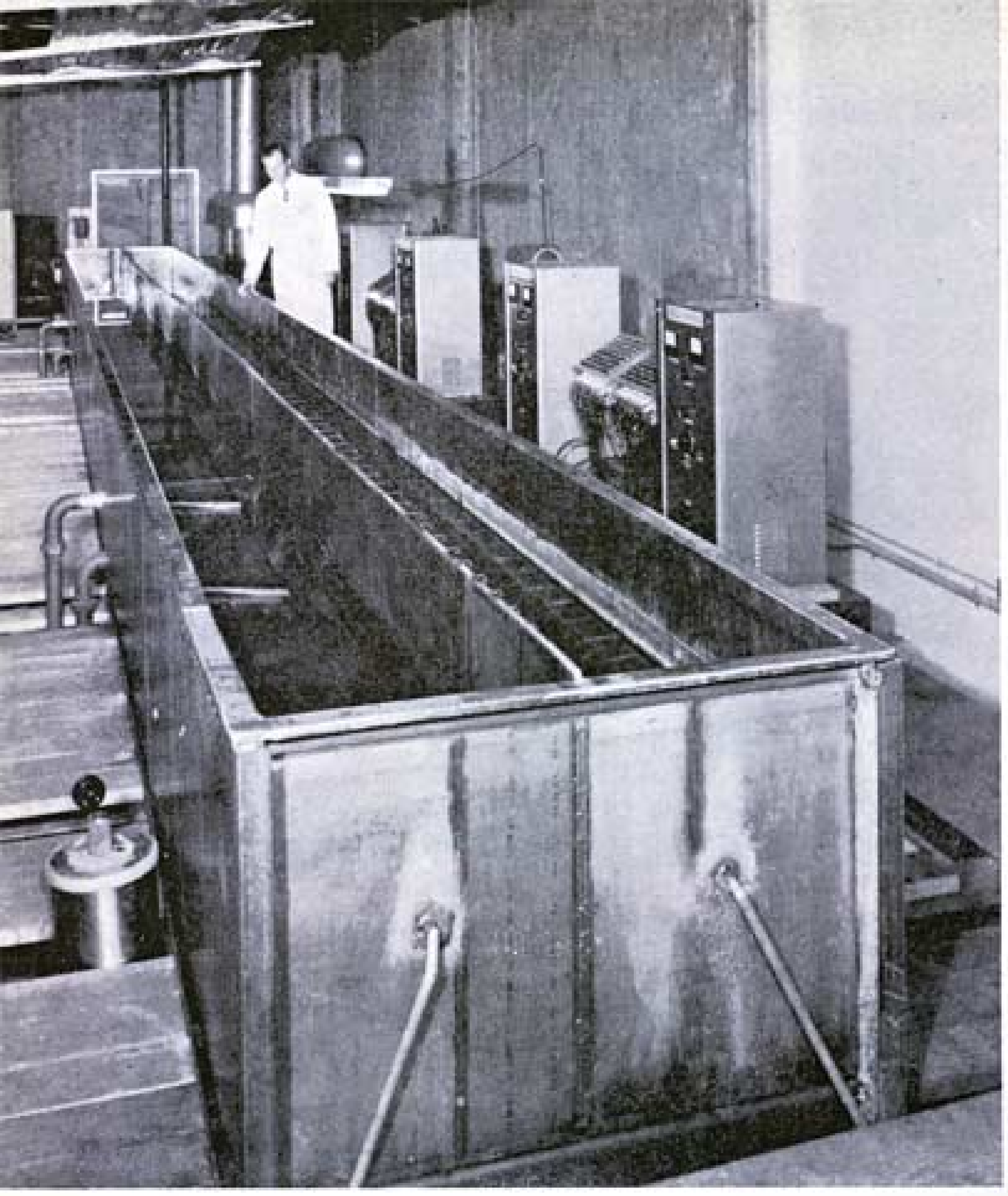
Enrico Caruso, according to legend, could shatter a wine glass with his great voice. There is nothing new about the idea of sound having powerful properties beyond its communicative functions, but few have seen its power in action even today.

Perhaps the simplest demonstration of the existence of ultrasonic "silent sound," is the silent dog whistle. Human ears can not hear its high-frequency waves, but they do register on Fido's wider hearing range. Ultrasonics differs from audible sound only in that ultrasonic frequency is higher, pitched above 18,000 cps, which is close to the limit of much human hearing; ultrasonic waves are shorter than audible wavelengths.

Both sonic and ultrasonic waves, caused by mechanical vibrations, travel through air, liquids, and solids at differing speeds: about 1100 feet-per-second in air against about 4700 feet-per-second in water, and 15,000 feet-per-second in metal. In most of the present-day commercial applications requiring some form of useful work, ultrasonics makes use of the liquid medium (or solids in liquid phase) for its powerful effect. Exceptions include lowered-power non-destructive testing of material for determining thickness or locating flaws in metals and the ultrasonic precipitation of air-borne particles, smoke, and smog.

Liquid, then, is the vital component in many standard ultrasonic equipments now on the market. On one hand, low-power ultrasonic devices measure liquid level ultrasonically as in missile fuel control systems. On the other hand, high-power ultrasonic devices "irritate" liquid by radiating ultrasonic waves through it; the resultant agitation, called cavitation, a "cold boiling" effect, is caused by the ultra-rapid formation and collapse of many millions of microscopic bubbles thousands of times per second. This agitation performs such useful functions as cleaning and degreasing parts im-

Printed circuits may be cleaned by ultrasonics.



Giant ultrasonic system, the largest in the country, cleans fully assembled fuel gauge apparatus (not shown) of an intercontinental missile, in this 42-foot long tank. More than 100 transducers attached along tank bottom irradiate the cleaning solution. Generators along side power the submerged transducers.

mersed in a suitable solvent liquid, processing, homogenizing, plating, and even drilling square holes through glass or in teeth. Fluid, in the form of an abrasive slurry, performs the action in the case of drilling, as in the other applications.

Since cavitation is the functional action in virtually all of ultrasonic industrial cleaning and processing equipment, as well as in new applications now on the drawing boards, it is important for us to understand it more fully. Cavitation is a difficult phenomenon to describe or explain. Scientists have only an approximate concept of its cause and effect.

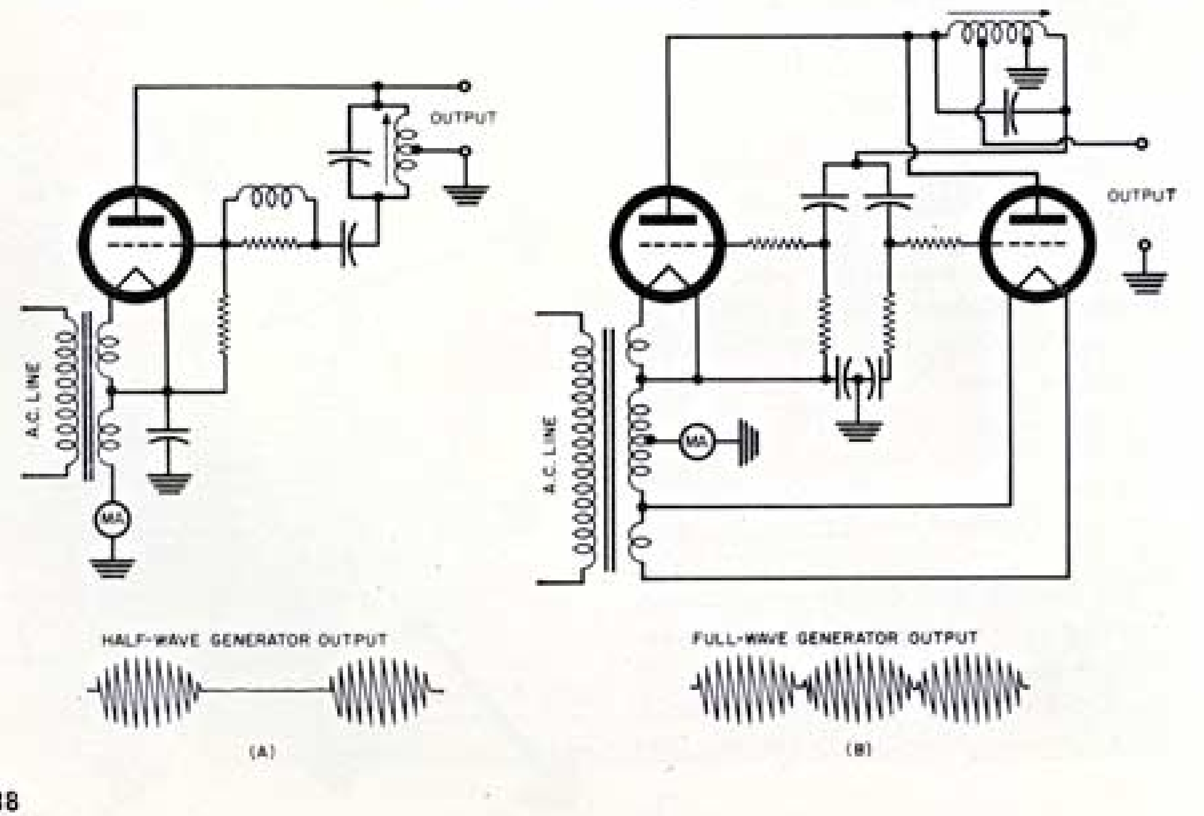
The ultrasonic waves are introduced into the liquid. These waves are usually produced originally by converting electrical energy to mechanical sound vibrations in a transducer. When the ultrasonic vibrations, nowadays generally ranging from 18,000 to 40,000 cps, are passed through the liquid, they actually rupture the fluid at a periodic rate. During fluid rupture, microscopic vapor bubbles or cavities form as the tension phase of the transmitted wave passes through the fluid. In other words, the negative pressure cycle of an ultrasonic wave creates local pressures lower than the vapor pressure of the liquid and so vapor cavities are formed. The cavities so produced are not stable because during the positive pressure cycle of the ultrasonic wave, pressures are higher than the vapor pressure. Thus, during the compression phase of the alternating sound pressure wave, these vapor cavities instantaneously collapse with subsequent release of quite tremendous localized forces.

Because of their great implosive force, collapsing globules impinging on objects immersed in the cavitating fluid can physically blast away any deposits of clinging dirt or foreign matter even within otherwise inaccessible crevices. In some cases, depending on the material and time of exposure, the surface of the object submerged in an ultrasonic cleaning tank is literally eroded away.

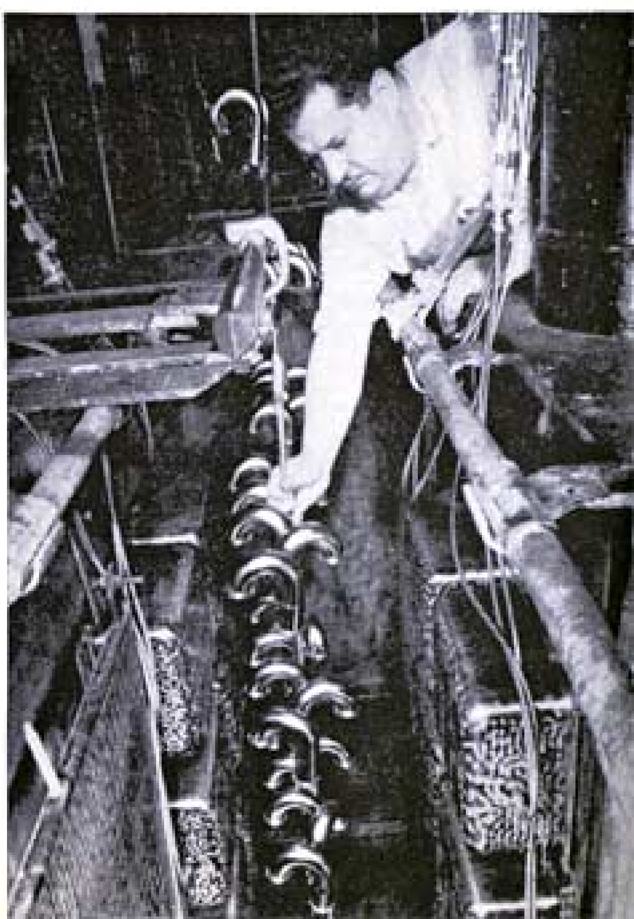
Cavitation also has great effect on the liquid itself. It can de-gas fluids, homogenize and emulsify, and perform other important processes that were difficult, costly, or even impossible to do at all before.

While cavitation is the *modus oper-*

Fig. 1. (A) Schematic of 60-watt average power self-rectifying half-wave generator, operated in class C, with its output 100% modulated at the line frequency. Peak power is 240 watts. Circuit is Hartley oscillator with grounded plate. Triode conducts only on half cycles of line frequency when filament goes negative. Tank coil uses poly-iron slug whose position is changed by tuning knob. This determines the frequency and is used to match generator frequency to that of transducer. It also serves as power output control. (B) This is a 125-watt average power self-rectifying full-wave generator which operates like the previous unit except that output is obtained on both half cycles. Peak power is twice average power in this case.



Banks of ultrasonic transducers are arranged, six to a side, within cleaning tank where they remove soils from brass plumbing fixtures during production at Keeney Mfg. Co. The mottled appearance of the transducer casings is the result of a surface phenomenon resulting from ultrasonic vibrations. This does not in any way affect the life or performance of the units.



and associated with practically all under-liquid applications requiring useful work, ultrasonic gauging generally operates at sound pressures which are below the so-called "threshold of cavitation." The familiar sonar equipment and related depth sounders, fish locators, and liquid level gauges transmit pulses of moderate power which return as echoes some intervals later, the measurement of those time intervals imparting the desired information.

Why can't these applications employ the same high power as in the liquid processing and cleaning equipment? Should the power be deliberately raised past the threshold of cavitation, the long-distance performance would be severely limited by the scattering effects of the cavitation bubbles on subsequent sound waves. Thus, the effective coverage of such information-seeking ultrasonic instruments may be severely curtailed.

Types of Transducers

To create cavitation in liquid, or the non-cavitating low-power waves for gaining information, how do we produce ultrasonic waves at the proper place and frequency? First, we need an appropriate driving source of power or energy for the transducer. Then, the transducer converts that energy, be it electrical, mechanical, or hydraulic energy, into sound waves. For all practical purposes today, the electro-acoustic transducer is used rather than purely mechanical or hydraulic transducers.

The transducer usually is separated from the generator and connected by cable to it. Generators generally employ an electronic oscillator as a source of power. They are simple and able to produce efficient pulsed power. The transducer is either attached to the bottom or sides of the tank or it may be immersed in the tank fluid itself.

Transducers fall into two major categories—magnetostrictive and piezoelectric—plus a new type of transducer[1] that combines the best elements of the other two basic types.

Magnetostrictive Transducer

A magnetostrictive transducer develops sound energy when alternating current is passed through a coil surrounding a material that changes dimensions under the influence of a magnetic field. The change in dimensions of such material under these conditions is known as the Joule effect, named after its discoverer. The material used is usually nickel or a nickel alloy in the form of sheets of thin punched laminations bound together in a stack, like a deck of cards. When the a.c. current is applied to the coil, the stack expands and contracts, setting up mechanical vibrations. When the stack is driven by alternating current at a frequency corresponding to its natural resonant frequency, even greater motion results. In practice, this is always the case.

Because the magnetostrictive nickel must form the core of what is essentially an a.c. solenoid, this type of transducer is most suitable where large forces are to be applied to relatively small areas, such as in ultrasonic welding, soldering, and drilling, or where an ability to withstand high temperatures is required. (The Curie point, above which magnetostriction no longer occurs, is 358° C. for nickel.)

When magnetostriction transducers are directly immersed in the process tank, cooling can usually be obtained from the liquid itself. Heating due to external losses of magnetostriction transducers not in direct contact with liquids is generally controlled by either cooling water or else by means of an air blast.

Piezoelectric Transducer

Piezoelectric transducers are made up of slabs of material such as quartz, barium titanate, and certain other ceramics in which alternating electrical energy is impressed across these

Cover Story

OUR cover this month symbolizes the important use of ultrasonics in cleaning the rosin flux from a printed circuit board. This is frequently done both before and after the components have been mounted. In order to dramatize the effect, we covered the board with green paint which we then allowed to dry.

Here is the plastic demonstration tank we used for our cover shot. The two transducers may be clearly seen at its bottom.

Photo below shows latest commercial ultrasonics cleaner for surgical instruments.

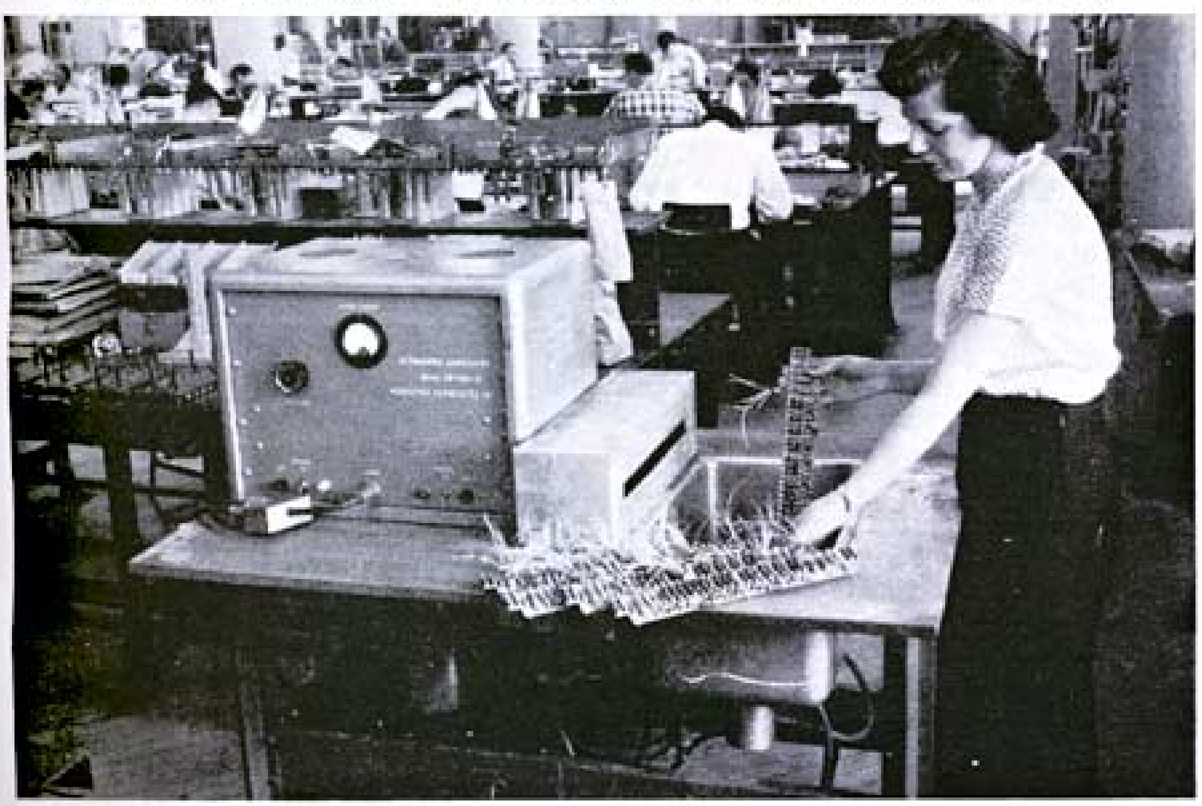
When the painted, printed board was dunked into the ultrasonic cleaning tank, the paint began to boil off.

The cleaning tank used was a special demonstration tank made of clear plastic so that the ultrasonic cavitation can be seen clearly. Two transducers were mounted at the bottom of the tank and these, in turn, were connected to the output of a small, portable ultrasonic generator. The setup was photographed at the Mineola, Long Island, New York, plant of Acoustica Associates.

The miniature printed board used was produced by Photocircuits Corp. for a large computer. The board is made of epoxy-glass laminate, with gold-plated conductors and rhodium-plated contact fingers. Seven half-watt resistors and a dozen semiconductor diodes are mounted on the board. —30—

(Cover photo by Dave Henderson)

Transistors and other electronic parts "take a bath" in ultrasonically radiated tank at Otis Elevator Co. plant. Transducer located at base of tank puts sound waves into liquid. Power is provided by the generator at the left of the tank.



[1] Developed by Acoustica Associates' General Ultrasonics Division.

Hundreds of camera lenses which are caked with hard pitch used to hold them during grinding, are dipped into this ultrasonics tank for a final cleaning operation.

slabs to set up vibrations at the natural resonant frequencies of the pieces. Barium titanates, artificially produced piezoelectric material, may be cast during fabrication into various shapes other than slabs which are suited to focusing ultrasonic energy within a small area where more intense cavitation can be developed for localized processing. Typical shapes include parabolic bowls and cylinders. Generally, the titanates operate below 100° C., although they are among the most efficient transducer materials.

Combination-type Transducer

The two conventional transducer categories, magnetostrictive and piezoelectric, first developed for underwater sound purposes, have certain limitations for commercial use. These have been overcome by a third type of transducer, which may be referred to as a combination or multi-power type.

The multi-power transducer makes use of a solid metal section as the major operating element. The active transducer material itself is positioned near the center of the element. The remainder of the vibrator is made of special alloys that are nearly loss-free at commonly used vibration frequencies. The transducer material itself can be made of any suitable vibrating material, including barium titanate if desired. The thermal conductivity of the metal permits almost any piezoelectric transducer element to be used continuously and at higher-power level.

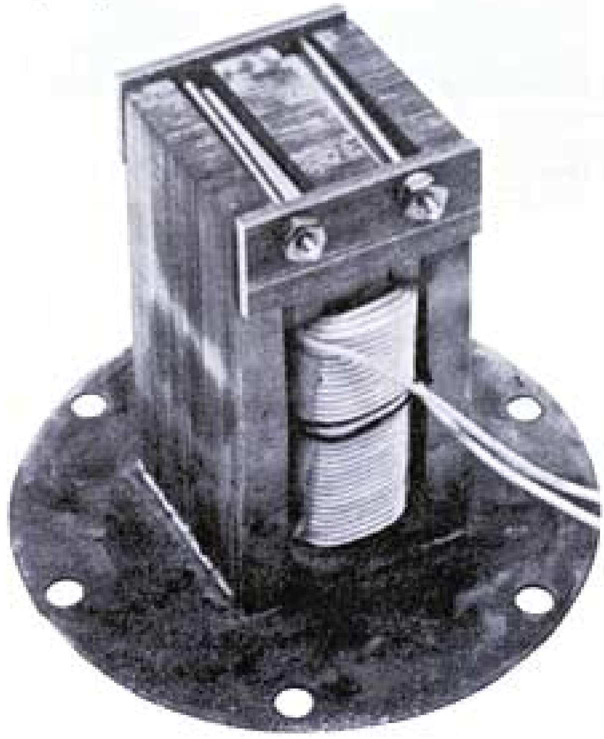
Ultrasonic cleaning and liquid processing equipment varies greatly in detail depending on the variable conditions of each specific application. You can buy off-the-shelf equipment from stock in appropriately scaled sizes. They range from small beaker size to tanks holding 150 gallons.

Equipment Specifications

Basic components of all ultrasonic cleaning systems are the generators, transducers, and tanks, assembled like building blocks, with one or more tanks, containing single or multiple transducers, operating off one generator in many cases. Larger or nonstandard systems are available on special order to meet requirements for virtually any cleaning system, whether it be a simple batch cleaning operation or a conveyorized system. In one interesting example where the long, slender assemblies used in the "Atlas" missile are cleaned, a 42-foot-long ultrasonic cleaning tank is used. The long liquid-filled tank is radiated by more than 100 transducers ranged along the entire tank bottom.

In addition to the necessary hardware, the liquid within the tank must also be considered an integral component of the system. This liquid may be plain water, water containing detergent, or appropriate solvents. Harmless water solutions frequently are used for cleaning items previously requiring highly toxic solvents which were harmful to the item itself and dangerous for the operators.

Magnetostriction transducer has been partly disassembled to show interior.



In selecting or designing a particular ultrasonic cleaning or processing system, there are many variables to be considered. The type of materials to be cleaned, the soils to be removed, the solvents and detergents used are all factors. The resulting reductions in direct labor costs, the requirements of quality control; all must be weighed and considered.

Most of the cleaning equipment operates at frequencies between 20 and 40 kc. at pulsed power outputs ranging from 50 watts average and 200 watts peak for small portable units to 2 kw. average and 8 kw. peak for large capacity equipment. Among the most important considerations in selecting operating frequency are power needed for the cleaning application, maximum efficiency, and audibility. Different liquids vary in their "threshold of cavitation" and so different acoustic powers must be utilized. The power required for frequencies above 50 kc. rises rapidly under usual conditions. For this reason, and because 18 to 20 kc. is too near the upper limit of human hearing, the frequency is selected to fall above the audible range but below the point where efficiency begins to fall off noticeably.

Modern ultrasonic generators almost invariably emit pulsed output rather than a constant amplitude output (c.w.). What is the reason for using pulsed or modulated generators over the continuous-wave type? (Fig. 1 shows diagrams of pulsed, or self-rectified, generators.)

We know that if an air barrier, however small, is present between the liquid to be cavitated and the vibrating transducer, we will greatly attenuate the sound energy, reducing the development of uniform and complete cavitation in the liquid. Just such an air barrier is apt to appear across the face of the vibrating transducer in the form of a screen of cavitation bubbles at the area of maximum acoustic power input. However, by pulsing the generator, we allow this screen of bubbles to die out momentarily. We can then send through another burst of sound. Cavitation will then develop farther into the cleaning tank than would otherwise be possible with a continuous power source. Pulsed power, therefore, allows

(Continued on page 172)

Ultrasonic footwear bath decontaminates radioactive soils on shoes of workers in nuclear plants thus preventing dangerous radioactive soils from being tracked from "hot" areas on soles of the rubbers. The small portable ultrasonics generator on the box at right supplies the power.

Ultrasonics—and its Uses

(*Continued from page 40*)

for complete development of copious cavitation everywhere within the cleaning tank.

Liquid Level Switches

The liquid level switches, or sensors, are miniaturized, hermetically sealed ultrasonic probes which are sensitive to the presence or absence of liquids. The probes are installed in the monitored area at predetermined levels, at high and low points in a tank for example. An associated control unit is placed at a convenient location for the operator, connected to the sensing probe by cable.

The control circuit consists of a single transistorized oscillator and a subminiature relay in a hermetically sealed metal case. The piezoelectric sensing element in the probe and the associated circuit in the control unit function effectively as a crystal oscillator. When liquid surrounds the probe tip, it has a damping effect, and the circuit does not oscillate because of the high acoustic impedance.

If the medium surrounding the probe changes again from liquid to air, the acoustic impedance abruptly drops and the circuit immediately starts to oscillate. The relay in the control unit, which is activated by the oscillator, is used to energize any auxiliary indicating or control system.

In missiles, the ultrasonic liquid level system will accurately measure the amount of liquid fuel in a tank at any angle during flight, relay the data to a missile-borne computer, which regulates missile fuel supply. It has also been used in such diverse applications as low- and high-level warnings in aircraft fuel, lubrication and hydraulic systems, and in food processing, chemical plants, and in the petroleum industry.

Applications

Powerful ultrasonic cavitation within a liquid will clean and degrease, even decontaminate radioactive materials and other soils from the most inaccessible crevices of instruments immersed in the cleaning tank. Such cleaning systems are being used today for cleaning everything from delicate electronic apparatus to surgical instruments, from camera lenses to giant missile assemblies. The penetrating ultrasonic cavitation eliminates the prior need to disassemble complex instruments. The cavitation, despite its great power, will not harm glass, chrome-plate, stainless steel, or etched and painted markings.

Some items that are being cleaned by ultrasonics include: motor and generator armatures, electric meters, relays, transistors, potentiometers, printed circuits, and vacuum tubes. The cleaning systems will quickly remove excess solder flux, etching resists, fingerprints, polishing compound, lint, waxes, and a wide variety of other soils from virtually all types of items.

Besides liquid level control systems for missiles, the military is also developing newer ultrasonic systems for search and depth sounders and for underwater communications and other similar applications.

Besides the surgical instrument washing machine, hospitals and the medical field are also using ultrasonics for various physical therapies where ultrasonic energy at certain frequencies will heat deep tissue, much like diathermy. Ultrasonics has also been found useful in locating tumors, and in brain surgery.

The metalworking industries have become prime users of ultrasonic equipment, not only for cleaning. Ultrasonic drills can make square holes in hard and brittle materials such as tungsten carbide, steel, brass and even in glass because they drill in an up-and-down movement rather than by turning. In drills, the ultrasonic energy activates an abrasive slurry which literally eats away the undesired material rapidly.

Up to now, soldering aluminum has been extremely difficult because of the problem of removing the oxide coating from the surface of the metal. But ultrasonic soldering irons transmit their sound waves through the molten solder to the surface of the metal. The turbulence tears off the protective oxide film permitting tinning to take place.

Because cavitation will de-gas fluids, it has become important in solving certain problems in this area. Sound waves, for example, are beamed through beer bottles just prior to capping, causing it to foam and forcing out the trapped air. If the air remained, it would cut down the shelf life of the beer. In certain wineries, ultrasonics has been used to greatly speed the aging process.

Ultrasonics is being used more and more as a tool of inspection in the railroad, aircraft, metals, and related heavy industries. Sound waves can "see" inside metal. When a crack, corrosion, or other defect, hidden from sight, is encountered by the sound waves, part of the waves are reflected back to the measuring instrument. The remainder travel to the opposite end of the material where they, too, are reflected back. The exact location of flaws in the metal as well as the thickness of the piece can be spotted by comparing the time it takes the waves to make the round trip with a reference.

The Future

We are developing the existing applications of "silent sound" in cleaning and processing and in liquid level measurement. We are exploring new ways of harnessing the power of ultrasonics, not only within or associated with liquids but outside the liquid medium. Greater research is needed by industry, laboratories, government, and individual scientists. Their discoveries will yield tremendous rewards in the decades to come from the amazing power of unseen, unheard ultrasonic waves. —30—