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ULTRASONIC DEVICE

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Fig. 1.

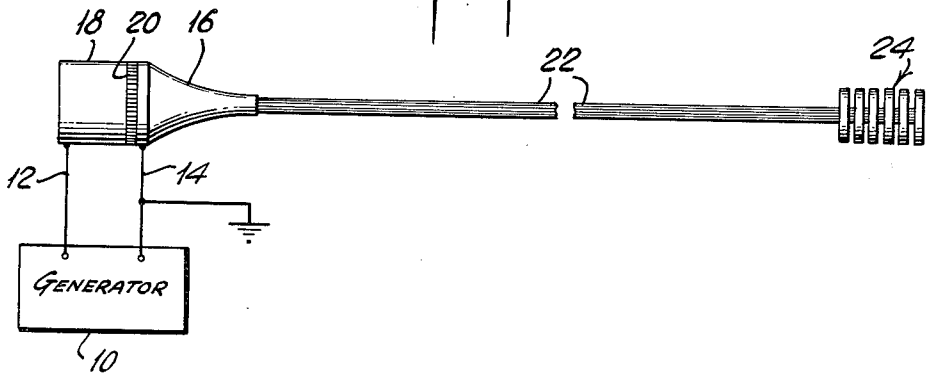



Fig. 2.

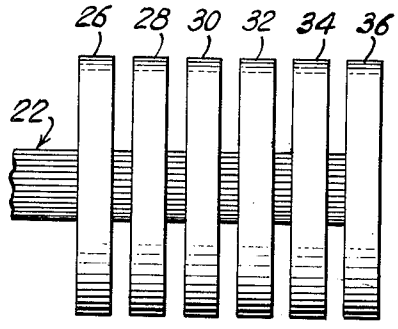
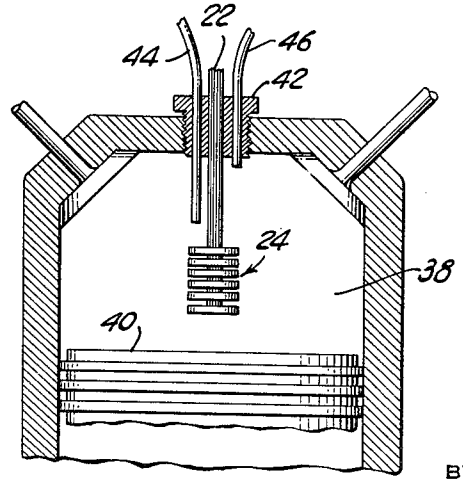



Fig. 3.




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# ULTRASONIC DEVICE

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This invention relates to an ultrasonic device for performing useful work at a location remote from the ultrasonic generator, and more particularly, to such a device utilizing a flexible transmission line.

Since the invention has particular utility as an ultrasonic cleaning device, it will be described in that environment, however, its wide applications will be immediately apparent to those skilled in the art and the breadth of the invention should be construed accordingly.

Referring now to ultrasonic cleaning, it is known that ultrasonics has given industry a new solution to many of its most difficult cleaning problems. Through it, many modern cleaning techniques have been developed which have resulted in greater economy and manufacturing ease with attendant saving in time, labor and space. One widely used application of ultrasonics is for cleaning metal parts.

The use of ultrasonics in metal cleaning rests upon the production of cavitation on the surface of the part to be cleaned by the action of high energy sound waves in a liquid medium. The sound pressure initially produces a movement of liquid away from the source of the sound and circulating currents are set up in the liquid. The alternating pressure maxima also cause an oscillating motion of individual liquid centers. If the intensity of the waves is higher than a given value dependent on treatment conditions, cavitation will be produced within the sound beam.

Cavitation requires a surface capable of having suitable cavitation centers. A static surface such as a metal covered with a contaminant adhering to it is obviously a ready source of such centers, and if the sound intensity is high enough, there will be repeated cavitation bursts immediately adjacent to the surface of the solid material. The very high instantaneous hydrostatic pressures produced by these bursts literally explode the adhering particles from the solid surface, and assisted by the alternating and steady liquid flow the particles are quickly removed from the vicinity of the surface. The lowering of surface tension at the interface between the contaminant and the work increases the wetting action of the liquid and thus assists in the removal of the foreign particles.

The ultrasonic cleaning of metal parts had heretofore been accomplished by immersing the parts to be cleaned in a non-polar solvent such as trichloroethylene or other chlorinated hydrocarbons. Acoustical energy is then beamed at the parts to be cleaned by means of piezoelectric barium titanate transducers immersed in the solvent. This cleaning method of the prior art has demonstrated outstanding results in the removal of contaminants remaining on such divers metal surfaces as galvanometer movements, electric shaver parts, sub-miniature measuring devices, miniature ball-bearing assemblies, elements of vacuum tubes, small motor parts, printed or etched circuitry and medical apparatus such as hypodermic needles.

However, there are many metallic parts for which the prior art has proved ineffective or impracticel. Some metallic parts are far too cumbersome to be totally immersed in a solvent bath, others are in a permanent installation where removal for cleaning would be both costly and impractical. Still others require frequent cleaning in only a small area on their surface or within the body proper for which the prior art has no satisfactory ultrasonic cleaning apparatus. There are also many applications where it is desirable to effect the cleaning of a machine or device without necessitating its dismantling.



This invention provides an ultrasonic cleaning apparatus particularly adapted for the cleaning of parts for which the prior art has been remediless, namely, those in a permanent installation or otherwise inaccessible; those too cumbersome for total immersion in a solvent bath and those requiring frequent particularized cleaning in a limited area.

The invention is predicated upon the use of a small diameter probe inserted through small apertures by means of which ultrasonic energy is introduced in close proximity to the contaminated surface. The apparatus comprises generally an electronic frequency generator, a transducer for converting the electrical frequency into sound waves, a flexible multiconductor transmission line for conducting the ultrasonic energy to a remote point and a small diameter probe located at the remote point for applying the ultrasonic energy to the surface to be cleaned.

It is, therefore, the principal object of this invention to provide an ultrasonic cleaning apparatus which utilizes a small diameter probe for conducting the ultrasonic energy into close proximity with the contaminant.

Another object is to provide a new and novel ultrasonic cleaning probe.

The above-mentioned and other features and objects of this invention and the manner of attaining them will become more apparent and the invention itself will be best understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawing, wherein:

FIG. 1 illustrates the ultrasonic cleaning apparatus and its components;

FIG. 2 is an enlarged view of the ultrasonic cleaning probe used in the apparatus of FIG. 1; and

FIG. 3 illustrates a use of an ultrasonic cleaning probe for cleaning the combustion chamber of a reciprocating engine.

Referring first to FIG. 1, the novel ultrasonic cleaning apparatus comprises an electrical frequency generator **10** which may be any one of several basic types of oscillators for producing electrical signals of a given frequency, usually in the kilocycle range. These signals are applied via the coaxial cable **12, 14** across two quarter-wave sections **16** and **18**. The quarter-wave sections ($\lambda/4$ where $\lambda$ is the wavelength) are determined on the basis of the operating frequency. The rear quarter-wave section **18** is electrically insulated from the forward section **16**. Clamped and bonded between the two sections is a transducer **20** which may be of any suitable type such, for example, as a thin efficient electrostrictive or piezoelectric wafer. The transducer changes the electrical vibrations of the oscillator into ultrasonic energy.

The ultrasonic energy so produced is coupled to the transmission line **22** through the forward quarter-wave section **16**, which is acoustically matched to the line by transforming the velocity of the wave through the exponential horn form of the forward section. The velocity transformation will be in the inverse ratio of the diameter at the ends of the matching section.

Since the basis of the ultrasonic cleaning apparatus of the present invention is predicated on introducing the ultrasonic energy in close proximity of the contaminant, a means must be provided for transmitting the ultrasonic energy generated at a remote point to a small diameter cleaning probe without the inherent losses attending the transmission through or diffraction around obstacles of dissimilar acoustic impedances. The flexible transmission line **22** provides just such a means for the present invention.

The nature of the transmission line is critical. The

primary object is to deliver useful energy for performing mechanical work at a location remote from the ultrasonic generator. Moreover, the line must be flexible in order to be practical. Accordingly, the flexible multicable transmission line must provide a large area to volume ratio to dissipate efficiently large amounts of heat caused by transmission line loss. In the absence of a satisfactory ratio, the line would store the heat and rapidly become subject to mechanical failure. Each of the cables must be of a low loss material to minimize the production of heat and absorption of energy. A suitable material in excess of two feet should have an absorption coefficient preferably not exceeding $1\times10^{-3}$. The absorption coefficient is defined by

$$\delta=0.11513\times\frac{\text{decay rate}}{\text{frequency}}$$

where "decay rate" in decibels per second is the rate of decay of amplitude of a freely vibrating body (rod) at its fundamental halfwave longitudinal resonance. "Frequency" in cycles per second is the resonant frequency of the rod and chosen to be at or near the frequency of the application energy. The coefficient as maximized above is based on physical measurement of the decay rate on a specimen of transmission material having a length-to-diameter ratio not less than 20/1, and the decay interval greater than 20 decibels. One class of metals which may be used is 18—8 stainless steel. Alloys of high nickel and chromium may also be used providing the carbon content is less than 0.1%.

The transmission line **22** is composed, for example, preferably of a plurality of 20-mill wires held together in close proximity. Through it, the ultrasonic energy produced by the transducer **20** is fed to the remotely located probe **24** for application to the contaminated surface.

The details of the probe **24** can be seen in the enlarged view of FIG. 2. A plurality of thin discs **26**, **28**, **30**, **32**, **34** and **36** are attached to the transmission line **22** and are preferably excited at the radial mode. It is to be understood, however, that the torsional mode of excitation may also be utilized. The discs are thin, being less than one-tenth wavelength in thickness. For a 100 kc. base frequency, this would be about 1/16". This thinness provides a high "Q" radial resonator which increases the amplitude of the radial component by essentially the "Q" of the resonator. The thinness also provides adequate compliance and low mass for the normally displaced center. The discs are spaced sufficiently close together that the in phase radiation from the periphery of each is essentially a plane wave radiator equal in extent to the length of the stack of discs. The displacement of the disc face is radial and circumferentially in phase. Displacement of the center of the end and top discs provides radiation normal to the plane of the discs.

FIG. 3 illustrates one of the many uses to which the ultrasonic cleaning apparatus of the present invention may be put. As is well known, the operation of an internal combustion engine is adversely affected by the deposits of carbon formed in the combustion chamber. Such deposits result in a reduction of volumetric efficiency, pre-ignition and an increase in the octane rating of the engine.

Heretofore, removal of these deposits was a costly operation. The engine would be disassembled, the deposits removed mechanically and the engine would then be reassembled. This procedure resulted in a prohibitively high labor cost so that the engine deposits were seldom removed except in connection with other major work on the engine.

The ultrasonic cleaning apparatus of the present invention accomplishes the removal of such deposits from the combustion chamber of a reciprocating engine without necessitating the costly diamantling of the engine.



As is seen in FIG. 3, the small ultrasonic cleaning probe **24** is inserted into the spark plug hole and lowered into the cavity **38** formed above the piston **40**. The crankshaft (not shown) is turned by hand to bring the piston up to the compression stroke. This will form the cavity **38** to approximately a one-pint size in a common type engine.

A threaded adapter and compression gland **42**, concentric with the transmission line **22**, is slid down the line and screwed into the spark plug hole. The compression nut is finger-tightened and Varsol or a similar detergent or solvent is introduced through the small flexible tube **44** connected to the gland. A return tube **46** carries the excess Varsol to a small recirculating or gravity system (not shown) after the cavity is filled. A pressure is maintained to counterbalance leakage around the valves or cylinder.

An ultrasonic generator together with a piezoelectric transducer are located external to the engine and are not shown in FIG. 3. The ultrasonic energy produced by these elements is fed to the probe **24** by means of the transmission line **22**. Since an automobile cylinder cavity is resonant for frequencies of approximately 100 kc. (kilocycles), transmission at this frequency of ultrasonic energy over the novel flexible multiconductor line is possible with small losses. The probe **24** will then bombard the chamber **38** with ultrasonic waves for a period sufficient to dislodge the deposits on the chamber surfaces. A visual indicator on the Varsol return tube could allow evaluation of the discoloration, or a pre-determined time exposure could be set. Cleaning time for a typical engine would be approximately one hour.

Another use of the apparatus of the present invention would be for flushing of chemical plumbing or liquid piping systems. These systems require flushing whenever fouling or change in load occurs. Since flushing is at most a dilution process requiring the reduction of the contaminant to an acceptable amount, much time has heretofore been consumed in repeated efforts to penetrate the boundary layer between the fluid and the wall. In accordance with the invention, rapid removal of the boundary layer contaminant is achieved by introducing the ultrasonic cleaning probe into the pipe and allowing it to bombard the contaminant with ultrasonic energy.

Chemical reaction apparatus, nuclear reactor vessels and plumbing associated with heat exchangers are also possible areas of usefulness for an ultrasonic cleaning probe which can be introduced into small apertures.

The invention and its numerous attendant advantages will be fully understood from the foregoing description. Many modifications relating to the power requirements, the length of the transmission line, the operating frequencies, the mode of excitation, e.g. longitudinal, radial and torsional, the type of driver transducer, the size and ratio of the resonant propagator and the specific applications may be made without departing from the spirit and scope of the invention or sacrificing any of its attendant advantages. Accordingly, it is to be understood that the invention shall be deemed limited only by the scope of the appended claims.

What is claimed is:

1. An ultrasonic device for producing energy capable of removing contaminants from metallic surfaces, comprising means for producing electrical frequency signals, a transducer for receiving said electrical signals and transforming them into ultrasonic energy, a low loss flexible ultrasonic transmission line for conducting said ultrasonic energy to a remote point, said transmission line having a large area to volume ratio and an absorption coefficient not exceeding $1\times10^{-3}$, and means for propagating said energy to perform mechanical work at the remote point.

2. The apparatus according to claim 1, wherein said flexible transmission cable is made of a material having a carbon content less than 0.1%.

3. The apparatus according to claim 1, wherein the means for propagating the ultrasonic energy comprises a high "Q" acoustical radial resonator.

4. An ultrasonic cleaning apparatus as set forth in claim 1, wherein the means for propagating the ultrasonic energy comprises a plurality of thin discs, the thinness of said discs being less than one-tenth the wavelength at the operating frequency, said discs being spaced sufficiently close together so that the in-phase radiation from the periphery of each disc is essentially a plane wave equal in extent to the length of the plurality of said discs.

5. Ultrasonic cleaning apparatus comprising an electrical oscillator for the production of electrical signals, a first quarter-wavelength section, a second quarter-wavelength section, means for applying said electrical signals across said first and said second quarter-wavelength sections, a transducer connected between said first and said second quarter-wavelength sections for transforming said electrical signals into ultrasonic energy, a flexible multiconductor transmission line having a large area to volume ratio and an absorption coefficient not exceeding $1\times10^{-3}$ connected to said second quarter-wavelength section, said second section being in the form of an exponential horn to acoustically match said transmission line with said second section, and a high "Q" acoustical radial resonator connected to said transmission line at a remote point.



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