

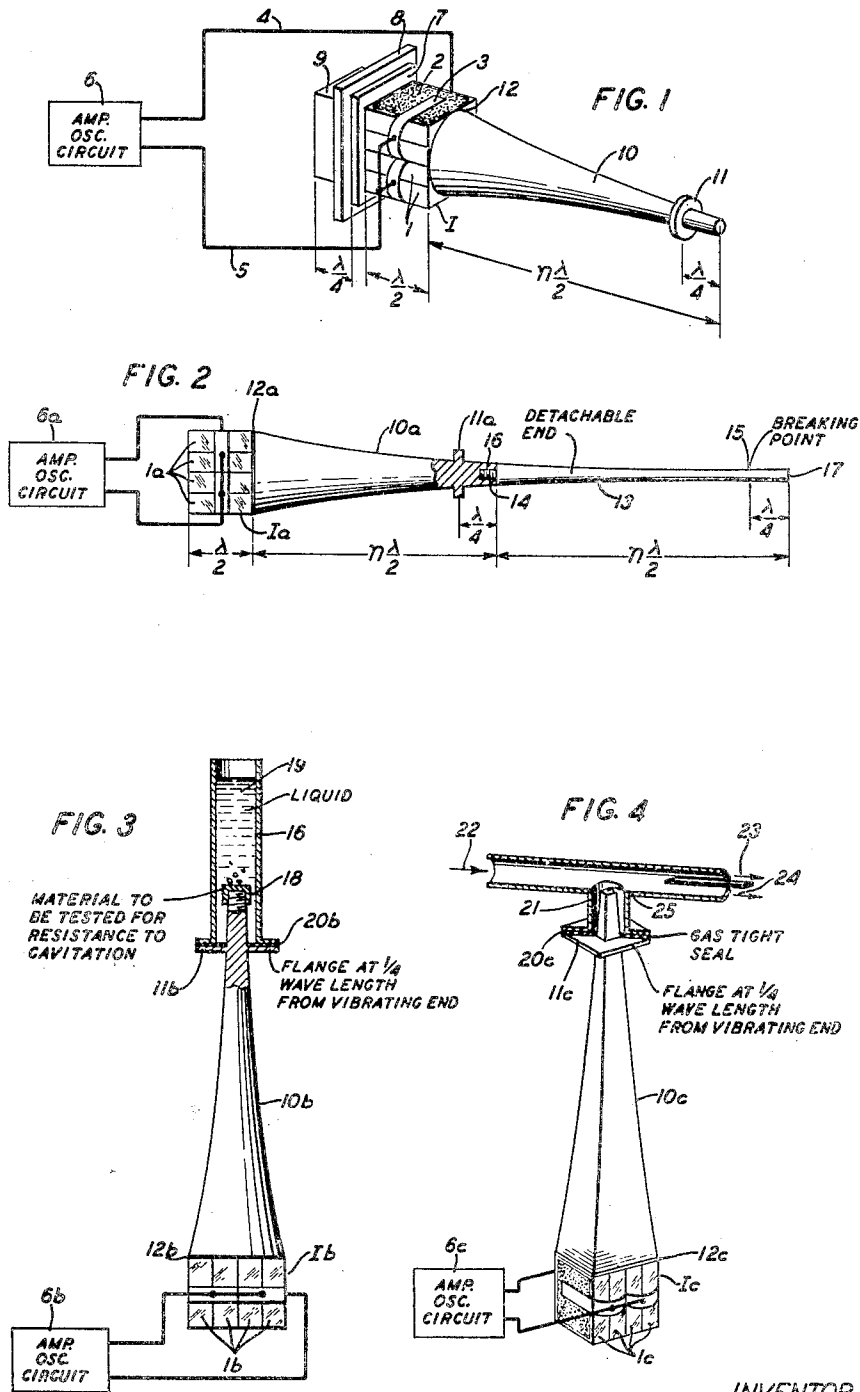
July 4, 1950

W. P. MASON

2,514,080

METHOD OF OBTAINING HIGH VELOCITY WITH CRYSTALS

Filed Jan. 10, 1945



INVENTOR
W. P. MASON

BY

E. V. Briggs

ATTORNEY

UNITED STATES PATENT OFFICE

2,514,080

METHOD OF OBTAINING HIGH VELOCITY
WITH CRYSTALSWarren P. Mason, West Orange, N. J., assignor
to Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application January 10, 1945, Serial No. 572,213

29 Claims. (Cl. 171-327)

1

This invention relates broadly to compressional vibrating systems and specifically to the generation of particle velocities of the order of sound in air with a piezoelectrically driven system.

In recent years, workers in the art have suggested that a method for producing particle velocities of the order mentioned might have important practical applications. However, attempts to produce such high-order particle velocities with conventional crystal driven systems have failed because of the relatively low tensile strengths of crystals with high piezoelectric constants, such as quartz or ammonium dihydrogen phosphate, which break when stretched one-tenth of one percent of their respective lengths.

It is therefore the primary object of this invention to provide a method whereby particle velocities of the order of sound in air may be generated piezoelectrically.

A second object of this invention is to provide a method for separating microparticles of slightly different masses.

A third object of this invention is to provide an improved method for fatigue testing.

A fourth object of this invention is to provide a method for examining the corroding effect of high velocity fluids on designated test substances.

Other objects may be seen from the specification and claims as hereinafter set forth.

Applicant proposes to produce particle velocities of the desired order of magnitude by means of an improved piezoelectric compressional wave generator which includes a transforming member attached to a vibrating face of a piezoelectric element driven at its resonant frequency. In a preferred embodiment, the transformer comprises a solid rod of elastic material approximately an integral number of half wavelengths long in the resonant frequency of the system and having a cross-sectional area which falls off exponentially from a value approximating the area of the face of the piezoelectric element at the joint therewith to a relatively small value at the end of the rod remote from the joint.

The vibrational energy concentrated in the small end of the above-described transformer member is utilized in the several different embodiments of the invention herein disclosed to perform several respectively different functions.

According to one embodiment of the invention, a system is provided for the separation of microparticles of slightly different mass, such as occur in a mixture of gases, or isotopic substances. Separation occurs by virtue of the differential accelerations imparted to the particles of different mass as they flow through a system of ducts lat-

2

erally disposed to a vibrating surface at the small end of a transformer member which is driven to oscillate with high frequency compressional vibrations as described above. Alternatively for the purposes of the specification and claims hereinafter, the small end of the rod may be designated as the impeller.

A second embodiment of the applicant's invention provides a novel apparatus for fatigue testing in which the transformer member described above is provided with an attached member of test material tapered down to a narrow neck at a nodal plane in the vibratory motion and expanded slightly therefrom. The tensile strength of the test materials may be determined by the reaction of the nodal neck of the sample to sustained high-frequency compressional vibrations.

According to another embodiment of the applicant's invention, an apparatus is provided by means of which the effect of high velocity fluids on designated test materials may be examined. As described above, high-frequency compressional oscillations are excited in a tapered rod, the small end of which is sealed in a chamber by means of a flange positioned near said end at a nodal plane in the vibratory motion. A cap of test material is fixed on the end of the vibrating rod which imparts compressional oscillations to a test fluid contained in the chamber. The corroding effect of the rapidly moving fluid on the test specimen may be observed after a definite period of high-frequency compressional vibrations by weighing the specimen or observing the pitting on its surface. The fluids referred to may be either liquid or gaseous. For example, the corroding effect of high velocity fluorine gases on metals may be tested in this manner. An apparatus of this nature may be used for the purpose of setting up cavitation in liquids and for studying the effect of cavitation on various liquids.

Referring to the drawings:

Fig. 1 shows in perspective a piezoelectric system embodying the invention which includes a tapered energy transformer for transforming compressional vibrational energies;

Fig. 2 shows a system for fatigue testing embodying the principles of the present invention;

Fig. 3 shows a system for setting up cavitation in liquids which utilizes the energy transformer of the present invention;

Fig. 4 shows an apparatus for separating a mixture of gases into its components which utilizes the method of producing high particle velocities of the present invention.

As stated hereinbefore, piezoelectric crystals

such as quartz or ammonium dihydrogen phosphate fracture when subjected to compressional vibration velocities approaching that of sound in air. This follows from the experimental fact that when a quartz or ammonium dihydrogen phosphate crystal stretches to 0.1 per cent of its length it breaks.

Let D_m equal the maximum particle displacement that a crystal can suffer without exceeding its elastic limit.

Then

$$D_m = l(y_y) = l \times 0.001 \quad (1)$$

where

y_y is the strain suffered by the crystal, defined as elongation per unit length, which value may not exceed 0.1 per cent; and l equals the length of the crystal.

Since the crystal is driven piezoelectrically to vibrate in a motion which is essentially simple harmonic, the maximum particle velocity may be computed from the following relationship.

$$V_m = 2\pi f D_m = 2\pi f l (0.001) \quad (2)$$

where

f = the frequency of the vibrating system; and D_m = the maximum allowable particle displacement.

Since the crystals vibrate in resonance, the following well-known relationship between frequency and length holds true.

$$f = \frac{\sqrt{E/\rho}}{2l} \quad (3)$$

where

E = Young's modulus if a long thin bar is involved or the plate modulus if a plate is involved; and ρ = the density.

Substituting Equation 3 in Equation 2, we have

$$V_m = \pi \sqrt{E/\rho} (0.001) = 0.00314 \sqrt{E/\rho} = 0.00314 V_p \quad (4)$$

where

V_p = the velocity of propagation in the particular crystal used.

The maximum particle velocity which can be obtained with an X-cut quartz crystal may therefore be computed from the above relationship by substituting the values E_q (Young's modulus for X-cut quartz) = 7.85×10^{11} dynes/cm.²; and ρ_q (density of quartz) = 265 g./cc. in Equation 4.

V_m (X-cut quartz) =

$$0.00314 \sqrt{\frac{7.85 \times 10^{11}}{265}} = 1710 \text{ cm./sec.} \quad (5)$$

which is less than 6 per cent of the velocity of sound in air.

The maximum particle velocity which can be obtained with a 45-degree Z-cut crystal of ammonium dihydrogen phosphate may likewise be computed from the relationship of Equation 4 by substituting therein the values

E_a (Young's modulus for ammonium dihydrogen phosphate) = 3.08×10^{11} dynes/cm.²;

ρ_a (density of ammonium dihydrogen phosphate) = 1.8 g./cc.; and

V_m (ammonium dihydrogen phosphate) =

$$0.00314 \sqrt{\frac{3.08 \times 10^{11}}{1.8}} = 1,040 \text{ cm./sec.} \quad (6)$$

which is 3.1 per cent of the velocity of sound in air.

The value cannot be higher for the reason that

the breaking strength for crystals is relatively low, i. e., about 11,400 pounds per square inch for quartz and about 2840 pounds per square inch for ammonium dihydrogen phosphate. Most metals have a much higher breaking strength than crystals. For example, the Chemical Handbook gives the following values:

Phosphor bronze, 110,000 to 140,000 lbs./sq. in.

Steel, 80,000 to 330,000 lbs./sq. in.

Nickel-steel, 330,000 lbs./sq. in.

Piano wire, 325,000 to 337,000 lbs./sq. in.

All of these values are from ten to thirty times the breaking strength of the X-cut quartz crystal.

In accordance with the present invention, multiplication of vibrational displacements is effected by incorporating a tapered rod of metal or some other elastic material of relatively high tensile strength as part of a vibrating piezoelectric system, the large end of the rod being fastened to the vibrating surface of the piezoelectric element. The tapered rod is preferably given a length equal to an integral number of half wavelengths in the frequency of the vibrating system, so that standing waves are set up in which loops occur at both ends of the rod, thereby causing the joint between the piezoelectric element and the rod to be positioned at a place of minimum vibrational stress. In the specification and claims herein, "loop" relates to those positions in the vibrating system in which particle velocities and displacements are at a maximum, and vibrational stress is at a minimum. Conversely, "node" relates to positions of minimum particle velocities and displacements and maximum vibrational stress. In the standing waves set up along the rod, nodes and loops are separated by space intervals equal to a quarter wavelength in the frequency of the vibrating system, since the nature of the vibratory motion changes progressively from loop to node and back to loop again through every half wavelength interval.

By use of the tapered rod, large vibrational energies are concentrated in a small cross-sectional area, thereby generating particle velocities which approach the velocity of sound in air, since the maximum particle velocities and also the stresses sustained in the vibrating member vary inversely with the square root of its cross-sectional area. Thus, if the small end of the bar has an area $\frac{1}{100}$ of the area of the large end, it will have a vibrating particle velocity ten times as great. Likewise, the small end of the vibrating rod will sustain ten times as great a vibrational stress as the large end and the face of the piezoelectric element contiguous thereto. However, since the metals have breaking strengths equal to from ten to thirty times that of piezoelectric crystals, this stress will be withstood without fracture by the tapered transformer member, thereby enabling particle velocities to be generated which are from ten to thirty times as great as those generated with conventional crystal systems.

Referring to Fig. 1 of the drawings, the bank of crystals 1 may be of any material known in the art possessing piezoelectric properties and which may be excited to longitudinal vibration. For the purposes of the embodiment shown, the applicant has employed 45-degree X-cut crystals of ammonium dihydrogen phosphate which has a high piezoelectric constant and therefore produces vibrations of relatively greater intensity than other well-known piezoelectric crystals. The two lateral surfaces of each of the crystals 1 are coated with layers of evaporated gold 2,

5

which serve as electrodes. A thin piece of gold-plated nickel silver serves as an electrode contact 3 which connects the top platings of the first and third crystals to the lower platings of the second and fourth along one side of the crystal bank. A similar member connects lower platings of the first and third crystals to the top platings of the second and fourth along the opposite end of the crystal bank I.

Lead wires 4 and 5 serve to connect the crystal assemblage through its electrodes to the output terminals of a conventional amplifier-oscillator circuit 6. For a detailed showing of a similar crystal assemblage and mounting together with one type of amplifier-oscillator circuit suitable for driving the piezoelectric crystal element at its resonant frequency of vibration, the reader is referred to application, Serial No. 559,096, filed by W. P. Mason in the United States Patent Office on October 16, 1944.

The bank of crystals I is cemented to the ceramic support 7 which is attached to the metal base 8. An impedance member 9, comprising a cubical metal block having approximately the same cross-sectional area as the crystal bank I, and having a thickness in the direction of the longitudinal vibrations equal to a quarter wavelength at the frequency of the vibrating system, is machined as part of the base member 8. The function of the impedance member 9 is to prevent the dissipation of vibrational energy and to provide a means for grasping the crystal assemblage without appreciably damping the vibrations.

The crystals I preferably have a dimension equal to a half wavelength in the direction of vibration. To a face of the piezoelectric bank I which is parallel with the support 7, is cemented the base of the tapered transformer rod 10 which is preferably of metal but may comprise any elastic substance of higher tensile strength than the conventionally used piezoelectric crystals. Any suitable adherent known in the art may be used for cementing the base of the rod 10 to the crystal bank I. The rod 10 preferably has a length equal to an integral number of half wavelengths at the frequency of the vibrating system and a circular cross-section, the area falling off exponentially from the place of junction 12 with the piezoelectric bank I. For convenient operation, the rod 10 has been given the following dimensions in the embodiment of Fig. 1: Length, 5 inches; cross-sectional diameter of large end, 1 inch; cross-sectional diameter of small end, $\frac{1}{16}$ of an inch. Twenty-five kilocycles has been found to be a convenient operating frequency for the ultrasonic vibrations. While the circular cross-sectional area is convenient for the transformer rod, the satisfactory operation of the rod is not dependent upon any particular cross-sectional shape. A rod having a rectangular, cross-section, such as shown in Fig. 4, would serve the purpose suitably. Furthermore, while experimentation has shown that a rod with exponentially decreasing cross-sectional area gives optimum performance, a rod tapered in any regular manner will function satisfactorily.

The flange 11, which for convenience in the embodiment of Fig. 1 has been given an outside diameter of one inch, is positioned at a nodal plane in the vibratory motion a quarter wavelength from the small end of the rod to enable the rod to be clamped in position without appreciably damping the vibratory motion, whereby the concentrated vibrational energy can be utilized in

6

certain practical applications such as described hereinafter.

Fig. 2 shows an apparatus for fatigue testing which embodies the principles of the present invention. The piezoelectric bank Ia is mounted as described hereinbefore with reference to Fig. 1, and driven to oscillate by means of the conventional amplifier-oscillator circuit 6a. As in Fig. 1, the tapered transformer rod 10a is shown to have a circular cross-section which decreases in an outward direction from the face of the piezoelectric element Ia. As mentioned before, although a circular cross-section is a convenient form for the rod 10a, it may operate equally well with other cross-sectional shapes. Any one of a number of adherents known in the art may be utilized to rigidly secure the transformer rod 10a to the face of piezoelectric crystal bank Ia. The transformer member 10a, which preferably but not necessarily comprises metal, has a length equal to an integral number of half wavelengths in the frequency of the vibrating system, and terminates in a screw socket 16. A flange 11a is positioned a quarter wavelength from the screw-socket end of the rod 10a.

Each of the metals or other materials which it is desired to subject to fatigue tests according to the method of this invention may be machined in the form of the detachable member 13, which has a protruding screw 14 on one end which fits into the socket 16 to engage with the transformer rod 10a in a secure and rigid joint. The test specimen 13 makes a smooth connection with the transformer rod 10a at the juncture 16-14 and extends therefrom to an over-all length equal to an integral number of half wavelengths in the frequency of the vibrating system. From the juncture 16-14 the specimen 13 tapers to a narrow neck 15 positioned at a node or plane of maximum stress one-quarter wavelength from the specimen end 17. In the embodiment of Fig. 2 the cross-section of the nodal neck 15 has a diameter equal to about one-tenth the diameter of the rod 10a at the base 12a. From the nodal neck 15 the cross-section of the specimen expands slightly to the end 17, where the diameter is about twice that of the neck 15.

Tests are conducted with the system in ultrasonic vibration to determine how long a time a given specimen will sustain vibrations before the neck 15, which is located at a nodal plane of maximum stress, actually fractures. If the cross-sectional areas of the nodal plane 15 and the transformer base 12a bear the ratio 1:100, respectively, then the tensile stress in terms of pounds per square inch which is exerted on the nodal plane 15 by the vibratory motion, is ten times as great as that sustained at a nodal plane in the crystal bank Ia.

Another method by which the apparatus of Fig. 2 can be utilized to test the weakening effect of continuous oscillations on specimens of given substances is as follows: The test specimen 13, attached as shown in Fig. 2, is subjected to oscillations for a given period such that the vibrational stress exerted on the nodal neck 15 is held under the breaking stress. The unfractured specimen 13 is then detached from the rod 10a by unscrewing the joint 14-16, the specimen 13 then being placed in a conventional tension machine where its tensile strength is subsequently tested by means of a static pull.

Fig. 3 shows an adaptation of the present invention which is suitable for setting up and studying cavitation in liquids and determining

7

the effect of the same on designated test solids.

The phenomenon of cavitation in liquids may be described as follows: Whenever the hydrodynamical pressure in a liquid is reduced to vapor pressure, a two-phase system is made possible in which both liquid and gaseous states may occur simultaneously. Under fortuitous circumstances, cavities or loose spaces then form in the liquid producing an effect analogous to the boiling of a liquid. Since ultrasonic vibration consists of a series of rapid periodic expansions and compressions, this means may be utilized to expel dissolved gases from gas-containing liquids and to bring about cavitation in degassed liquids.

The significant feature in the study of cavitation is that during the collapse of the cavities mentioned very high pressures are momentarily developed which concentrate high kinetic energies in a small space thereby producing heavy erosive action on surfaces which come in contact with liquids in a state of decavitation. The formation and collapse of the cavities take place intermittently due to the rapid fluctuations in pressure in the ultrasonic field. Even chemically inert substances, such as glass, are eroded in this manner. Studies of liquids in cavitation have many practical applications, one of the most important being the erosive action produced in certain critical places on the hulls of fast-moving ships. Propeller action causes cavities to form and collapse in the surrounding water because of rapid fluctuations in pressure as the ship passes at high speed through the water in wave motion.

Referring to Fig. 3, the piezoelectric element 1b is mounted and driven by the oscillator 6b in the manner described hereinbefore. The energy transformer 10b, which preferably but not necessarily comprises metal, is an integral number of half wavelengths long at the frequency of the vibrating system and of such size and shape as described hereinbefore with reference to Fig. 1. The flange 11b is positioned at a nodal plane in the vibratory motion of the system at a distance of a quarter wavelength from the small end of the rod. By means of the flange 11b, the small end of the transformer rod 10b is sealed with the liquid-tight joint 20b into the liquid chamber 16 which is filled with a liquid 19 such as water or castor-oil, or mineral oil. The test material may be fastened onto the small end of the transformer rod 10b in the form of a screw-threaded cap 18.

The rod 10b is set in vibration by means of the piezoelectric element 1b whereby supersonic vibrations are induced in the liquid 19 through the cap 18 which is at a loop or position of maximum particle velocity in the vibrating system. This sets up cavitation in the liquid 19 which is especially pronounced in the vicinity of the test cap 18. The collapse of the cavities in the liquid 19 against the test surface 18 causes a pitting or erosion of the surface. This effect may be investigated by weighing the test cap before and after a given period of vibration, e. g., two hours, and also by a visual examination of the test cap 18 after removal from the apparatus.

In a similar manner, by replacing the liquid 19 with a designated gas in the chamber 16, in which the liquid-tight seal 20b is replaced by a gas-tight seal, tests may be made of the corroding effects of high velocity gases on metals and certain other materials. Of particular interest is the corroding effect of high velocity fluorine on metals.

8

Fig. 4 shows an apparatus for separating a mixture of gases into its components which utilizes the principles of the present invention. The piezoelectric element 1c is mounted as described hereinbefore with reference to Fig. 1 and driven to oscillate by means of the conventional amplifier-oscillator circuit 6c. The transformer member 10c, which is cemented to the vibrating face of the piezoelectric element 1c, is shown in Fig. 4 to have a cross-sectional area at the joint 12c which is approximately the same size as that of the element 1c. As explained with reference to Figs. 1, 2 and 3, the transformer cross-section could alternatively be round or any other convenient shape. The transformer rod 10c is tapered, the cross-sectional area decreasing preferably, but not necessarily, in an exponential manner. The rod extends outward from the juncture 12c to a length equal to an integral number of half wavelengths in the frequency of the vibrating system. A flange 11c is positioned at a nodal plane in the vibratory motion of a quarter wavelength from the small end of the transformer member 10c. By means of the flange 11c the small end of the transformer member 10c is sealed with a gas-tight seal 20c into the chamber 21 which is laterally disposed to a system of ducts 22, 23 and 24. When ultrasonic vibrations are induced in the transformer member 10c at the juncture 12c by means of the piezoelectric element 1c, the small end 25 thereof is caused to vibrate with particle velocities approaching that of sound in air, as described hereinbefore.

For convenience in the embodiment of Fig. 4 the crystal bank 1c, and the base of the rod 10c contiguous thereto, has a cross-sectional dimension equal to approximately two and one-half inch square, while the vibrating tip 25 has a cross-sectional dimension equal to approximately one-quarter inch square. As stated before, 25 kilocycles have been found to be convenient frequencies of vibration. A mixture of the gases to be separated, e. g., deuterium and hydrogen, is caused to flow through the duct 22 in the direction of the arrow whereby a portion of the gas molecules are subjected to the high energy oscillations of the vibrating surface 25 which moves with the velocity nearly equal to that of sound in air. Since the molecules of different mass receive slightly different energies in the intense ultrasonic field, the heavier molecules tend to pass off through the upper duct 23, while the lighter weight molecules tend to pass off through the nearer duct 24. The separation of particles occurs because the heavy particles with more energy will progress farther into the mixture before they lose their added energy than will the lighter particles. The maximum separation will occur when the diameter of the gas conducting tube is several times the mean free path of the molecules in the gas. Thus the gas collected from the duct 23 has a higher proportion of heavy molecules than the gas collected from the duct 24. If this process is carried on fractionally, with the reintroduction at each step of either the heavy or the light-weight mixture, depending on which is ultimately wanted, an end product of any desired degree of purity may be obtained.

In solid substances, the separation of isotopes or other microparticles of slightly different weights could be accomplished in a similar apparatus. The solid substances could be dissolved in a suitable solvent, and the solution caused to flow past the vibrating surface 25 where it would

be subjected to the supersonic vibrations in much the same manner as the gases, the heavier and lighter components passing off through different ducts.

The present invention is not limited in its application to any or all of the particular embodiments disclosed herein, nor is it limited to the use of any particular piece of apparatus, or elements of any particular size or shape.

What is claimed is:

1. A method for obtaining particle velocities of the order of sound in air which comprises electromechanically setting up standing compressional waves in a solid tapered member which have an approximate anti-node at the end of large cross-section of said member and utilizing the increased concentration of vibrational energy in a nodal plane of said tapered member having relatively small cross-section.

2. An apparatus for obtaining particle velocities of the order of sound in air which comprises in combination a generator of ultrasonic vibrations of a given frequency having an electromechanical vibratory driving element, a transformer for multiplying vibrational energy densities comprising a tapered rod, the end of said rod of relatively large cross-section coupled to the said driving element of said generator at a junction, the vibrating system comprising said driving element and said rod resonant to the frequency of said generator and having substantially an anti-node at said junction, and the small cross-sectional portion of said rod coupled to means for utilizing the increased vibrational energy concentrated in a given area.

3. An apparatus for obtaining particle velocities of the order of sound in air which comprises in combination a motor having an electromechanical driving element with a given surface of high peak displacement at resonance of the said driving element of the motor, a solid metal rod attached in a joint to the given surface of said crystal element, said rod having a length equal to an integral number of half wavelengths in the resonant frequency of the said driving element and having substantially an anti-node at said joint, the cross-sectional area of said rod decreasing exponentially from a value substantially equal to the area of the given surface of the said driving element at said joint to a portion of relatively small cross-sectional area near the end of said rod remote from said driving element, and means coupled to the relatively small cross-sectional portion of said rod for utilizing the vibrational energy concentrated in said small portion.

4. An apparatus for obtaining particle velocities of the order of sound in air which comprises in combination a motor having an electromechanical driving element with a given surface of high peak displacement at resonance of the said driving element of the motor, a solid metal rod having a length equal to an integral number of half wavelengths in the resonant frequency of said driving element, the surface of said rod assuming substantially the shape of an exponential curve of revolution, the large end of said rod substantially equal in cross-section to the area of the given surface of said driving element and cemented thereto to form a junction, said junction disposed at substantially an anti-nodal plane in the vibrating system including said driving element and said rod, the small portion of said rod remote from said driving element being

coupled to means for utilizing the vibrational energy concentrated in said small portion.

5. A high speed impeller for gas comprising a motor having a piezoelectric element with a given surface of high peak displacement at resonance of the piezoelectric element of the motor, and a velocity multiplying transformer comprising a tapered metallic rod approximately an integral number of half wavelengths long in the resonance frequency of the vibrating system comprising said rod and said piezoelectric element, said rod having a base of approximately the same area as the given surface of the piezoelectric element and cemented to said surface at substantially an anti-node in said vibrating system, the cross-section of said rod diminishing exponentially with the distance from said base, and terminating in an impeller surface which is relatively small compared to the area of said base.

6. An apparatus for testing the strength of a test rod which tapers from a maximum cross-section at one end to a neck of minimum cross-section near the other end thereof which comprises in combination a source of ultrasonic vibrations having a contacting joint with said rod at said end of maximum cross-section, the vibrating system comprising said source and said rod having substantially an anti-node at said joint and substantially a node at said neck.

7. An apparatus for testing the breaking strength of a test specimen which tapers from a maximum cross-section at one end to a narrow neck of minimum cross-section near the other end which comprises in combination a motor having a piezoelectric element with a given surface of high peak displacement at resonance of the piezoelectric element of the motor, a tapered metal rod, the large end of said rod attached in a first joint to the given surface of said piezoelectric element, the small end of said rod having a cross-section substantially equal to the maximum cross-section of said test specimen and formed to fit in a second rigid joint therewith the vibrating system which includes said piezoelectric element, said rod, and said specimen having substantially anti-nodes at said joints and a node at said neck.

8. The method of studying the corrosive action of high velocity fluids on given test solids which comprises inducing ultrasonic vibrations in the end of relatively large cross-section of a solid tapered rod, sealing the end of relatively small cross-section of said rod in a chamber containing a designated fluid, attaching a specimen of said test solid to the small end of said rod for a given period of vibratory motion, and observing the effect of said motion on said test specimen.

9. An apparatus for studying the corrosive action of high velocity fluids on a given test solid which comprises in combination a source of ultrasonic vibrations, a solid tapered rod, the end of relatively large cross-section of said rod being coupled to said vibration source, a chamber containing a designated fluid, the end of relatively small cross-section of said rod being introduced into said fluid chamber, and means for fastening said test specimen to said vibrating rod in said fluid chamber.

10. An apparatus for studying the corrosive action of high velocity fluorine on a given metal which comprises in combination a source of ultrasonic vibrations, a solid tapered rod, the end of relatively large cross-section of said rod being coupled to said vibration source, a chamber containing fluorine, the end of relatively small

11

cross-section of said rod being sealed in said fluorine chamber, and means for fastening a specimen of said test metal to said vibrating rod in said fluorine chamber.

11. The method of studying the corrosive action of high velocity liquids on designated test solids which comprises inducing ultrasonic vibrations in the end of relatively large cross-section of a solid tapered rod, introducing the end of relatively small cross-section of said rod into a chamber containing a designated liquid, attaching a specimen of said test solid to the small end of said rod for a given period of vibration, and observing the effect of said motion on said specimen.

12. An apparatus for studying the corrosive action on a given test solid of cavitation in liquids which comprises in combination a source of ultrasonic vibrations, a solid tapered rod, the end of relatively large cross-section of said rod being coupled to said vibration source, a chamber containing a designated liquid, the end of relatively small cross-section of said rod being sealed in said liquid chamber, means for fastening a specimen of test material to said vibrating rod in said liquid chamber.

13. An apparatus for studying the corrosive action of cavitation in liquids on a given test solid which comprises in combination a piezoelectric crystal element, means for driving said piezoelectric element to vibrate compressionally, said piezoelectric element having a surface of high peak displacement at the resonant frequency thereof, a solid metal rod cemented to the given surface of said piezoelectric element, the cross-sectional area of said rod diminishing from a value substantially equal to the area of the given surface of the piezoelectric element at the juncture between said rod and said element to a relatively small value at an end of said rod remote from said juncture, a chamber containing liquid, means to seal the small end of said rod in said liquid chamber, and means for attaching said test specimen to said rod in said liquid chamber.

14. The method of setting up cavitation in liquids which comprises inducing standing ultrasonic waves in a solid tapered rod which have approximate anti-nodes at the ends of said rod, and introducing the end of smaller cross-section of said rod into a chamber containing liquid, whereby concentrated vibrational energy is transmitted to said liquid.

15. A piezoelectric element having a natural longitudinal resonance mode of vibration at a high frequency, a displacement multiplying transformer comprising an elongated element having a high compliance for longitudinal stresses at one end and a low compliance at the opposite end, said element having its high compliance end fixedly connected to a surface of the piezoelectric element which is subjected to greatest displacement during longitudinal vibration of the piezoelectric element and means for subjecting the piezoelectric element to an alternating electric field of its longitudinal mode resonance frequency and of such direction with reference to the piezoelectric element as to excite longitudinal vibrations of the piezoelectric element.

16. An apparatus comprising in combination a source of oscillations, a compressional wave driving means in energy transfer relation with said source, and means connected in driven relation to said driving means comprising a metal rod tapered from a maximum cross-section at the

12

end thereof adjacent said driving means to a minimum cross-section at the other end of said rod, the vibrating system comprising said rod and said driving means being resonant to a given frequency of said source of oscillations, said rod having a protuberance near the said end of minimum cross-section at a node in said vibratory system to serve as a point of attachment to said rod.

17. A system in accordance with claim 16 in which a support is located at substantially a node in the motion of said vibrating system.

18. A system in accordance with claim 17 in which said driving means comprises a piezoelectric crystal element.

19. A system in accordance with claim 18 in which said piezoelectric driving means is connected to said driven means at substantially an anti-node in the motion of said vibrating system.

20. An apparatus comprising in combination a source of oscillations, a compressional wave driving means in energy transfer relation with said source, and means connected in driven relation to said driving means comprising a metal rod tapered from a maximum cross-section at the end thereof adjacent said driving means to a minimum cross-section at the other end of said rod, the vibrating system comprising said rod and said driving means being resonant to a given frequency of said source of oscillations, said rod having a protuberance near the said end of minimum cross-section of said rod to serve as a point of attachment for said rod wherein the end of minimum cross-section of said rod terminates in a fitting constructed to form a disengageable rigid joint with said specimen.

21. An apparatus comprising in combination a source of oscillations, a compressional wave driving means in energy transfer relation with said source, and means connected in driven relation to said driving means comprising a metal rod tapered from a maximum cross-section at the end thereof adjacent said driving means to a minimum cross-section at the other end of said rod, the vibrating system comprising said rod and said driving means being resonant to a given frequency of said source of oscillations, said rod having a protuberance near the said end of minimum cross-section of said rod to serve as a point of attachment for said rod wherein the end of minimum cross-section of said rod terminates in a fitting constructed to form a disengageable rigid joint with said specimen and wherein said fitting is substantially at an anti-node in the motion of said vibrating system.

22. An apparatus comprising in combination a source of oscillations, a compressional wave driving means in energy transfer relation with said source, and means connected in driven relation to said driving means comprising a metal rod tapered from a maximum cross-section at the end thereof adjacent said driving means to a minimum cross-section at the other end of said rod, the vibrating system comprising said rod and said driving means being resonant to a given frequency of said source of oscillations, said rod having a protuberance near the said end of minimum cross-section of said rod to serve as a point of attachment for said rod wherein the end of minimum cross-section of said rod terminates in a fitting constructed to form a disengageable rigid joint with said specimen and wherein said fitting comprises a screw-threaded member.

23. An apparatus for fatigue testing specimens

13

comprising in combination a source of oscillations, a compressional wave driving means in energy transfer relation with said source, and means connected in driven relation to said driving means comprising a metal rod tapered from a maximum cross-section at the end of said rod adjacent said driving means to a minimum cross-section at the other end of said rod, the end of minimum cross-section terminating in a fitting constructed to form a disengageable rigid joint with a test specimen.

24. A system in accordance with claim 23 in which said fitting comprises a screw-threaded member.

25. The method of fatigue testing a given material which comprises forming a rod of said material which tapers from a relatively large cross-section at one end to a narrow neck intermediate of the ends of said rod, inducing forced vibrations in the end of relatively large cross-section of said rod which are of such a frequency as to produce a substantial node at said neck, and continuing said vibrations until the fracture of said neck.

26. The method of testing the breaking strength of a substance which comprises inducing standing compressional waves in a rod of said substance which varies from a maximum cross-section in one portion thereof to a narrow neck in another portion thereof, said waves having an approximate node at said neck, and inducing vibrations in the end of maximum cross-section of said rod for a given interval to deter-

14

mine the weakening effect of said vibrations on said neck.

27. An apparatus in accordance with claim 2 in which said electromechanical driving element is a piezoelectric crystal element.

28. An apparatus in accordance with claim 3 in which said electromechanical driving element is a piezoelectric crystal element.

29. An apparatus in accordance with claim 4 in which said electromechanical driving element is a piezoelectric crystal element.

WARREN P. MASON.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,546,632	Dow et al.	July 21, 1925
1,635,787	Hort	July 12, 1927
2,045,403	Nicholides	June 23, 1936
2,163,649	Weaver	June 27, 1939
2,163,650	Weaver	June 27, 1939
2,185,966	Pfanstiehl	Jan. 2, 1940
2,274,541	Fontana et al.	Feb. 24, 1942
2,300,761	Amy	Nov. 3, 1942

FOREIGN PATENTS

Number	Country	Date
445,775	Great Britain	Apr. 15, 1936
852,150	France	Oct. 16, 1939