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July 13, 1965 A. NELKIN ETAL 3,194,209

ULTRASONIC GENERATOR

Filed Jan. 31, 1962 2 Sheets-Sheet 1

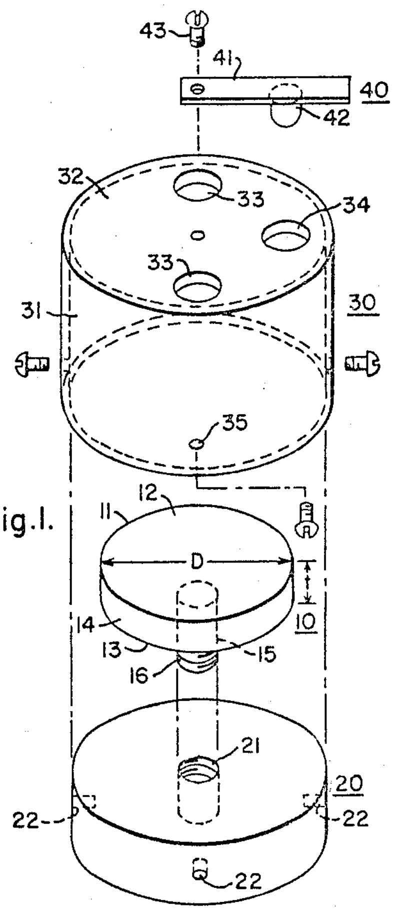

Fig. 1.

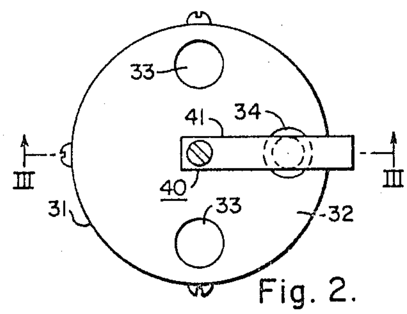

Fig. 2.

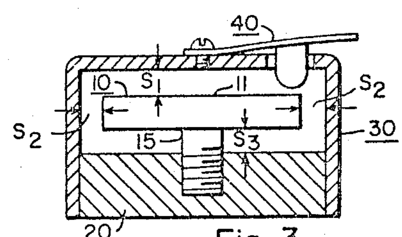

Fig. 3.

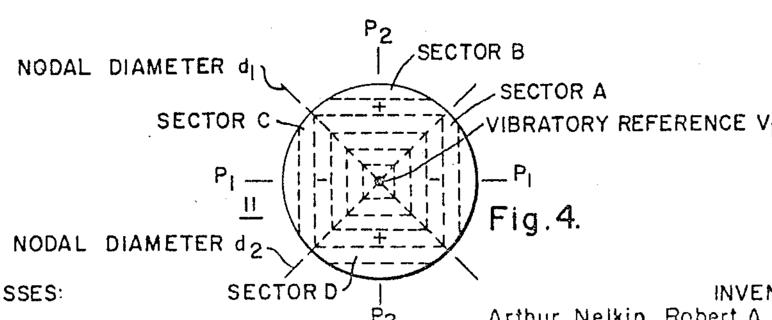

Fig. 4.

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ULTRASONIC GENERATOR

Filed Jan. 31, 1962 | 2 Sheets-Sheet 2

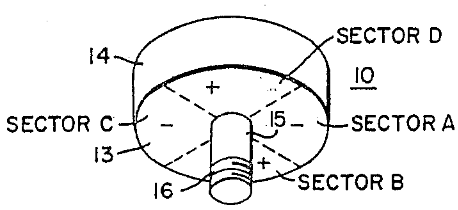

Fig. 5.

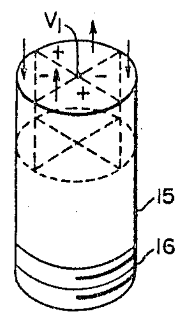

Fig. 6.

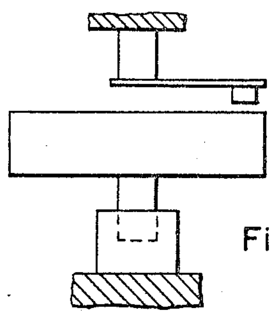

Fig. 7.

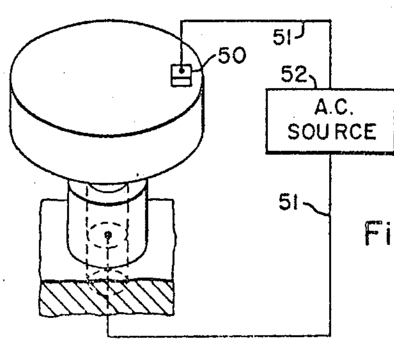

Fig. 8.

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ULTRASONIC GENERATOR

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5 Claims. (Cl. 116—137)

The present invention relates to a transmitter for generating ultrasonic signals and more specifically to a flexural mode mechanical resonator to generate ultrasonic signals of the predetermined frequency in the supersonic or ultrasonic range.

The requirements for usable mechanical resonators is that they can vibrate with sufficient amplitude and also sufficient duration. In addition, if these resonators are to be used as ultrasonic transmitters they must be capable of producing such signals of a frequency within a range of frequencies so that the ultrasonic receiver will be able to accurately detect the transmitter signal despite various other signals which may be present. Such a desirable range would be in the order of 30 kilocycles to 60 kilocycles where there is a minimum of extraneous sound signals from such things as squeaky door hinges, ripping of paper, and also a minimum of extraneous electromagnetic signals such as from radio station transmitters, etc. Further in this frequency range the air absorption is relatively low. In addition the resonator should be relatively small.

The types of vibration which bars or plates assume after they are actuated have been known for many years. Examples of various types of modes are illustrated in the book "Acoustical Engineering" by Olson published by D. Van Nostrand Co., 1957. Page 65 of this book illustrates various types of "flexural modes of a disc or plate" while on page 67 of this book longitudinal vibrations of a rod are illustrated. Many of the modes illustrated in this book have been found unsatisfactory for use as a mechanical resonator or an ultrasonic transmitter either because the discs, rods or plates cannot be or have not been satisfactorily mounted to provide sufficient output from the resonating element. More specifically, most heretofore known mounting means for many of these resonators, absorbs most of the vibratory energy so that amplitude and ring time of the vibrations or the resonating elements are very small.

A complete theory of the vibration of a plate suspended in air was described in a celebrated memoir by Kirchhoff in 1850. In this memoir, it was described that the gravest of all normal modes has no nodal circle but rather vibrates with at least two nodal diameters in a flexural mode. It is stated in this memoir and other works that a circular plate and a square plate has its gravest mode with two nodal lines that cross each other through the center of the circular or square plate. Since the Kirchhoff grave mode is predicated upon a circular plate or square plate being suspended in air with no suspension or contact or very little suspension contact, it has heretofore been found to be impractical to utilize such a vibrating resonator for producing ultrasonic signals.

Accordingly, it is an object of the invention to provide a new and improved ultrasonic generator utilizing a flexural mode resonator having at least two nodal diameters to generate ultrasonic signals of a predetermined frequency.

A further object of the invention is the provision of a

new and improved Kirchhoff grave mode resonator for generating ultrasonic signals.

It is a still further object of the invention to provide a flexural mode resonator in the form of a plate which can produce ultrasonic signals of the predetermined frequency having relatively large amplitude and duration.

An ultrasonic generator embodying the present invention includes a resonator which vibrates in a flexural mode with a plurality of nodal diameters which diameters intercept at a reference point to form an axial reference through the resonator. A mounting pin is integral with the plate and positioned concentric with the reference axis. The pin extends outwardly from the plate so that the vibrations of the plate travel a short distance down the integral pin and are cancelled so that there is no vibratory energy at the lower mounting portion of the pin and hence no energy is lost to the mounting. Means are applied to the outer edges of the plate to impart energy to the plate to initiate oscillations of the flexural mode resonator. To further increase the output of the ultrasonic resonator, a housing is employed around the resonator and is spaced parallel with the resonator surfaces a distance

$$\frac{\lambda}{4}+\frac{N\lambda}{2}$$

wherein λ is the wave length of the ultrasonic signals caused by the vibration of the resonator and N equals any integer or zero. This housing includes apertures therein so that the phase of the ultrasonic signals coming out of the housing are substantially in phase whereas the energy from the quadrants in the other phase of vibration are not transmitted into space so as to prevent cancellation of the first named phase vibrations.

These and other advantages of this invention will be more clearly understood from the following description when read in conjunction with the accompanying drawings in which:

FIG. 1 is an isometric exploded view of an assembly layout of an ultrasonic generator constructed in accordance with the present invention;

FIG. 2 is a top view of the device illustrated in FIG. 1;

FIG. 3 is a cross-sectional view taken along lines III shown in FIG. 2;

FIG. 4 is a top view of the resonant plate illustrated in FIG. 1 with the housing illustrated therein shown in dotted lines;

FIG. 5 is an isometric view of the resonant plate and mounting member of the resonator shown in FIG. 1;

FIG. 6 is a cross-sectional view of the mounting pin of the resonator illustrated in FIGS. 1 through 5;

FIG. 7 is a side view of another embodiment of the invention; and,

FIG. 8 is an isometric view of a third embodiment of the invention.

FIG. 1 shows an assembled isometric view of an ultrasonic generator constructed in accordance with the present invention. This generator comprises generally a resonator **10** which is mounted on a base member **20**. The resonator **10** shown is a plate, shown as circular in FIG. 1, which when energy is imparted near the periphery thereof, will vibrate in a flexural mode having at least two nodal diameters so as to provide opposite sectors on the plate which are in phase during vibration as shown in FIG. 4. As shown in FIG. 4, the plus sign indicates sectors B and D on the disc which will be traveling toward the viewer whereas the negative sections A and C will be traveling away from the viewer at point in time during the vibration of the plate. This type of vibration is characteristic of a resonator which is suspended in free air contacting no other external structure. Ordinarily mounting such a plate to produce such a vibration absorbs such a great amount of the vibratory energy in the mounting means that ultrasonic signals transmitted to the air are negligible. In the present invention, however, a mounting means which was found to produce or effect relatively large amplitude and duration vibrations is employed. The mounting means which enables one to utilize the vibration characteristic of an air suspended plate is a pin or mounting means which is integral with the vibratory plate. When such a plate suspended in free air vibrates, the vibrations are described by nodal diameters d_1 and d_2 shown in FIG. 4. The diameters define sectors of vibrations or movement up and down. These nodal diameters intersect at a vibratory reference point V_1 on the plate and define a reference axis extending through and normal to the plate. The mounting pin for such a resonator is integral with the plate with the axis of the pin intersecting the above described reference axis at a point which is in the plane of intersection of the two members. In this fashion, the sections of vibrations of the plate are transmitted down the integral pin so that the plus and minus vibrations or up and down vibrations transmitted down the pin are equal and opposite and at some point before the mounting portion of the pin these vibrations are completely canceled so as to provide no transmission of energy outwardly from the pin. Hence, there is substantially no loss of energy from the resonator except to the free air.

It has been discovered that in order to effect substantially no loss to the mounting portion of the mounting pin, the mounting pin and the resonator must be integral and preferably made of the same piece of material as the plate. Integral, however, is not meant necessarily to mean that the pin is constructed from the same piece of material or metal as the resonator but rather is meant to include any similar connection such as where the pin is alloyed to the resonator.

A housing **30** is constructed around the disc and a striker means **40** is secured to the housing so as to impart energy to the disc to initiate vibrations thereof. The housing is spaced at odd quarter wave lengths from the sides of the disc or the plate so as to effect storage of energy back to the disc which it is not desired to utilize. As shown in FIG. 1, apertures are provided in the housing **30** which are opposite vibrating surfaces of the plate that are in phase and hence utilizing only one phase of ultrasonic energy coming from the resonant disc **10**. Still another aperture is provided in the housing which in the embodiment of FIG. 1 is a striker mounted on a spring to impart mechanical energy to the outer edges of the disc to initiate oscillations thereof.

In the embodiment of the invention illustrated in FIG. 1, the resonator **10** comprises a circular disc **11** having an upper major surface **12** and a lower major surface **13** with a circular outer peripheral side edge **14**. Extending downwardly from the vibrating plate **11**, as shown in FIG. 5, is an integral cylindrical pin **15** having a mounting portion with screwthreads **16** at the free end thereof to define a mounting portion for mounting the vibrator. The pin **15** is integral with the plate **11** and is concentric with the periphery of the plate **11**. In a preferred form for optimum or greatest ultrasonic output, the pin **15** and the plate **11** are formed out of the same piece of material such as by constructing the pin **15** by taking a cylindrical body and turning down one portion thereof with a lathe to produce the pin **15**.

The pin **15** is shown as extending from the lower major surface **13**, however, a similar pin could also extend from the upper major surface **12**. Such a pin must also be integral with resonator **11** and concentric with the reference axis described by the nodal diameters d_1 and d_2.

FIG. 4 illustrates a top view of the resonator **11**. This view illustrates a typical flexural mode vibration of the disc which is described by two nodal diameters d_1 and d_2. As shown in FIG. 4, when the plate **11** vibrates, it will describe four vibrating sections A, B, C and D. In this configuration where the plate is a circular disc, these four sections are 90° sectors. As shown in FIG. 4, sector A and sector C are in phase and are designated as such with a minus sign (−), whereas the sector B and sector D are also in phase designated as such by a plus sign. That is, at a given point in time the sectors A and C are going away from the viewer whereas the sectors B and D are out of phase with the sectors A and C and are coming up toward the viewer of the drawing. As can be understood, the maximum point of vibratory amplitude is in the center of the sectors and these vibrations are produced about the two nodal diameters d_1 and d_2. The vibration illustrated in FIG. 4 is descriptive of a vibration of a circular disc which is in free air and has no structural contact with any other element. As described above, this is the gravest mode of a plate although as explained above, the problem of mounting such a vibratory system without losses to its support has heretofore been quite unsatisfactory. In addition, it is possible under some conditions and with certain dimensions and modulates of elasticity to produce a flexural mode of vibration where there is more than two nodal diameters. The particular mounting means disclosed in the embodiment of the invention, however, will work satisfactorily with any flexural mode resonator having at least two or more nodal diameters. Further the resonator can be a circular plate or cylinder or a square or rectangular plate or block.

The particular vibrations illustrated in FIG. 4 are produced by imparting energy such as by a mechanical striker or a piezoelectric crystal, to either surface **12**, **13** or **14**. The point at which the energy is applied to the resonator determines the location of the nodal diameters d_1 and d_2 with d_1 being 45° in one direction from this point and d_2 being 45° in the opposite direction from this point. In order to provide a maximum of energy transfer from the actuating means, such as a striker mounted on a spring, the striker should hit the outer peripheral edge **14** or should hit the surfaces **12** and **13** of the vibrating plate **11** near the periphery thereof. The closer the energy is applied to the center of the disc the less the amplitude and duration of the vibrations. If the energy is applied to the surface of the resonator at a point in actuating planes P1 and P2 nodal diameters d_1 and d_2 will be set up as shown in FIG. 4.

More specifically, when the disc is struck by a striker, this point on the disc preferably substantially outwardly from the center of the disc, then sets up nodal diameters at 45° extending radially from the center of the device, from the point at which the energy was imparted to the disc. If the vibrating plate **11** is struck near the center thereof, very little vibrating will be initiated since only a very small amount of the deflection of the vibrating plate **11** will be effected.

When the disc or plate **11** commences to vibrate as shown in FIG. 4, the nodal diameters d_1 and d_2 describe a point of vibratory reference v_1 and a reference axis at the inner section thereof. On the lower major surface **13** of the disc **11**, this point as projected on the lower major surface is also the symmetrical center of the mounting pin **15** with the intersection of the disc **11**. More specifically, the reference axis, in the embodiment of the invention, is the center about which the pin **15** is mounted on disc **11**.

FIG. 6 illustrates the pin **15** with a cross section taken through the plane at which the pin **15** joins the lower major surface **13** of the vibratory plate **11**.

The motion imparted to the pin **15** by the sectors A and C will be equal and opposite to the motion imparted by the pin body sectors B and D. Consequently, equal and opposite motions will oppose each other and cancel out a short distance down pin **15** so as to retain the energy within the disc **11** and not allow this energy to be dissipated in the mounting on the disc.

In order for the motion transmitted down the shaft **15** from sectors A and C to be equal to the sectors B and D, it has been discovered that the pin must be integral with the vibratory plate **11**. Forcing the pin **15** into a hole on the disc **11** will not produce satisfactory vibrations and much of the energy will be dissipated down through the mounting portion or threads **16** on the pin **15** so as to provide an unsatisfactory resonator. In short, the pin **15** must be secured to the disc **11** in such a manner so that the transmission of energy down pin **15** by sectors B and D must be equal (and opposite) to the energy transmitted up the pin **15** by the sectors A and C. This can only be accomplished by having a continuity of material between the pin **15** and the disc **11**.

As shown in FIG. 1 and FIG. 3, the resonator **10** can be mounted by the mounting portion having screw-threads **16** on a circular mounting disc **20** having a threaded hole **21** in the center thereof. Threaded apertures or holes **22** are provided in the circular mounting base **20** to receive screws for mounting a housing **30**. As will be explained later, this housing **30** increases the ultrasonic output of the resonator over and above the use of the resonator **10** in open air.

The housing **30** includes a cylindrical section **31** having holes **35** for receiving screws that will screw into the apertures **22** of the mounting base **20**. At the upper end of the housing **30** is a flat planar top **32** which is perpendicular to the cylindrical section **31**. This top cover is secured to the cylindrical section **31** and has two diametrically opposed apertures **33** therein with another aperture **34** to provide an opening for the actuating mechanism that imparts energy to the disc. As shown in FIG. 3, the actuating mechanism **40** includes a leaf spring **41** having a striker **42** near the outer end thereof. The leaf spring **41** is secured to the top cover **32** by a screw **43**. The leaf spring **41** is of such a resiliency so that when the leaf spring is forced upwardly a predetermined distance the striker **42** will move into contact and impart one striking blow or tap to the resonant plate **11** to thereby initiate vibration therein. As will be understood, this striker could be mounted to impart a striking force to either the side edges **14** or the lower major surface **13** of the fluexural disc or plate **11**. When the resonator or transmitter is assembled as shown in FIG. 3, the mounting base **20** is parallel to the lower major surface **13** of the flexural mode plate **11** a distance S3 whereas the cylindrical section **31** of the housing **30** is spaced a distance S2 from the peripheral edges **14** of the vibrating plate. The top cover **32** of the housing **30** is parallel to and spaced a distance S1 from the upper major surface **12**. These distances S1, S2 and S3, for optimum performance of the embodiment illustrated in the drawings, are distances which are odd quarter wave lengths of the frequency of vibration of the vibratory plate **11**. More specifically these distances S1, S2 and S3 are equal to

$$\frac{\lambda}{4}+\frac{N\lambda}{2}$$

where N is any whole integer (1, 2, 3, 4 etc.) or zero.

In order for the resonator **11** to provide any usable

ultrasonic output, the material of resonator **11** should have a Q of at least 5,000 to 10,000. Some aluminum base metals as well as other metals have Q's of at least this amount.

Although the side walls of the housing are spaced a predetermined distance from the resonator, there are, as shown in FIG. 1, two apertures **33** in the top cover **32**. These apertures in the top cover **32** are located above sectors of vibration having the same phase since the hole **34** is 90° from hole **33**. More specifically, as shown in FIGS. 4 and 1, these apertures are located above sectors B and D. Hence, practically all the ultrasonic signals which come out of the housing **30** are of the same phase. Consequently, cancellation due to opposite phase of the signals coming from the vibrator to the free air is minimized. Although the hole **34** is to accommodate the striker **42** in the upper top plate **32** is over a sector A which is of the opposite phase of sectors B and D, there will be very little cancellation therefrom due to its being covered substantialy by the spring **41** and the striker **42**. Hence, the housing **30** enables the ultrasonic signals of the first phase described emanating from sectors A and C to be effectively stored back in the disc and without allowing them to effect any substantial cancellation of the second phase of the vibration emanating from the sectors B and D. Hence the energy from the ultrasonic signals of the phase emanating from sectors A and C is conserved and the output of the transmitter itself will be that of the energy having the second phase from the sectors B and D.

Although the housing **30** as described above increases the ultrasonic output of the generator, the resonator **10** can be utilized without such a reflective or resonant housing and still produce a substantial ultrasonic signal such as shown in FIG. 7, the lower portion of pin **15** is secured to a base having only a very small reflecting surface. In addition as shown in FIG. 8, energy can be transmitted to the virbratory disc **11** by means other than a mechanical striker such as by a piezoelectric crystal **50** which has an A.C. applied thereto by a source **52** through leads **51**. The frequency of source **52** is the same as the resonant frequency of the resonator **11**. The crystal is secured to the surface of the vibrator **11** by some suitable conducting adhesive. One of the leads **51** is electrically connected to the upper side of crystal **50** and the other lead **51** is electrically connected to the mounting pin **15**.

As stated previously, the most desirable frequency range for ultrasonic signals is between 30 kilocycles and 60 kilocycles since in this frequency band there is a minimum of interference due to extraneous electromagnetic waves and sonic waves. The following resonator was constructed with systems Q's in free air of about 35,000 made of 7075S–T6 and 6061S–T6 aluminum discs. None of these units lost any energy through the mounting portion (the threaded portion of the pin **15**). No housing was employed in the tests on these models. Other tests were made with housings and a substantial output increase was realized.

In these tables *f* is frequency of output, in kilocycles, D is diameter of disc in inches, and *t* is thickness of disc in inches.

TABLE I

Data for 6061S–T6 aluminum disks

Point	D/t	D, inches	t, inches	f, kc.	f·D²/t, kc.-in.	fD, kc.-in.	Mounting pin post dia., in. (Pin 15)	Unthreaded post length, in. (Pin 15)
a	2.58	1.125	.437	50.6	146	57	.360	.093
b	4.0	1.028	.256	43.12	178	44.3	.360	.249
c	4.36	1.118	.256	37.9	183	42.4	.140	.195
d	4.36	1.118	.256	38.67	188	43.2	.360	.194
e	4.50	1.150	.256	36.74	188	42.2	.360	.194
f	4.80	1.500	.312	25.5	188	38.2	.360	.194
g	6.36	1.500	.235	19.8	190	29.7	.140	.365

TABLE II

Data for 7075S–T6 aluminum disks

Point	D/t	D, inches	t, inches	f, kc.	$f \cdot D^2/t$, kc.-in.	f D, kc.-in.	Post dia., in.	Post length, in.
A	2.15	1.615	.750	37.00	128	59.6	.140	.250
B	3	1.500	.500	33.31	150	50.3	.140	.250
C	4	1.025	.256	40.64	167	41.7	.140	.197
D	4.35	1.118	.256	35.00	170.8	39.1	.140	.197
E	6.5	1.615	.250	17.67	184	28.5	.140	.250
F	3	1.500	.500	33.46	151	50.4	Minor diameter of 10-32 mch. scr.	¼″ threaded—¼″ non-threaded
G	2.93	1.290	.439	30.25	149	50.6		
H	3	1.120	.373	44.92	151	50.3		
I	2	1.120	.560	55.37	124	62		
J	1.5	1.120	.746	61.60	103.2	69		
K	1	1.120	1.120	68.70	77.0	77		
L	.75	1.120	1.492	48	40.4	53.7		
M	.5	1.120	2.240	25.3	14.2	28.7		
M′	.5	1.120	2.240	47.0	26.3	52.6		

While particular embodiments of the invention have been shown and described, it is apparent that modifications and alterations may be made, to cover all such modifications as they fall within the true scope and spirit of the invention.

We claim as our invention:

1. A mechanical resonator comprising, a vibrating plate resonant in a flexural mode with a plurality of nodal diameters, said plate having a pair of parallel planar major surfaces with peripheral edge surfaces extending perpendicular to the planes of said major surfaces, a cylindrical pin extending outwardly from one of said major surfaces and being concentric with said peripheral surfaces, said pin being integral with said plate, and means for applying energy to said plate to actuate said plate into resonant vibration in a flexural mode with a plurality of nodal diameters.

2. A mechanical resonator comprising, a vibrating plate resonant in a flexural mode with a plurality of nodal diameters, said plate having a pair of parallel planar major surfaces with peripheral edges extending therebetween, a pin extending outwardly from the center of one of said major surfaces, said pin being integral with said plate, a reflecting surface spaced from one of said major surfaces a distance equal to

$$\frac{\lambda}{4}+\frac{N\lambda}{2}$$

where λ equals the wave length of the ultrasonic waves produced by the said vibrating plate and N being any integer or zero, means for applying energy to said plate to actuate said plate into resonant vibration with a plurality of nodal diameters, said reflecting surface having an aperture therein with said aperture defining a projective surface on said one of said major surfaces with said projected surface being located within an area between two adjacent nodal diameters.

3. A mechanical resonator comprising, a vibrating plate resonant in a flexural mode with a plurality of nodal diameters, said plate having a pair of parallel planar major surfaces and an outer minor peripheral surface transverse to the plane of said major surfaces, a circular pin extending outwardly from one of said major surfaces and concentric therewith, said pin being integral with said circular plate, and means for applying energy to said plate near the outer periphery thereof to actuate said plate into resonant vibration in a flexural mode with a plurality of nodal diameters.

4. A mechanical resonator comprising, a vibrating plate resonant in a flexural mode with a plurality of nodal diameters, said plate having a major and a minor surface with said minor surface comprising the peripheral edges thereof, mounting means for said plate comprising a mounting pin, means connecting said pin to the center of said major surface to apply equal and opposite vibratory forces to said pin, and means for applying energy to said plate to actuate said plate into resonant vibration in a flexural mode with a plurality of nodal diameters.

5. A mechanical resonator comprising, a vibrating plate resonant in a flexural mode with a plurality of nodal diameters, said plate having a pair of parallel planar major surfaces with peripheral edge surfaces therebetween, a mounting pin, connecting means providing an undamped connection between said pin and the center of one of said major surfaces, and means for applying energy to said plate to actuate said plate into resonant vibration in a flexural mode with a plurality of nodal diameters.

References Cited by the Examiner

UNITED STATES PATENTS

3,004,620 10/61 Baschet .... 84—410

FOREIGN PATENTS

364,651 11/22 Germany.
387,613 1/24 Germany.

OTHER REFERENCES

Publication, "Grits and Grinds," January 1951, vol. 42, Issue 1, pages 10–12.

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