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HIGH EFFICIENCY SONIC GENERATOR

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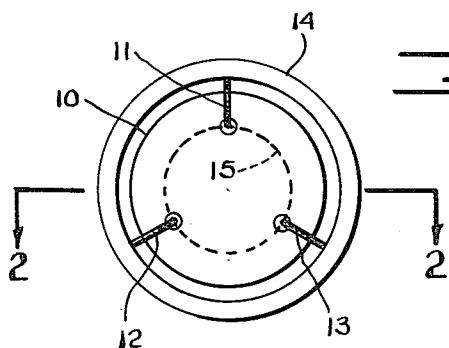


Fig. 1.

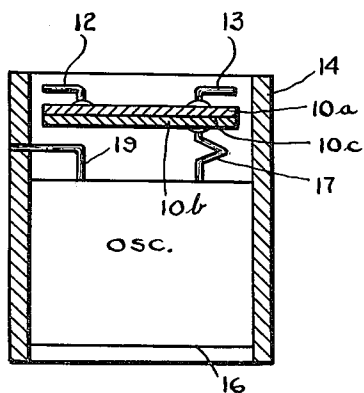


Fig. 2.

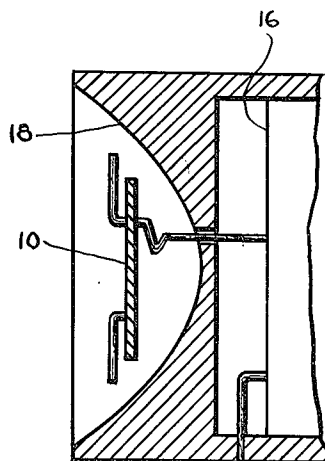


Fig. 3.

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HIGH EFFICIENCY SONIC GENERATOR

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The present invention relates to vibration generators and has particular reference to means for producing vibrations in air.

Many devices have been developed for the conversion of electrical energy into sound vibrations. In every case difficulty is experienced in producing these sound vibrations with efficiency. The problem becomes more difficult as the acoustic impedance, product of density and propagation velocity, of the medium is lowered. Reasonable efficiencies, as high as 90%, within a narrow band can be produced with quartz resonators when working into liquid and solid media. A severe problem, however, arises when attempting to produce these vibrations into air or gas. Due to the low density of the gas compared to any vibrating solid medium, large deflections must be produced in order to deliver any significant amount of energy to the medium. These large deflections are usually accompanied by large restraining forces built up in the transducing solid or its supporting structure. In addition where supersonic vibrations are desired, the increase in frequency further aggravates the "lossiness" of the transducing structure making it extremely difficult to realize efficiencies above 5%, in the frequency domain above 20,000 c.p.s. The present invention is means for generating these vibrations as well as frequencies within the audio spectrum with high efficiency.

In establishing a mode of vibration for a solid transducer, it is necessary to maximize the ratio of energy delivered to air per cycle of vibration to the energy stored per cycle of vibration. In this way a more favorable condition will exist for any given support structure. This statement can be expressed by stating that the air loaded Q is to be minimized. Here Q is defined as in all vibrat-

$$Q = 2\pi \frac{\text{Max. energy stored per cycle}}{\text{Energy dissipated per cycle}}$$

If the air loaded Q is made small enough, reasonably poor mounting structures can be tolerated. In addition internal losses in the vibrating transducers can then be small compared to the energy delivered to the air.

The conventional thickness mode vibration, e.g.: x cut quartz plate, is actually a poor choice for this criterion. In order to produce moderate displacement of air, the crystal must expand and contract working against its modulus of elasticity, thus producing large values of stored energy for small displacements of air.

The Q of thickness mode vibrational crystals for plane wave propagation, diameter large compared to wavelength, is well developed in the literature and is given by Equation 1:

$$Q = \frac{\pi Z_q}{2 Z_a}$$

where:

Z_q =acoustic impedance of transducer material

Z_a =acoustic impedance of air

For example, Z_q of quartz is of the order of 35,000 times that of air so that the air loaded Q is of the order of 50,000. The internal losses of quartz itself in tensile-compressive cycling result in a Q of the order of 30,000. For a perfect mounting, the maximum efficiency is limited to something of the order of 30%.

A mode of vibration of a flat plate which is far more

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favorable is a flexure mode. In causing a plate or a strip of material to flex or bend, large displacements can be obtained for smaller values of internal stored energy. The difficulty here, however, is that for given dimensions, the resonant frequency is lower, and in an attempt to raise the frequency to the supersonic region, thick sections or small lengths must be used. In the first case, the flexibility advantage is lost, and in the second case, the transducer tends to become too small to preserve plane wave propagation and the air loading is again reduced. However, an optimum configuration does exist where highly efficient transducers may be devised, according to the present invention, as will be described.

As an example, consider a disk transducer of diameter D and thickness t in a flexure mode vibration produced by a free ended condition in its fundamental symmetrical form where a single nodal circle exists on the transducer disk. The mathematical analysis of the air loaded Q of this disk results in the following approximate expression:

$$Q = C_1 \frac{Z_t}{Z_a} \left(\frac{t}{D} \right)^2 \left[\frac{1}{J_1 \left(\frac{2\pi D}{\lambda} \right)} \right] \quad (1)$$

where

C_1 is a constant determined by mode and material=6.5 for quartz in the chosen mode Z_t/Z_a =ratio of the acoustic impedance of transducer material to that of air=35,000 for quartz

t is the thickness of the plate in centimeters

D is the diameter of the plate in centimeters

λ is the wavelength of the exciting frequency in the propagating medium

J_1 represents the first order Bessel function

Also, it is known that the frequency of resonance is given by the expression

$$f = C_2 \frac{t}{D^2} \quad (2)$$

where C_2 is a constant determined by mode and material, 1122 for quartz in free edge symmetrical mode.

From (1) it will be seen that Q can be reduced by choosing an appropriately small value of t/D, and D can apparently be made arbitrarily small to adjust the resonant frequency as desired. Since t is a direct function of D, from Equation 2

$$\frac{t}{D} = kD$$

for any given frequency it appears that the smaller the diameter, the lower the Q.

However, a lower limit is imposed on D by certain practical considerations. It will be seen that the smaller values of D reduce the air loading as shown in Equation 1 where the factor

$$\left(\frac{J_1 \left(\frac{2\pi D}{\lambda} \right)}{1 - \frac{\pi D}{\lambda}} \right)$$

opposes the effect of decreasing D below

$$\frac{D}{\lambda} \cong .6$$

Even so, a lower Q value is obtained as the D/ λ ratio is made smaller. The advantage in efficiency gained by D/ λ values below .3 however, is small compared to the problems associated with manufacturing the smaller units

and therefore a lower limit of D/λ may be arbitrarily set at

$$\frac{D}{\lambda} = .3$$

For high frequency or ultrasonic vibrations, a diameter equal to or less than the wavelength may be impractically small. For this reason an upper limit for the D/λ ratio should be specified. The efficiency of the transducer depends on the t/D ratio. Assuming that the Q_m due to mounting effects only is of the order of 6000, the air loaded Q_a for any efficiency can be expressed as

$$Q_a = \frac{(1 - \text{efficiency})}{\text{efficiency}} Q_m$$

For 90% efficiency, Q_a is therefore about 600 and Equation 1 indicates that if $Q=600$, t/D should be in the vicinity of 1/20 for quartz. From Equation 2 the D/λ ratio for $t/D=1/20$ is found to be substantially 1.7. For 80% efficiency, a t/D ratio of approximately 1/12 and a D/λ ratio of 2.7 is the upper limit. Larger disks will have correspondingly lower efficiency.

For a more complete understanding of the invention, reference may be had to the figures in which:

FIG. 1 is a plan view of a mounted transducer;

FIG. 2 is a sectional view through 2—2 of FIG. 1; and

FIG. 3 is a modification of FIG. 2.

Referring now to FIGS. 1 and 2, a typical embodiment of a sonic transducer using the present device is illustrated, the frequency of which could be audible or ultrasonic, as desired. A disk 10 is supported by three supporting members 11, 12, 13 which extend between a frame 14 and the disk 10. The supports 11, 12, 13 are equidistantly spaced on the surface of the disk 10 and are located exactly on the nodal circle 15 of the disk 10. The supporting members 11, 12, 13 are preferably proportioned so as to have a resonant frequency equal to that of the disk 10 whereby the effects of errors in the placement of supports on the disk 10 are minimized. One or all the supporting members 11, 12, 13 are electrically connected to one terminal of an exciting oscillator power supply 16, which is conveniently located in the frame 14 behind disk 10, the electrical connection may be made by means of the frame 14 to which the oscillator 16, FIG. 2, is grounded by lead 19 and to which the leads 11, 12, 13 are attached. The other terminal of oscillator 16 is connected to the disk 10 through the connector 17 which may also be mechanically resonant at the resonant frequency of the supports 11, 12, 13 and is attached to the opposite side of disk 10 on a nodal circle. The disk 10 is preferably a bimorph transducer prepared by bonding a pair of circular x-cut quartz plates 10a, 10b with like polarity faces in contact at the junction plane 10c. The bonding may be by soldering, plastic resins, or other suitable media. Other types of flexure transducer plates may be employed, if desired, as for example, cut quartz plates adapted for vibration in shear. Although at this

time quartz appears to be the preferred transducer material, the invention is not to be limited to the use thereof but any suitable piezo-electrical material can be used, if desired. The desired mode of flexure vibration is any symmetrical mode which, for the disk 10, is any mode in which at least one nodal circle is found on disk 10. This symmetrical mode is obtained by forcing the disk into vibration at the proper frequency by proper design of the oscillator 16 in which the disk 10 is used as the frequency-controlling element. The supports 11, 12, 13 being on the nodal circles, assist in insuring that the desired mode of vibration is obtained.

It has been found that the orientation of the Y and Z axes of the plates will affect the operation of the transducer, but not to a very great extent. If the Y axis of one disc 10a is aligned to be opposite the Y axis of the other disc 10b, certain subsidiary resonances are produced in the vibrating composite disk. These subsidiary resonances disappear when the Y axis of one disk is opposite the Z axis of the other disk, and this is the preferred arrangement.

I claim:

1. In a sonic transducer for producing sonic vibrations in air, a flexure mode circular piezoelectric plate having its edges free to vibrate and said plate having a nodal circle, a support for said plate, said plate being suspended from said support by supporting members attached to said plate at the nodal circle and having a resonant frequency substantially the same as the resonant frequency of said plate, the ratio of diameter of the plate to the wavelength of the resonant frequency of the plate in air being greater than .3 but less than 3.

2. In a sonic transducer for producing sonic vibrations in air, a flexure mode circular piezoelectric plate having its edges free to vibrate and said plate having a nodal circle, a support for said plate, said plate being suspended from said support by supporting members attached to said plate at the nodal circle, said supporting members consisting of low loss wires, the ratio of diameter of the plate to the wavelength of the resonant frequency of the plate in air being greater than .3 but less than 3.

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