ELASTOMER RESONATOR FOR ORBITING MASS OSCILLATOR

6 Claims, 5 Drawing Figs.

ABSTRACT: An orbiting-mass oscillator is coupled to a low-impedance elastomer in which a resonant standing wave pattern can be established. The elastomer serves as a transmission and energy storage medium for the energy in the resonant system to enable utilization of the energy in various work functions. In one embodiment the elastomer is coupled to water, while in another embodiment the elastomer is coupled to a free standing heavy mass.
ELASTOMER RESONATOR FOR ORBITING MASS OSCILLATOR

In prior devices or systems utilizing sonic energy, elastomeric material such as rubber, for example, has been used as an isolator. As such, the elastomeric material prevented the dissipation of the sonic energy to areas not being worked upon. As is known, elastomers such as rubber can absorb vibratory energy such as is generated in acoustic resonators. In the prior art, an acoustic generator, such as for example an orbiting-mass oscillator, has been coupled to an elastic material such as steel, in which a standing wave pattern could be generated. Such systems are taught in many of my issued patents wherein such combination of an orbiting-mass oscillator together with an elastic material such as steel have been utilized as an effective means for the transmission of resonant sonic energy. Never before have the unusual advantages to be attained by using an elastomeric material such as rubber for the resonator been appreciated.

The herein invention utilizes elastomeric material as a resonator element in a system utilizing acoustic energy. Preferably, the resonator element comprises a hollow thick-walled cylinder of an elastomeric material such as rubber. Attached to one end of the cylinder is an oscillator for generating acoustic waves in the resonator. Preferably, the oscillator is an orbiting-mass type such that a standing resonant wave is established and maintained in the resonator column. In one embodiment the resonator is partially submerged in a liquid bath. This provides, as will be explained, a good impedance match since both an elastomeric resonator and water have a low acoustical impedance. Articles to be cleaned or washed can then be submerged in the liquid bath, the cleaning action being transmitted to the sonic energy generated therein. Alternatively, in a second embodiment, the resonator can be coupled to a heavy mass, which in turn can drive an element such as a drill. The heavy mass between the elastomeric resonator and the drill tool acts as the motor to drive the oscillator. Additionally in the foregoing embodiments of the invention the elastomeric resonator column is supported and isolated from nonfunctional parts of the system at its nodal portion where minimum vibration occurs.

It is believed the invention will be better understood from the following detailed description and drawings in which:

FIG. 1 is a partially sectional view of a first embodiment of this invention showing the use of an elastomeric resonator embedded in a water bath.

FIG. 2 is a sectional view of an alternative means for supporting the resonator of FIG. 1 and acoustically isolating it from the support system.

FIG. 3 is a sectional view of a second embodiment of the herein invention, utilizing a nodal adjustment in the elastomeric resonator and additionally depicting parts embedded in the water bath.

FIG. 4 is an enlarged sectional view of the seal element 69 of FIG. 3, showing the adjustable means for isolating and supporting the resonator column.

FIG. 5 is a partially sectional view of a further embodiment of this invention showing the elastomeric resonator utilized in combination with a drill.

It is helpful to the comprehension of this invention to make an analogy between a mechanical resonant circuit and an electrical resonant circuit. This type of analogy is well known to those skilled in the art and is described, for example, in Chapter 2 of "Sonic" by Hucker and Burt, published in 1955 by John Wiley and Sons. In making such an analogy, for the first time is equated with electrical voltage E, velocity of vibration u is equated with electrical current i, mechanical compliance Cm is equated with electrical capacitance Cc, mass M is equated with electrical inductance L, mechanical resistance (friction) Rm is equated with electrical resistance R, and mechanical impedance Zm is equated with electrical impedance Zc. Thus, it can be shown that if a member is elastically vibrated by a sinusoidal force, F, sinωt, ω being equal to 2π times the frequency of vibration, that

\[ Z_m = R_m + \frac{1}{\omega C_m} \]

Where ωM is equal to \( \frac{1}{\omega C_m} \), a resonant condition exists, and the effective mechanical impedance Zm is equal to the mechanical resistance Rm, the reactive impedance components ωM and \( \frac{1}{\omega C_m} \) canceling each other out. Under such a resonant condition, velocity of vibration u is at a maximum, effective power factor is unity, and energy is most efficiently delivered to the object being vibrated. It is such a high-efficiency resonant condition that the resonant circuit beneath the mass is driven by is preferably utilized in the methods and devices of the invention to achieve the desired end results.

It is to be noted by reference to equation (1) that velocity of vibration u is highest where impedance Zm is lowest, and vice versa. Therefore, a high-impedance load will tend to vibrate at relatively low velocity, and vice versa. Thus, at an interface between high- and low-impedance elements, a high relative movement results by virtue of such impedance mismatch which, as in the equivalent electrical circuit, results in a high reflected wave. This is accomplished in the embodiment of the invention where the elastomer resonator is coupled to a heavy mass which in turn is affixed to a chisel drill. High relative movement between the elastomer-coupled mass and drill results. Alternatively, where a low-impedance load, such as water, is present, the acoustic impedance of the elastomer so closely matches that maximum transfer of the vibratory energy is achieved. The mismatch of impedance arises at the interface of the water and parts submerged therein wherein the desired cleaning can occur.

As just the sharpness of resonance of an electrical circuit is defined as the "Q" thereof, and is indicative of the ratio of energy stored to the energy used in each cycle, so also the "Q" of a mechanical resonant circuit has the same significance and is equal to the ratio between ωM and Rm. Thus, high efficiency and considerable cyclic motion can be achieved by designing the mechanical resonant circuit for high "Q".

Of particular significance in the implementation of the methods and devices of this invention is the high acceleration of the components of the elastic resonant system that can be achieved at sonic frequencies. It can be shown that the acceleration of a vibrating mass is a function of the square of the frequency of the drive signal times the amplitude of vibration. Under resonant conditions, the amplitude of vibration is at maximum and thus even at moderately high sonic frequencies very high accelerations are achieved.

In considering equation (1), several factors are to be noted. First, this equation represents the total effective resistance, mass and compliance in a vibrating circuit, and these parameters are generally distributed throughout the system rather than being lumped in any one component or portion thereof. Secondly, the vibrating system often includes surrounding components, a container holding the water and the water itself.

It is also to be noted that orbiting-mass oscillators are utilized in the devices of the invention that automatically adjust their output frequencies to maintain resonance with changes in the characteristics of the load. Thus, in situations where we are dealing with parts which are placed in a bath during the operation of the device which will change that load, the system automatically is maintained in optimum resonant operation by virtue of the "Q"-imparting orbiting-mass oscillators. The vibrational outputs from such orbiting-mass oscillators are generated along a predetermined coherent path to provide maximum output along a desired axis or axes. The orbiting-mass oscillator automatically changes not only its frequency but its phase angle and therefore its power factor with changes in the resistive impedance and hence efficiency of operation at all times. Such orbiting-mass oscillators are capable of efficiently generating high-level vibrational outputs.

By utilizing as a resonator element an elastomeric material such as rubber, a much greater feedback to the oscillator is accomplished than when the resonator is of a high-impedance
material such as, for example, a steel column. This feedback results, since the elastomer, because of its inherently low impedance, provides a greater cyclic stroke for a given frequency of the oscillator as it is connected. Previously, other low-impedance resonator elements such as air springs have been affixed to an oscillator. However, these elements have lumped constant impedance characteristics. On the other hand, the elastomeric material is a distributed constant system. A distributed constant system has the advantage of being able to accomplish an acoustic lever effect where, for example, a high velocity or amplitude vibration at the face of the oscillator can be converted to a low velocity with a high force at the end of the resonator exposed to the load element.

Further, as indicated, one of the advantages of an orbiting-mass oscillator is its lock-in characteristics with the automatic adjustment of operating frequencies to accommodate for sudden changes in environmental reactive impedance. This feedback is best accomplished by a low-impedance resonator, such as the elastomeric element disclosed which has a large-amplitude vibration to better accomplish the feedback. Additionally, in this same vein, the automatic accommodation for changes in environmental resistive impedance caused by a work load is better fed back to the oscillator through a low-impedance resonator since there is greater activity when the resonator is coupled.

Referring now to FIG. 1 where a first embodiment of the invention is seen, a fluid-containing vessel 11 having a liquid such as water, oil or cleaning bath 13 therein is shown. The vessel 11 is open at both ends and has a radially extending flange 15 at its bottommost portion. Extending upwardly into the vessel 11 is an elastomeric resonator column 17, which can be of a material such as a high-“Q” rubber to more nearly match the acoustic impedance of the liquid 13. Surrounding the resonator column 17 is a support and isolator ring 19. The ring 19 is of metal such as steel which is tightly fitted to the column 17 forming a seal therewith. The ring 19 has an outwardly radially extending flange portion 21 which is tightly fitted against the flange 15 of the vessel 11. Elastomeric washers 19a are placed between portion 21 and flange 15 to prevent the liquid from leaking out of the vessel. Portion 21 is thus sandwiched between the flange 15 and a support structure 23 by bolts 25. The ring 19 is pressed fit so tightly to the elastomeric resonator 17 that the liquid 13 is sealed between the walls of container 11 and the resonator 17. Additionally the ring 19 serves to vertically support the resonator 17 and the associated vibratory equipment. Isolator washers 22 support the ring 19.

Vulcanized to the bottom end of the resonator 17 is a platen 27 that thus seals the bottom of the resonator and serves to transmit the vibratory energy thereto from an orbiting-mass oscillator 29. The platen 27 is provided with a collar 31 which surrounds the oscillator 29. The orbiting-mass oscillator 29 can be of the configuration shown in U.S. Pat. No. 3,217,551 issued Nov. 16, 1965. A motor 33 drives the oscillator through a universal connection 35. A fan 37 can be connected to the universal shaft, serving to cool the surrounding area wherein heat is generated due to the vibratory energy.

As can be seen from FIG. 1, the elastomer resonator 17 is in the form of a large diameter column with a hole through its center. It is thus in the form of a thick-walled tube. This design provides good stability for the resonator in a lateral direction. Additionally, the hole in the center functions to improve the cooling action of the liquid medium in contact with the resonator. A standing wave pattern 39 is developed in the element 17, such that the node 41 is at the point where the ring 19 is in contact with the resonator so that minimum transmission of the vibratory energy is passed into the surrounding system. It is to be noted that in the embodiment shown in FIG. 1 some adjustment is permitted whereby the point of attachment between ring 19 and resonator element 17 can be made to coincide with the node of the standing wave pattern in resonator element 17. This enables a precise vertical positioning of the resonator for minimum energy dissipation in the support system.

FIG. 2 discloses an embodiment that does not permit adjustment of the resonator 17 shown therein, since a portion 43 which serves to support the resonator is integrally formed therewith rather than being a separate metal ring such as shown in FIG. 1.

The liquid as shown in FIG. 1 could be an oil, water or various liquid chemicals. The result of the vibratory action of the resonator can be used to clean particles immersed in the liquid as will be later described and shown, or it can mix liquids in the tank 11. Additionally, the energy can be used to activate chemical reactions at lower temperatures.

Turning now to FIG. 3, there is seen a second embodiment of the invention embracing essentially the same concepts disclosed in FIG. 1, however providing for a different means for mounting the elastic resonator and adjusting the position of the attachment between the resonator and the support structure. The vessel 45 is double walled having an inner wall 47 and an outer wall 49. Between the two walls is a space for insulating material 51 which serves to prevent excessive noise from being transmitted to the surrounding environment. The insulating material 51 can be, for example, sand or a fibrous composition used for acoustic purposes.

The bottom of the container 45 is welded to a platen 53 which is in the form of a large circular disk. Extending upwardly from the platen 53 concentrically within the container 45 is a cylindrical wall 55 which forms a concentric fluid-containing passage 57 between it and the inner wall 47 of the container. The platen 53 is supported by a circumferential reinforced structure 59. A throated mug 61 is provided adjacent the bottom of the vessel to facilitate evacuation of the fluid therethrough.

Extending upwardly within container 45 concentrically therein is an elastomeric resonator 61 in a tubular form similar to that shown in FIG. 1. The bottom end of the resonator is vulcanized to a vibratory plate 63 which is connected to an oscillator 65 in the same manner as disclosed in FIG. 1. It is to be noted that a fan blade 67 is disposed so as to circulate air between the resonator element 61 and the inner cylinder walls 55. This is a relatively confined area wherein considerable heat can be generated through the vibratory energy of the resonator 61. Thus the fan serves to circulate the air and cool this region.

Surrounding the resonator 61 and between it and the inner cylinder walls 55 is a movable seal element 69 which is shown in detailed cross section in FIG. 4. This movable element provides for easy adjustability of the position of attachment between resonator 61 and cylinder walls 55, such adjustment being made for optimum vibration efficiency by bringing the attachment portion into coincidence with the node of the standing wave pattern. As particularly seen in FIG. 4, the adjustable seal member comprises two concentric elastomeric rings 71 and 73, respectively, wherein 73 is the ring adjacent the resonator and in tight sealing contact therewith. Disposed between the two rings are two flat circular plates 75 which are held together by a threaded bolt 77 which can be adjusted by tightening nut 79. As can be appreciated, the two plates 75 when tightened tend to squeeze the elastomeric rings 71 and 73 outwards against the inner cylinder walls 55 and elastomeric resonator 61, respectively, forming a tight immoveable seal therewith. Loosening of the nut 79 reduces the pressure of the two rings 71 and 73 against their associated elements so that they can be moved up and down the exterior of the resonator 61. As shown, the most preferable wave pattern 81 is for an antinodal region to result at the end of the resonator exposed to the liquid material 83 in the container, so as to generate a maximum of vibration therein. The seals 69 are positioned at a node of the wave pattern so that a minimum of vibration is dissipated in the surrounding structure. As shown, disposed in the liquid 83, which in the particular instance shown can be water, is a basket 85 hung from the top ridge 86 of the container 45. The basket has a plurality of
parts 87 disposed therein for cleaning in the bath 83. The vibratory energy coupled by the resonator element 61 into the liquid 83 is transmitted to the parts causing a cleaning action at the interface of the part with the liquid.

Turning now to FIG. 5, there is shown a further embodiment of this invention utilizing an elastomeric resonator element. As shown therein, a C-shaped handle 91 is connected at a first end 93 to a plate 95 for supporting a motor 97. Extending downwardly from plate 95 and integrally formed therewith is an arm 99 connected at a pivot point 101 to a movable arm 103 which in turn is affixed to a drill chisel 105. Attached to a second end 107 of the handle 91 is a support arm 109 extending downwardly to an attachment ring 111 which may be of metal. The ring 111 surrounds and helps to support a tubular-shaped elastomeric resonator 113. A portion of the ring 111 is additionally affixed to the arm 99 and connected therewith by means of bolts 114. Motor 97 drives oscillator 115 through a flexible shaft 117 connected therewith. The output of oscillator 115 is coupled to a platen 119 affixed to the top of the resonator element 113. The bottom of the resonator element is connected to a second platen 121 having a heavy mass 123 affixed thereto. Platens 119 and 121 are preferably vulcanized or glued with an epoxy resin to the elastomeric resonator 113 and thus integrally connected therewith. Heavy mass 123 is in contact with a raised portion 125 of the movable arm 103 directly in line with the chisel drill 105.

In the operation of the device, the motor which can be driven by means of electrical power provided through line 127 drives orbiting mass oscillator 115, which may be of the type described in my U.S. Pat. No. 3,217,551, causing a standing wave 129 to be developed in the resonator element 113. The resonator element in turn drives heavy mass 123 against the raised portion 125 above the chisel drill. Since the mass is not attached to the portion 125 and the general movement of the resonator is in a vertical direction, the chisel drill will only move downwardly in response to the downward vibratory excursions of mass 123, causing a solely unidirectional action of the chisel drill. In this manner, effective rectification of the sonic energy is achieved. Pivot 101 permits the arm 103 to move the chisel drill downward into the ground as the heavy mass 123 strikes the portion 125 during the downward vibratory excitations of the resonator. It is to be noted as in the other embodiments that ring 111 surrounds the resonator element 113 at a nodal point so that a maximum vibrational energy is dissipated into support arms 99 and 109 or carried back to parts such as handle 91.

While the invention has been described and illustrated in detail, it is to be clearly understood that this is intended by way of illustration and example only and it is not to be taken by way of limitation, the spirit and scope of the invention being limited only by the terms of the following claims.

1. In combination: a fluid-containing vessel; a tubular elastomeric resonator extending upwardly into said vessel from the bottom thereof; means surrounding said resonator forming a tight seal between it and the bottom of said vessel; and means for establishing a standing wave pattern in said resonator.

2. In combination: a fluid-containing vessel; a tubular shaped body disposed within said vessel extending upwardly from the bottom thereof and spatially displaced from the walls of said vessel; means for sealing the bottom of said tubular body to the bottom of said vessel; a tubular elastomeric resonator extending upwardly into said vessel, said resonator disposed concentrically within said tubular shaped body; an adjustable ring seal surrounding said resonator, sealing said resonator to said tubular body whereby said liquid can fill the area between said resonator and said body above said seal; and means affixed to the bottom of said resonator for effecting the resonant vibration thereof.

3. The combination of claim 2 wherein said adjustable seal comprises: a first elastomeric ring surrounding said resonator; a second elastomeric ring concentrically disposed about said first ring in contact with said tubular body; two circular plates disposed respectively above and below said rings in contact therewith; and means for adjustably decreasing the space between said plates forcing said rings into tight engagement with the tubular body and resonator, respectively.

4. In combination: an orbiting mass oscillator; means for driving said oscillator; a tubular elastomeric resonator element coupled to said oscillator whereby a resonant standing wave pattern can be established in said element; and a vessel adapted to contain a liquid bath at least partially surrounding said resonator element.

5. The combination of claim 4 additionally comprising means for adjustably supporting said resonator element in said vessel.

6. The combination of claim 5 wherein said resonator element extends upwardly into said vessel from the bottom thereof whereby said liquid may entirely fill the cavity within the tubular resonator element and the position of said supporting means determines the amount of liquid surrounding the outer circumference of said resonator element.