United States Patent

Bodine

[15] **3,682,397**

[45] **Aug. 8, 1972**

[54] **APPARATUS FOR CRUSHING AND SEPARATING ORE MATERIAL**

[72] Inventor: **Albert G. Bodine,** 7877 Woodley Avenue, Van Nuys, Calif. 91406

[22] Filed: **Feb. 27, 1969**

[21] Appl. No.: **802,907**

[52] **U.S. Cl.**.....**241/46 R,** 241/264, 241/283

[51] **Int. Cl.**.....**B02c 19/16**

[58] **Field of Search**.....241/DIG. 30, 86, 102, 264, 241/201, 202, 146, 46 R, 46.02, 46.04, 46.13, 265, 290, 283, 262

[56] **References Cited**

UNITED STATES PATENTS

258,552	5/1882	Brown	241/102
2,959,830	11/1960	Castera	241/86 X
3,348,781	10/1967	Sackett	241/264
3,465,976	9/1969	Vinitsky	241/262 X
1,219,408	3/1917	Hackstaff	241/46.13 X
3,100,088	8/1963	Podmore	241/290 X
3,414,203	12/1968	Bodine	241/202

Primary Examiner—Donald G. Kelly
Attorney—Sokolski & Wohlgemuth

[57] **ABSTRACT**

Earth is crushed and ore can be separated therefrom by passing the earthen material over a sonically activated surface. The earth is kept acoustically coupled to the surface through the use of a low impedance medium which can be rubber, liquid mercury, and the like.

3 Claims, 14 Drawing Figures

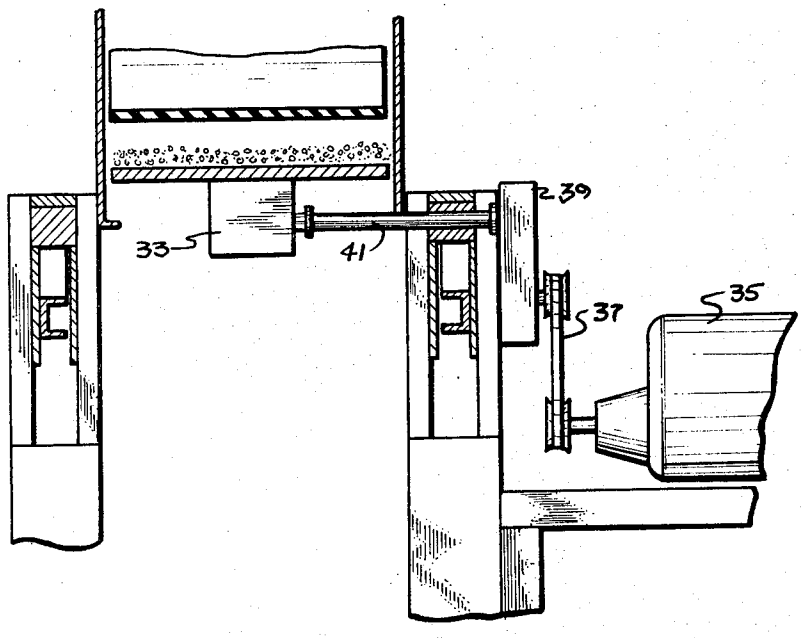


Fig. 1

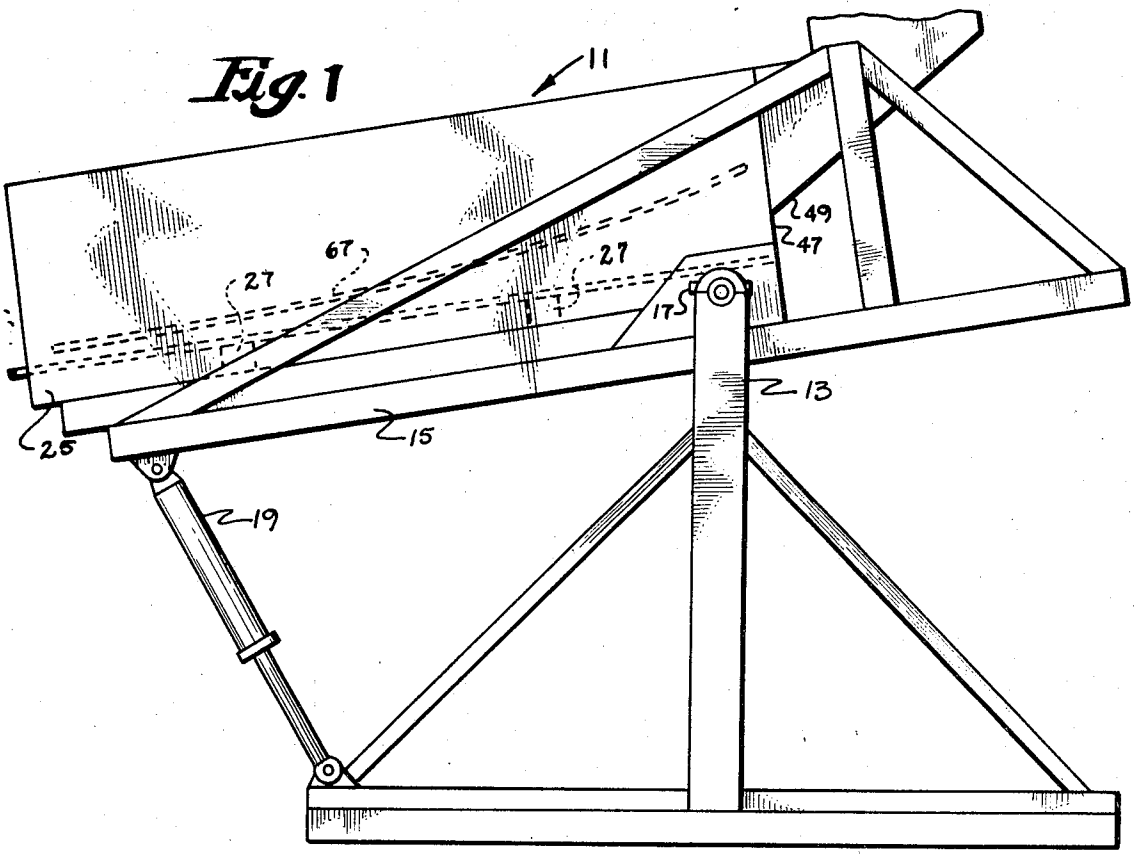
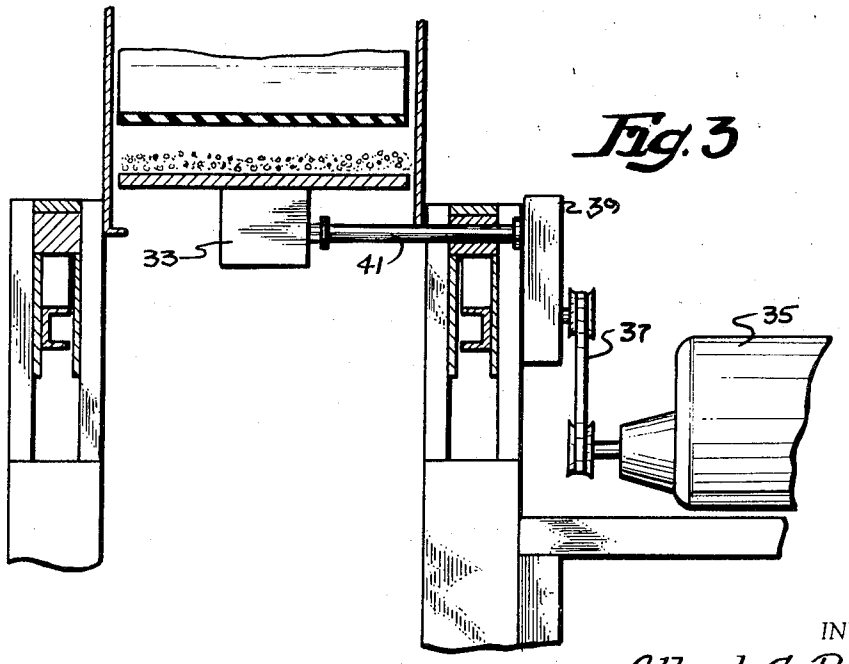


Fig. 3



INVENTOR.
Albert G Bodine
BY
Sokolski & Wohlgemuth
Attorney's.

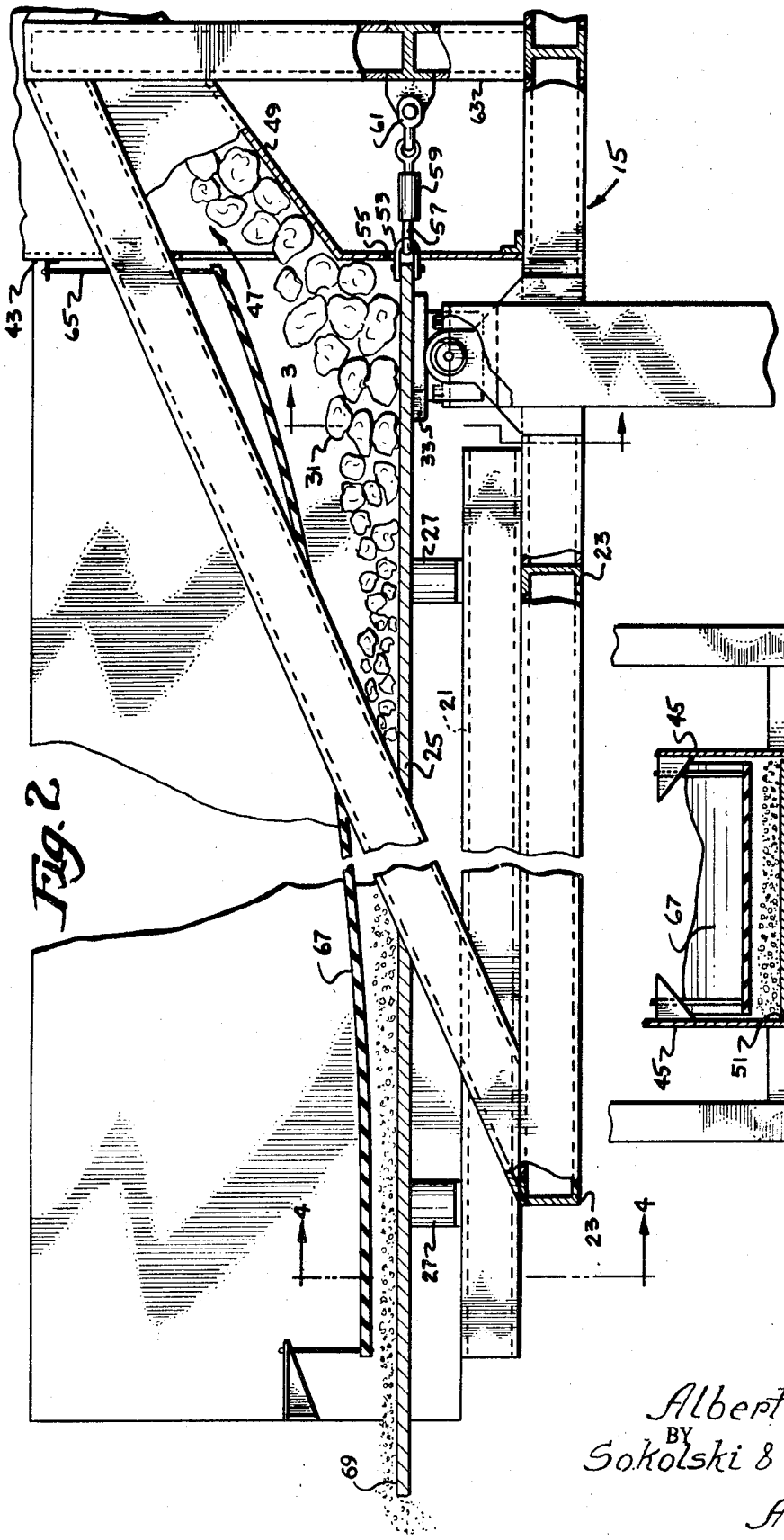


Fig. 2

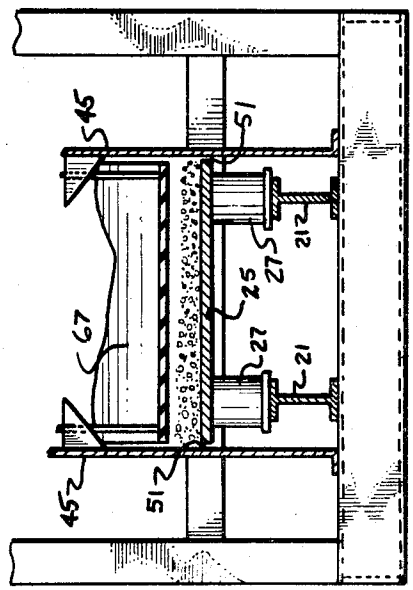


Fig. 4

INVENTOR.
Albert G. Bodine
BY
Sokolski & Wahlgemuth
Attorney's.

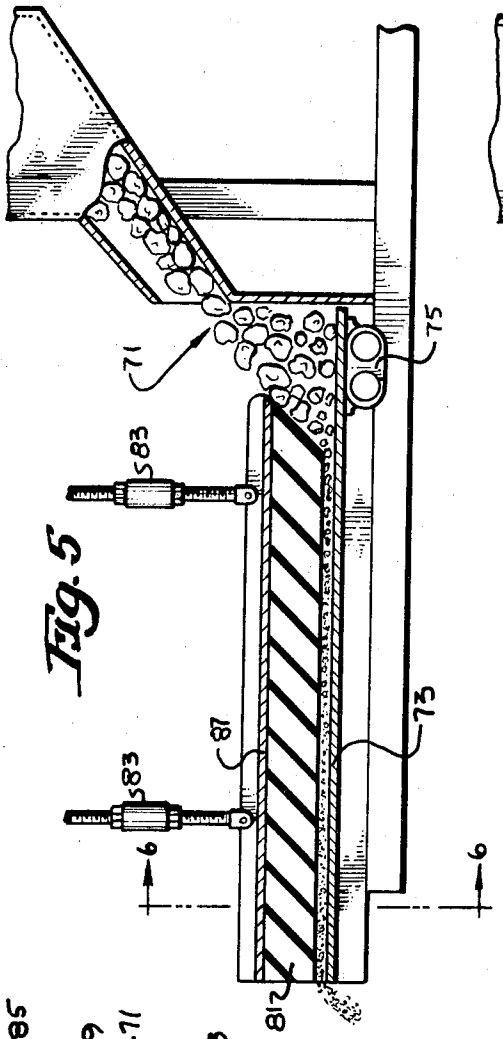


Fig. 5

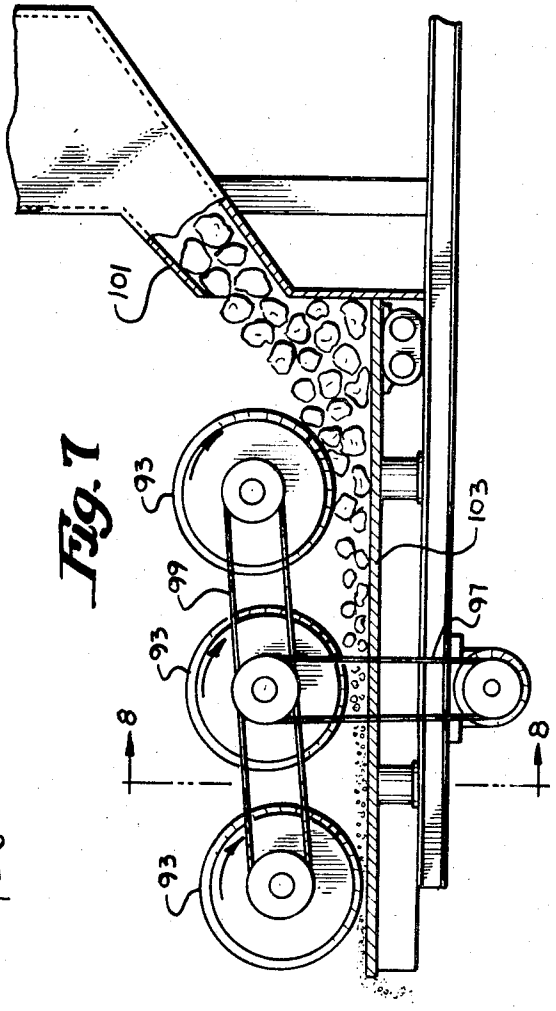


Fig. 7

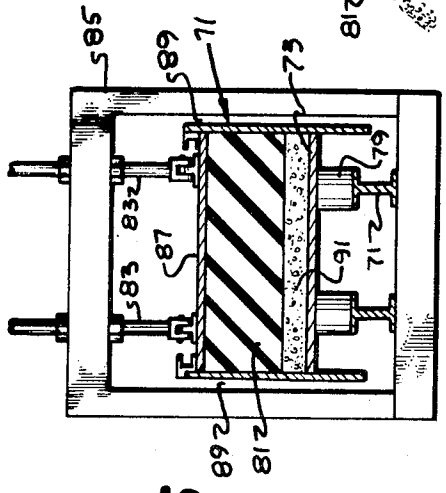


Fig. 6

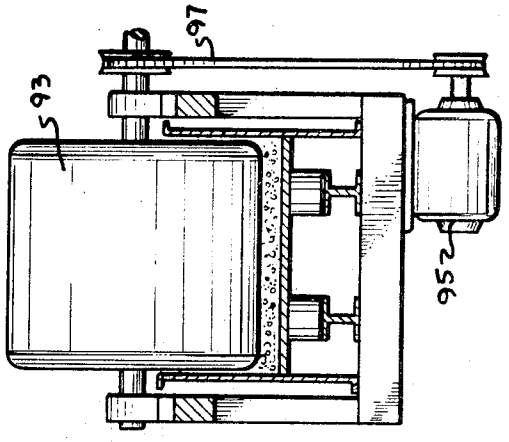
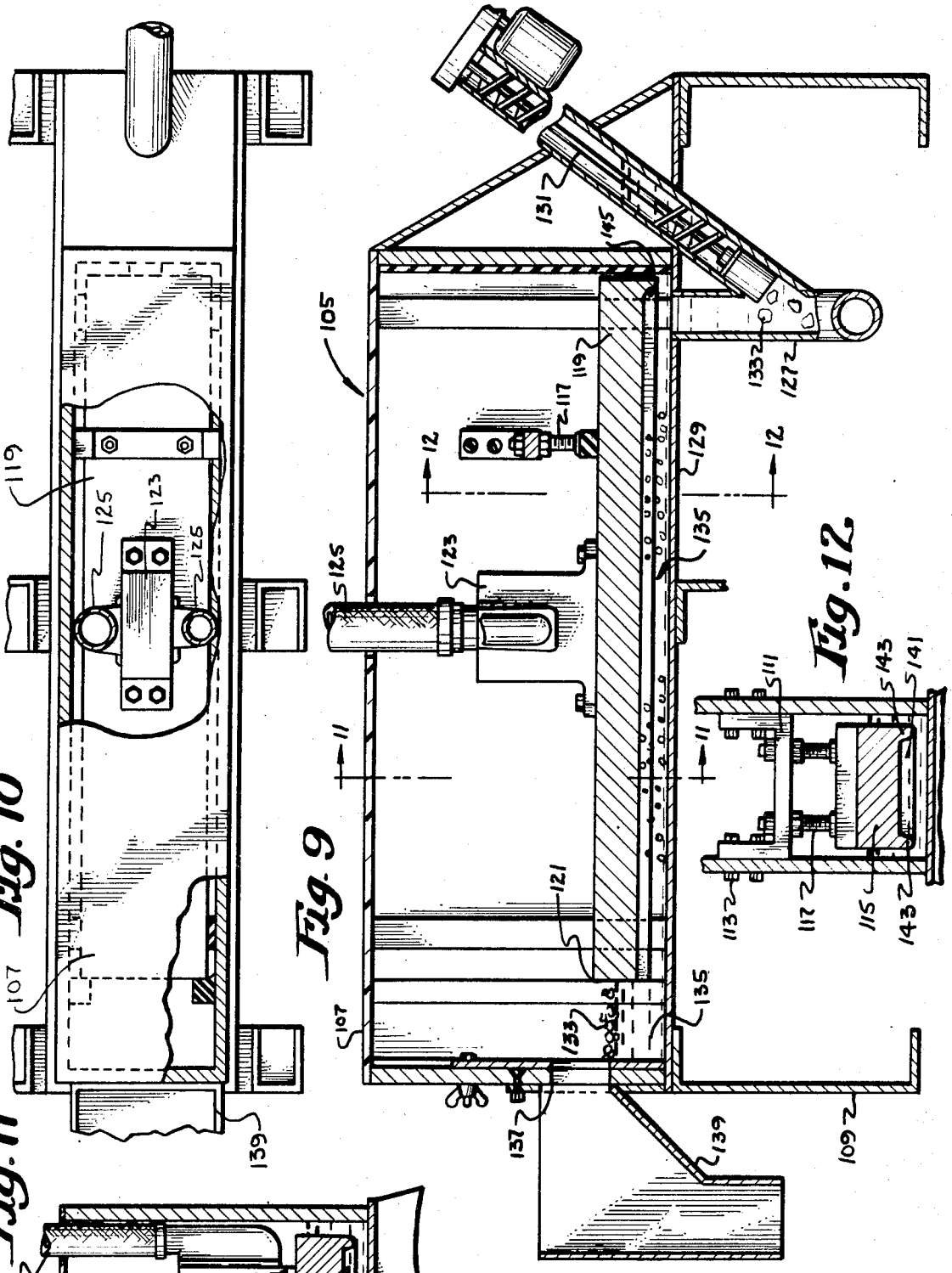


Fig. 8

INVENTOR.
Albert G. Bodine
BY
Sokolski & Wohlgemuth
Attorneys



INVENTOR.
Albert G Bodine
BY
Sokolski & Wohlgemuth
Attorneys.

Fig. 14

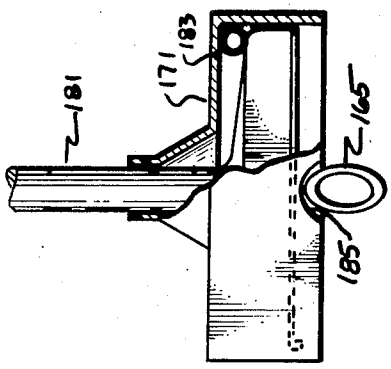
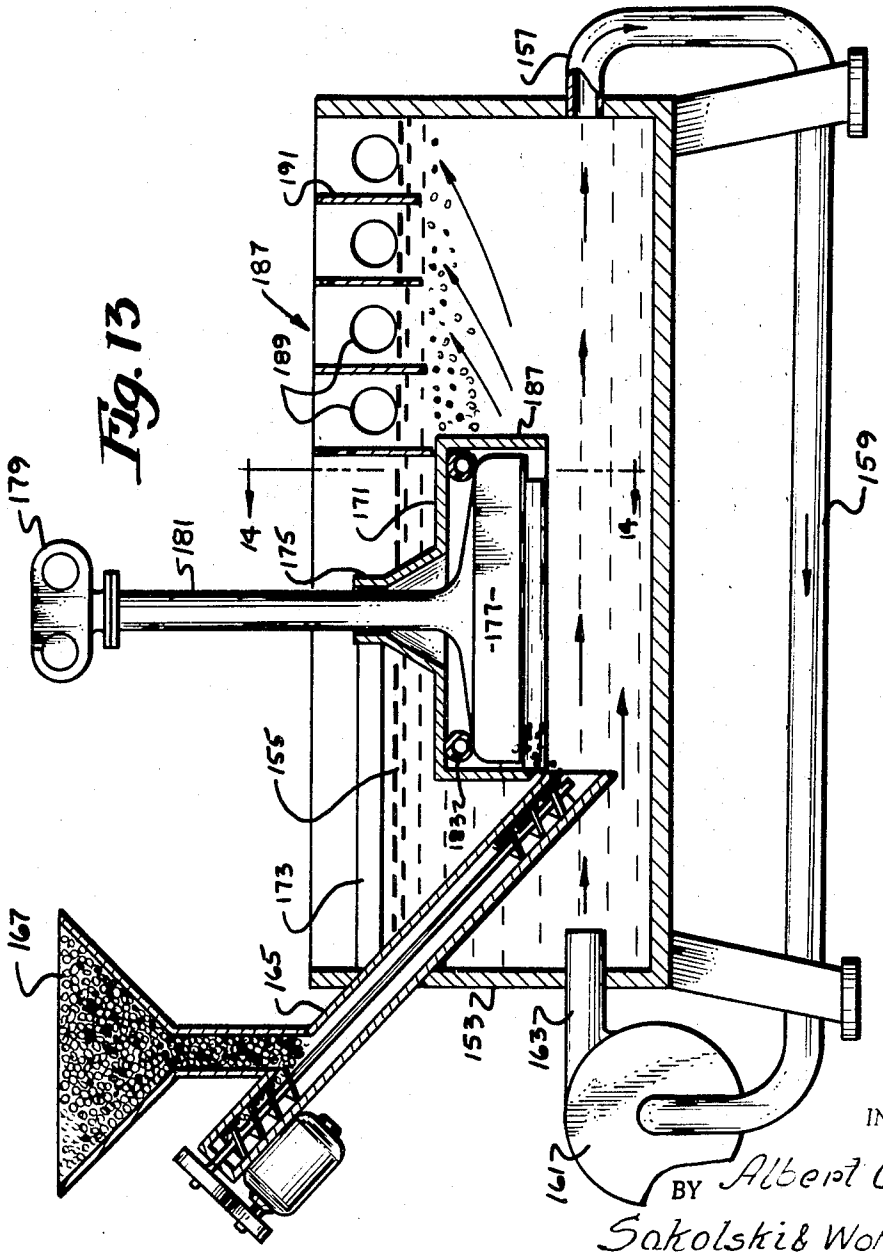


Fig. 13



INVENTOR.

BY Albert G. Bodine

Sokolski & Wohlgemuth

Attorneys.

APPARATUS FOR CRUSHING AND SEPARATING ORE MATERIAL

Prior to the herein invention, sonic energy has been used for the crushing of rock and earthen material. If one wishes to crush earth in a continuous operation where the earth particles or clod particles flow in a chute or the like, there is a problem relating to keeping the material to be crushed or treated acoustically coupled to the radiating surface. The tendency is for the earthen material to bounce away from the surface and not stay acoustically coupled. As a result, one does not obtain effective or efficient crushing or treatment of the earth. The herein invention is particularly concerned with the crushing of earth material where ore is apt to be located. If a rigid wall is used to trap the earthen material against acoustic radiant surface such as a solid piece of steel, there is a tendency to crush or treat everything between this rigid wall and the radiating surface. The tool then in effect becomes a sonic rock crusher. In such an instance, hard rocks and other undesirable material are equally treated acoustically along with the softer earth material.

Thus an object of this invention is to provide a device having a proper selection of impedance so as to selectively match up with the impedance of a desired material in a medium and also utilized to keep earth in contact with a sonically vibrating surface, such that rocks and other undesirable materials are not treated, and in effect remain in their original size so that they can easily be rejected at a subsequent stage of the process.

Another object of this invention is to provide a medium for keeping earth acoustically coupled to a sonically radiating surface.

The above and other objects of this invention are accomplished by an apparatus whereby a surface of an elastic material, for example metal plate, is provided. Coupled or fixed to the plate is a means for sonically vibrating it, such as an orbiting mass oscillator. Means is provided for feeding the earth material to be crushed to the vibrating surface. A low impedance medium, such as a layer of rubber, serves to keep the earth material to be crushed in contact with the vibratory plate. The rubber in one embodiment can be in the form of rotating wheels or in another embodiment can be a single flat sheet or the like. In another embodiment of the invention the low impedance medium utilized to deep the earth in contact with the vibratory surface is liquid metal, such as liquid mercury. The advantage of utilizing mercury as a medium is that it can serve to separate the various particles as a function of their density, which will be further explained. The invention will be further understood from the following detailed descriptions and drawings, in which:

FIG. 1 represents a schematic side representation of a first embodiment of this invention;

FIG. 2 is a large cross sectional view of a portion of the device of FIG. 1 showing the details of the rock crushing mechanism;

FIG. 3 is a sectional view taken along lines 3—3 of FIG. 2;

FIG. 4 is a sectional view taken along lines 4—4 of FIG. 2;

FIG. 5 is a cross sectional side view of a second embodiment of the invention;

FIG. 6 is a sectional view taken along lines 6—6 of FIG. 5;

FIG. 7 is a cross sectional side view of a third embodiment of the invention;

FIG. 8 is a sectional view taken along lines 8—8 of FIG. 7;

FIG. 9 is a cross sectional front view of a fourth embodiment of this invention utilizing liquid mercury;

FIG. 10 is a top plan view of FIG. 9;

FIG. 11 is a cross sectional view taken along lines 11—11 of FIG. 9;

FIG. 12 is a cross sectional view taken along lines 12—12 of FIG. 9;

FIG. 13 is a cross sectional view of a fifth embodiment of the invention utilizing liquid mercury; and

FIG. 14 is a sectional view taken along lines 14—14 of FIG. 13.

It has been found most helpful in analyzing this invention to analogize the acoustically vibrating circuit utilized to an equivalent electrical circuit. This sort of approach to analysis is well known to those skilled in the art and is described, for example, in Chapter 2 of "Sonics" by Hueter and Bolt, published in 1955 by John Wiley and Sons. In making such an analogy, force F is equated with electrical voltage E, velocity of vibration u is equated with electrical current i, mechanical compliance C_m is equated with electrical capacitance C_e, mass M is equated with electrical inductance L, mechanical resistance (friction) R_m is equated with electrical resistance R and mechanical impedance Z_m is equated with electrical impedance Z_e.

Thus, it can be shown that is a member is elastically vibrated by means of an acoustical sinusoidal force $F_o \sin \omega t / u$ (ω being equal to 2π times the frequency of vibration), that

$$Z_m = R_m + j\left(\omega M - \frac{1}{\omega C_m}\right) = \frac{F_o \sin \omega t}{u} \qquad (1)$$

Where ωM is equal to $1/\omega C_m$, a resonant condition exists, and the effective mechanical impedance Z_m is equal to the mechanical resistance R_m, the reactive impedance components ωM and $1/\omega C_m$ cancelling each other out. Under such a resonant condition, velocity of vibration u is at a maximum, power factor is unity, and energy is more efficiently delivered to a load to which the resonant system may be coupled.

It is important to note the significance of the attainment of high acoustical Q in the resonant system being driven, to increase the efficiency of the vibration thereof and to provide a maximum amount of power for crushing the earth particles and separating ore. As for an equivalent electrical circuit, the Q of an acoustically vibrating circuit is defined as the sharpness of resonance thereof and is indicative of the ratio of the energy stored in each vibration cycle to the energy used in each such cycle. Q is mathematically equated to the ratio between ωM and R_m. Thus, the effective Q of the vibrating circuit can be maximized to make for highly efficient, high-amplitude vibration by minimizing the effect of friction in the circuit and/or maximizing the effect of mass in such circuit.

In considering the significance of the parameters described in connection with equation (1), it should be kept in mind that the *total* effective resistance, mass, and compliance in the acoustically vibrating circuit are represented in the equation and that these parameters may be distributed throughout the system rather than being lumped in any one component or portion thereof.

It is also to be noted that orbiting mass oscillators are utilized in the implementation of the invention that automatically adjust their output frequency and phase to maintain resonance with changes in the characteristics of the load. Thus, in the face of changes in the effective mass and compliance presented by the load with changes in the conditions of the work material as it is sonically excited, the system automatically is maintained in optimum resonant operation by virtue of the "lock-in" characteristic of applicant's unique orbiting mass oscillators. Furthermore, in this connection 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 load, to assure optimum efficiency of operation at all times. The vibrational output from such orbiting mass oscillators also tends to be constrained by the resonator to be generated along a controlled predetermined coherent path to provide maximum output along a desired axis.

Turning now to FIGS. 1 to 4, there is seen a first embodiment of the invention. The first embodiment utilizes a rubber blanket in a manner that will be described. The device 11 can be pivotally mounted on a support structure 13. An I beam structure 15 serves as the basic support for the operative portion of the device. One end of the structure 15 is connected to a pneumatic piston 19 which serves to rotate it about point 17 from a horizontal position as for example shown in FIG. 2 to a slightly downward position shown in FIG. 1.

Two I beams 21 are affixed to cross pieces 23 of the support structure 15. The I beams support a flat metal plate 25 through rubber mounts 27. The rubber mounts 27 are rigidly affixed to the I beams 21, while not being affixed to the plate 25. As seen, plate 25 is the plate upon which the earth 31 moves as it traverses along the device. Connected to the forward end of plate 25 is an orbiting mass oscillator 33, which serves to sonically vibrate the plate in accord with this invention. The oscillator 33 is driven by motor 35 acting upon gears 37 and a gear box unit 39 so as to drive the shaft 41 to cause rotation of the oscillator. The oscillator used can be that shown for example in U. S. Pat. No. 3,402,612. Adjacent the forward end of the vibratory plate 25 is an upright wall portion 43, having an opening 47 therein. The earthen particles 31 are directed by a chute 49 affixed to opening 47 onto the plate 25.

Side walls 45 parallel the vibratory plate and serve to confine the earthen particles. Walls 45 are spaced a very slight distance 51 from the plate so as to allow free vibratory motion of the plate without interference from the walls.

Since the bottom of vibratory plate 25 is essentially freely suspended, undue dislocation can effect the drive shaft 41 to the oscillator. To prohibit such movement, a shackle 53 is affixed to the forward end of the plate 25 which passes through an aperture 55 in wall 43. The shackle is connected to a cable 57 which is enclosed in a damping pipe 59. The cable 57 in turn is connected to a second shackle 61 affixed to a support beam 63. Where the plate 25 is vibrated the vibrations are carried through the cable 57 which would snap if not damped by the enclosed pipe piece 59. Thus it can be appreciated the arrangement of the shackle and cable 57 prevent undue horizontal displacement of the vibratory plate, as well as preventing the plate from slipping out of the device when it is tilted in a position such as shown in FIG. 1.

Freely suspended by a cable 65 from the back wall 43 is a blanket 67 of an elastic material such as rubber or the like. The blanket 67 serves as the aforementioned low impedance drive or reflective medium which keeps the desired earth particles in contact with the vibratory surface 25 in the operation of this device. The rubber blanket 67 is a good acoustic match for earthen clods and softer earthen materials wherein very often finely divided ore dust such as gold particles exist. The rubber medium contains the softer earth material and acoustically couples it to the sonic radiant surface 25, whereas rocks and other hard particles freely bounce around in the space between the rubber blanket 67 and the surface 25. The rocks are then dropped off at the end 69 of the surface together with the finely divided material leaving the device.

The orbiting mass oscillator 33 utilized forms a main sonic circuit together with the radiating surface or plate 25. The sonic circuit has a very discreet acoustic impedance so that the resonant phenomena is well defined and quite stable. The earthen material 31 being treated appears in the sonic circuit only as a resistive impedance, not having too much effect upon the resonant frequency phenomena. However, the earth does occasionally have some effect upon resonant frequency when there is mass loading due to high density regions of the ore being applied to the resonating circuit. As a result, it is desirable to use a vibratory type of orbiting mass sonic oscillator, since it tends to adjust its frequency automatically as the circuit impedance factors change. Further, the orbiting mass oscillator adjusts its phase angle and its power factor to accommodate changes in resistive impedance as different quantities of ore come into contact with the sonic radiating surface 25. One particular advantage of using the orbiting mass oscillator is that it has a capability of a very high power output without requiring complicated electronic gear, which is difficult to maintain and uneconomic in field processes such as the treatment of ore or other materials. A simple diesel engine or electric motor 35 can drive the oscillator as shown.

As can be seen, the sonic circuit is designed so that the radiating surface is used in combination with a fairly high mass reactive or inductive impedance such as a large chunk of steel. In the embodiment of FIGS. 1 to 4 this takes the form of the large metal plate 25. The advantage of the heavy mass forming the high impedance in the circuit is the mass that maintains the circuit at a fairly high acoustic Q even though there will be a fairly high resistive impedance at the point where the surface of this mass is applying energy into the ore that is being treated.

Without the presence of the low impedance media, satisfactory results in crushing the earth particles and separating the ore are not easily achieved. The earth material, since it is granular in nature, will act as an entire body when subjected to the vibratory energy and stand away some short distance from the vibrating surface. This, of course, minimizes the amount of energy that is received. The low impedance rubber blanket 67 prevents this from occurring.

Turning now to the embodiment schematically shown in FIGS. 5 and 6, it is seen that the same arrangement essentially shown in the embodiment of FIGS. 1–4 is utilized. The device 71 shown therein comprises a flat vibratory plate 73 driven by a pair of orbiting mass oscillators 75 operating in unison in a manner similar to that disclosed in U. S. Pat. No. 3,417,966. Plate 73 is supported on I beams 77 and rubber isolators 79 in the same manner as disclosed in the previous embodiment. The main difference between this device and that previously described is that the herein embodiment uses a large fixedly secured rubber mat 81 which is adjustable by jack screws 83. The jack screws 83 in turn can be connected to a support frame 85 for the device. As shown, the rubber mat can be affixed to an upper plate 87 which in turn is affixed to side plates 89 that serve to enclose the earthen material 91 between the rubber mat 81 and the vibratory plate 73. Thus the mat can be adjusted to accommodate various size earthen particles and control the size of the final crushed material.

Another embodiment utilizing rubber as a low impedance can be seen in FIGS. 7 and 8 wherein the rubber takes the form of a cylindrical body 91. Shown for example, are three large rubber or pneumatic wheels 93 which can be driven by a motor 95 and pulley arrangement 97 and 99. The wheels can be angularly disposed as shown in FIG. 7, so that the wheel closest to the inlet chute 101 is furthest away from vibrating plate 103. This provides for a stepwise breakdown of earth particles to the final desired size. The wheels are rotated in a clockwise direction which serves in a manner similar to a rubber conveyor and force the ore into the area between the rollers and the vibrating surface 103. Additionally, the rollers serve to maintain the contact area in a fairly thin layer in a similar manner as seen in the embodiment of FIG. 5.

Turning now to FIGS. 9–12, there is seen an embodiment of the invention utilizing a liquid mercury as a low impedance medium for keeping earth particles in contact with a vibratory sonic radiating surface. The device 105 comprises an enclosed housing 107 which can be supported by a stand 109. A U-shaped support frame 111 is disposed within the housing 107 and secured by bolts 113. Suspended from the frame 111 is an elongated flat metal plate 115 which comprises the vibratory element of the system. The bar is secured to the support frame 111 by jack screws 117 so as to be adjustable. The jack screws 117 are located toward the one end of the plate 115 as particularly seen in FIG. 9 such that an adjustment of the jack screws can move the rear end 119 of the plate downward and tilt the front end 121 upwardly for reasons to be subsequently explained.

Affixed to a mid portion of the vibratory plate 115 is an orbiting mass oscillator 123. The orbiting mass oscillator can be of the type seen in the embodiments of FIGS. 1 to 4. Lines 125 carry air pressure to drive the oscillator from a source outside of the device and not shown. Adjacent the rear end 119 of the vibratory plate 121 is provided an inlet 127 intersecting the bottom 129 of the housing 107 for admitting earthen particles to the device. Intersecting the inlet line 127 is a screw feed mechanism 131 to force feed the earth particles 133 to the device. This is necessary to overcome the effect of the mercury present. As can be seen, of course, the mercury 135 will seek a level in the screw feed equivalent to its level in the device. The level of the mercury in the device is kept to a point just below an exit port 137 to which is affixed an outlet shute 139 to carry the crushed particles of earth 133 out of the apparatus.

As can be seen, the vibratory plate 115 is in intimate contact with the layer of mercury immediately under it. It is particularly apparent in cross sectional views of FIG. 11 or 12. The plate 115 is actually formed with a channel 141 along its bottom surface. The channel is formed by two lateral sides 143 and a downward protrusion 145 at the rear end thereof, thus serving to enclose the entering particles within the confines of the channel 141 as they move through the device preventing them from passing around the sides of the plate to the top of the mercury level, which is considerably above the bottom surface of the plate.

Thus it can be appreciated that the embodiment shown in FIGS. 9–12 provides a radiating surface wherein a contact area exists against which the mercury is pressing so as to form an extended surface. Thus as the earth material is introduced into this contact region it is automatically spread out in a thin layer. Because the mercury is of greater density, the earthen material cannot sink down. The earth then literally floats on the surface of the mercury and against the radiating surface which in effect is the ceiling above the mercury body. The earth particles will flow from the inlet line 127 to the exit port 137 by gravity flow. This is accomplished by slightly tilting the surface 115 downwardly at its rear end 119, utilizing the jack screws provided. Thus in effect the surface of the mercury underneath the platen 115 tilts upwardly toward the exit and the force of the mercury against the earth particles will direct them from the inlet to the outlet. The successive earth particles 133 are built up on top of the mercury 135 adjacent the exit port 137. They will tend to leave the device and fall out through the chute 139.

Turning now to FIGS. 13 and 14, there is seen another embodiment of an apparatus utilizing the principle of the invention together with liquid mercury. Device 151 comprises the large tank 153 containing liquid mercury bath 155. The tank is provided with an outlet port 157 which is connected to a recirculating line 159. Thus the mercury is pumped through the device and recirculated by pump 161 back to an inlet line 163. This provides for a constant current of mercury as shown by the arrows through the bath in a direction from the inlet to the outlet. Located on the inlet side of the device is a screw feed auger 165 which directs the earth particles 167 from a hopper 169 into the mercury bath. Disposed in the bath below the surface thereof is a housing 171 supported by structure 173 connected to a neck portion 175. The housing may be rectangularly or circularly shaped as shown with the upperwardly extending enclosed neck portion 175. Disposed within the housing is a massive sonic radiating plate 177. A pair of orbiting mass oscillators 179 acting in unison as shown in U. S. Pat. No. 3,123,043 are coupled through bar 181 to the radiating surface 177 and serve to create resonant vibration on bar 181 and plate 177. Acoustic isolators 183 of elastomeric material are located preferably in the upper corners of the housing 171, as seen in both Figures. The bar 181 freely slides

within the neck portion **175** of the housing and thus allows the radiating surface **177** to move independent of the housing. A guide channel **185** for the earth particles is provided in housing **171**, by the side walls thereof, with flow starting at a cut away portion of the side walls of the housing adjacent the end of the feed auger thereof as seen in FIG. **14**. The opposite side of the housing is also cut away at **187** to complete the aforementioned channel **185** at the exit end of the vibrating plate **177**. As the particles leave the plate **177** through the aperture provided in **187**, they are selectively separated. They ultimately pass out through a plurality of exit holes **189** in the side walls of the device. Baffles **191** between the exit holes **189** further serve as separation means. As can be appreciated, the lightest particles will rise first to the surface of the mercury and pass through the exit hole **189** closest to the vibrating surface **177** while the heaviest particles will rise more slowly and be carried by the current to the exit hole furthest from the vibrating plate. By providing a varying number of exit holes **189** selected particle classifications can be obtained from successive openings.

I claim:

1. A device for crushing earth particles comprising:

a flat plate,

means connected to said plate for acoustically vibrating said plate,

means for directing said earth particles to said plate,

and low acoustic impedance means comprising a liquid mercury bath disposed adjacent said plate for maintaining said earth in contact with said plate.

2. The device of claim **1** wherein said vibrating plate is disposed below the surface of said mercury bath.

3. The device of claim **1** and further including a housing wherein said mercury is disposed, said plate being adjustably disposed in spaced relationship to the bottom of the housing, said means for directing the earth to said device serving to direct the earth between said housing bottom and said plate.

* * * * *