Oct. 14, 1969 A. G. BODINE, JR 3,472,431

SONIC METHOD AND APPARATUS FOR FACILITATING GRAVITY FLOW OF GRANULAR MATERIAL

Original Filed May 10, 1965 2 Sheets-Sheet 1

FIG. 1

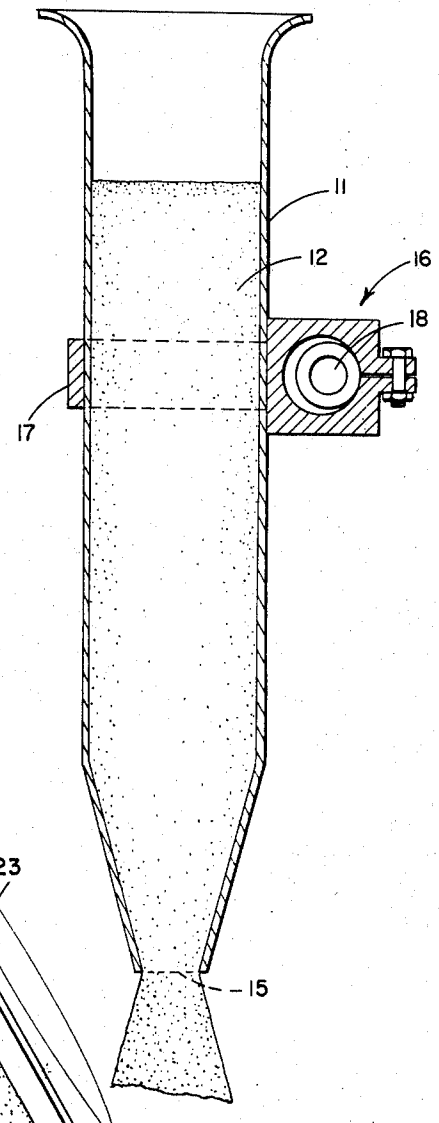
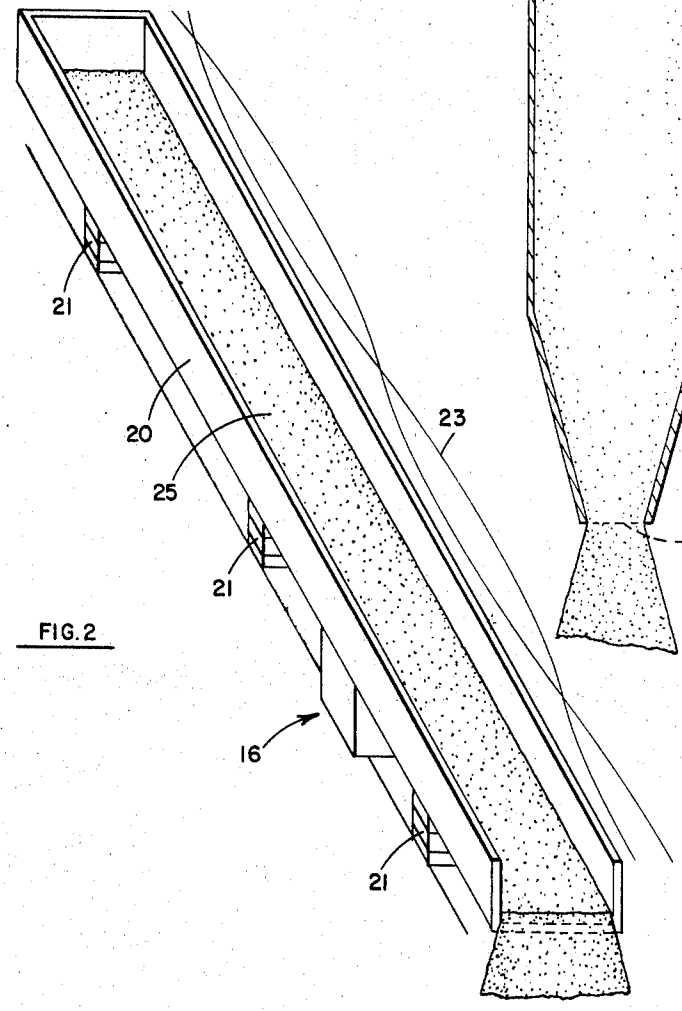


FIG. 2



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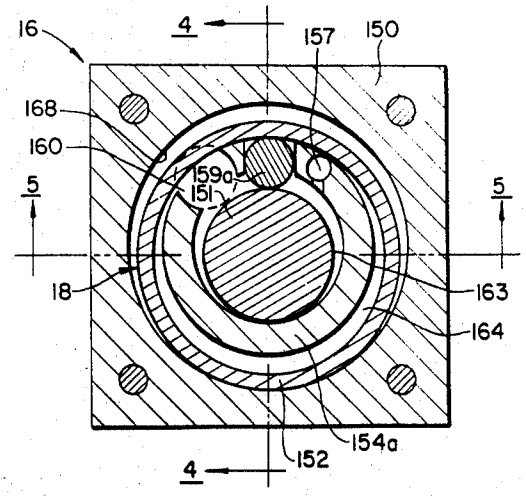

FIG. 3

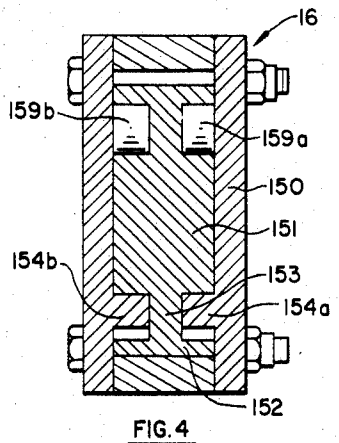

FIG. 4

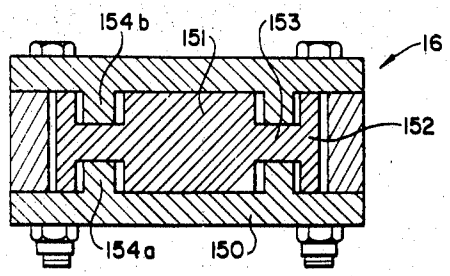

FIG. 5

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SONIC METHOD AND APPARATUS FOR FACILITATING GRAVITY FLOW OF GRANULAR MATERIAL

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Continuation of application Ser. No. 454,335, May 10, 1965. This application July 24, 1967, Ser. No. 659,835
Int. Cl. B65g 27/08, 27/20
U.S. Cl. 222—196 3 Claims

ABSTRACT OF THE DISCLOSURE

A member which defines the flow of granular material is oriented so as to permit the gravity flow of such material. The output of a sonic oscillator is coupled to the flow defining member, such oscillator being operated at a frequency so as to produce resonant elastic vibration of the flow defining member, whereby the friction between the individual particles of the material and the material and the flow defining member is minimized.

SPECIFICATION

This application is a continuation of my application Ser. No. 454,335, filed May 10, 1965, now abandoned for Sonic Method and Apparatus for Facilitating Gravity Flow of Fluid Material.

This invention relates to a method and apparatus for facilitating gravity flow of granular material and more particularly to such a technique and apparatus wherein sonic energy is imparted to the material to minimize the friction between the particles thereof themselves and such particles and associated members with which the granular material comes into contact.

There are many operations in which granular material must be conveyed from one position to another, in a flow defining member of some sort, by virtue of gravity action. Many problems present themselves in such gravity feed devices, such problems being primarily concerned with friction between the particles of the material themselves and friction between the particles and the conduit or other associated members. Thus, the flow of material is often seriously impeded by cohesion of the particles thereof to each other and adhesion to the surrounding members.

Various prior art techniques have been utilized in an attempt to alleviate this problem. These generally involve the bodily shaking or low-frequency vibration of the conveyor in an effort to shake the particles loose. Such prior art techniques, while helpful in alleviating the problem slightly, for the most part fail to provide the desired end result and cause undesirable shaking of surrounding equipment, which tends to loosen components, etc.

The device and method of this invention provide simple yet highly effective means for lowering the friction between the particles of granular material themselves and between such particles and surrounding members to the point where such particles tend to act as if they were in free space and are affected to a significant degree only by the force of gravity.

This desired end result is achieved by vibrating the granular material at high amplitude at a sonic frequency. Such high-amplitude vibration is accomplished by acoustically coupling a sonic oscillator to a resonant elastic system. Included in the elastic system is a flow defining member, which may be a conduit, which conveys the sonic energy to the material. The high-amplitude sonic energy acts on the material to result in high relative vibration between individual particle members and between the material and the flow defining member, thus minimizing friction and enhancing flow.

A unique orbiting-mass oscillator is preferably utilized in the device and method of this invention, which automatically adjusts its output frequency in accordance with changes in the load impedance to maintain optimum resonant operation at all times.

It is therefore an object of this invention to provide means for enhancing the gravity flow of granular material.

It is another object of this invention to provide means for controlling the gravity flow of granular material.

It is still another object of this invention to provide means for utilizing sonic energy to minimize the effects of friction between the particles of granular material and between such material and associated flow defining members.

Other objects of this invention will become apparent from the following description taken in connection with the accompanying drawings, of which:

FIG. 1 is an elevation cross-sectional view of a first embodiment of the device of the invention;

FIG. 2 is a perspective view of a second embodiment of the device of the invention;

FIG. 3 is an elevation cross-sectional view of a pneumatic orbiting-mass oscillator which may be utilized in the device of the invention;

FIG. 4 is a cross-sectional view taken along the plane indicated by **4—4** in FIG. 3; and

FIG. 5 is a cross-sectional view taken along the plane indicated by **5—5** in FIG. 3.

In order to facilitate the comprehension of the operation of the device of the invention, it is helpful to make an analogy between an electrical resonant circuit and a mechanical resonant circuit. This type of an analogy 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 & 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 (such as friction) R_m is equated with electrical resistance R. Mechanical impedance Z_m is equated with electrical impedance Z_e. Thus, it can be shown that if a member is elastically vibrated by a sinusoidal force $F_0 \sin \omega t$, ω being equal to 2π times the frequency of vibration, that

$$Z_m = R_m + j\left(\omega M - \frac{1}{\omega C_m}\right) = \frac{F_0 \sin \omega t}{u} \quad (1)$$

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, effective power factor is unity, and enrgy is most efficiently delivered to the object being vibrated. It is such a high efficiency resonant condition in the elastic system being driven that is preferably utilized in the method and device of this 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 Z_m 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. Such an impedance mismatch condition between a conduit and the material being conveyed can be utilized

to free the material from each such conduit and effectively provide low friction between the two.

Just as 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 the mechanical resonant circuit has the same significance and is equal to the ratio between ωM and ωR_m. 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 method and device of this invention, is the high acceleration of the components of the elastic resonant system that can be achieved at sonic frequencies. The acceleration of a vibrating mass is a function of the square of the frequency of the drive signal times the amplitude of vibration. This can be shown as follows:

The instantaneous displacement y of a sinusoidally vibrating mass can be represented by the following equation:

$$y=Y \cos \omega t \tag{2}$$

where Y is the maximum displacement in the vibration cycle and ω is equal to $2\pi f$, f being the frequency of vibration.

The acceleration a of the mass can be obtained by differentiating Equation 2 twice, as follows:

$$a=\frac{d^2y}{dt^2}=-Y\omega^2 \cos (\omega t) \tag{3}$$

The accelerations a thus is a function of Y times $(2\pi f)^2$. At resonance, Y is at a maximum and thus even at moderately high sonic frequencies, very high accelerations are achieved.

In consideration Equation 1, several factors should be kept in mind. Firstly, this equation represents the total effective resistance, mass, and compliance in a mechanical 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 not only the conduit but surrounding components and the fluid material itself. Thus, it may be desirable to purposely add members exhibiting predominantly compliance C_m or mass M characteristics to balance out one or the other of these parameters to make for a resonant system. Thirdly, an orbiting-mass oscillator is utilized with the device of the invention, that automatically adjusts its output frequency to maintain resonance with changes in the characteristics of the load. Thus, in situations where we are dealing with a fluid material which solidifies in the process involved and thereby changes its characteristics, the system automatically is maintained at optimum resonant operation by virtue of the "lock-in" characteristics of applicant's unique orbiting-mass oscillators. With these basic considerations in mind, let us now turn to the specific embodiments of the device of the invention.

Referring now to FIG. 1, the device of the invention is shown as incorporated into a device for feeding granular material. Receptacle **11** is filled with granular material **12** which is to be fed by gravity feed through restricted orifice **15** in the bottom of the receptacle. This type of feed mechanism might be utilized for example in feeding ceramic material in processes such as the manufacture of spark plug insulators. Normally, such granular material, especially when moist, will tend to stick to the sides of container **11** and the grains themselves will adhere to each other. The free flow and control of flow rate of such material is obtained by attaching orbiting-mass oscillator unit **16** to the walls of container **11** by means of clamping mechanism **17** and driving the orbiting-mass oscillator at a frequency so as to cause controlled resonant vibration of container **11**. Orbiting-mass oscillator **16** is preferably of the type to be described further on in the specification in connection with FIGS. 3–5. It will suffice here to say that it utilizes a pneumatically driven eccentric rotor member **18**, which vibrates container **11** along its longitudinal and transverse axes. It is to be noted that orbiting-mass oscillator **16** tends to lock in at a resonant frequency of the elastically vibrating system, so that as the effective load changes as granular material **12** is released from the container, the frequency of the oscillator likewise changes to maintain resonant vibration of the system. With the resonant vibration of container **11** standing waves are set up therein.

Referring now to FIG. 2, utilization of the orbiting-mass oscillator to enhance the flow of granular material down a chute such as, for example, a grain chute, is illustrated. Grain chute **20** is supported on resilient supports **21**. Attached to the bottom of grain chute **20** is an orbiting-mass oscillator unit **16**, similar in configuration to that described in connection with FIG. 1. The frequency of orbiting-mass oscillator **16** is such as to cause resonant vibration of chute **20**, setting up standing waves **23** along the longitudinal axis thereof. The granular material **25**, by virtue of the resonant vibration, is induced to flow freely down the chute with minimal frictional effect. It it to be noted that several basic advantages inhere in the utilization of the device of the invention in a chute such as shown in FIG. 2. First, with the free flow induced by virtue of the resonant sonic vibration, it is possible to utilize a gradual descent angle for chute **20** without any impairment of the flow. This greatly facilitates the mechanization of the grain chute, and reduces the required elevation at the source. Further, with a gradual descent angle, it is possible to utilize the sonic vibration mechanism as a control valve. Thus, the flow of material can be greatly reduced or halted entirely by turning off oscillator **16**, and then can be started again merely by turning on the oscillator. The speed of flow can also be controlled by varying the speed of rotation of the rotor of the orbiting-mass oscillator with maximum flow being attained at the resonant frequency and various lesser degrees of flow being attained as we depart from resonance.

In the embodiments of FIGS. 1 and 2, the sonic action tends to break up caking effects and also makes the material behave as true granular media. In view of the impedance mismatch between the granular material and the walls of their respective conduits, high relative movement results therebetween, and frictional contact at these interfaces is minimized. The device of the invention enables the utilization of gravity flow in situations where only a very gradual low-angle descent is possible, such as for example in the draining of shallow tanks and the like. In a vertically oriented device having a restricted exit orifice, such as that shown in FIG. 1, the sonic drive can be varied in frequency and amplitude to control the flow of the granular material, particularly the flow rate past a constricted nozzle as shown.

While the precise reasons for the remarkable flow effects attained by virtue of the sonic action of the invention are not fully understood, an expert opinion on the subject indicates that the individual irregular grains when energized by the sonic energy each separately vibrates in a random path as an acoustic resistance with a relatively fixed radius of vibration which changes in direction but remains fixed in magnitude. Such random vibration effectively separates the irregular particles from each other so that they cannot adhere to each other or to the conduit sides and thus are free to flow in response to the force of gravity. This end result can be achieved by virtue of the high velocity vibration in the resonant system of the device of the invention. It is to be noted that in the elongated chute mechanism **20** of FIG. 2, it is desirable to employ longitudinal resonant waves **23** in attaining the desired end results. This provides a shear wave function at the interface between the conduit and the granular media. With this type of resonance, the sonic activity is maintained at a fairly high energy

level throughout the entire chute with minimum drop-off in wave amplitude.

Referring now to FIGS. 3, 4 and 5, a preferred embodiment of the pneumatically driven orbiting-mass oscillator which may be utilized with the device of the invention is illustrated. This orbiting-mass oscillator has the unique characteristic of adjusting its frequency of operation with load changes, in effect locking in with a resonant load to maintain such resonant operating condition.

Mounted within case **150** is rotor member **18** which includes a central circular portion **151** and an outer circular portion **152** joined together by a web portion **153**. Extending inwardly from case **150** are a pair of C-shaped portions **154***a* and **154***b*. Pressurized air is fed through inlet port **157** to the interior of casing **150**. Disc-shaped members **159***a* and **159***b* are held between the ends of C-shaped portions **154***a* and **154***b*, respectively. Disc-shaped members **159***a* and **159***b* are held so that they are free to rotate and to move radially and at the same time provide a divider which prevents any significant amount of the inlet air from passing directly from one side thereof to the other. An air outlet is provided from the interior of casing **150** by means of outlet aperture **160**.

The air entering through inlet **157** enters crescent-shaped cavity portions **163** and **164** and tangently drives both inner portion **151** and outer portion **152** of the rotor in a counterclockwise direction. Such counterclockwise rotation of the rotor on its axis results in a clockwise rolling of the rim of outer rotor portion **152** around the raceway formed by the inner wall **168** of casing **150**. In view of the eccentricity of the rotor in this rolling action, case **150** is vibrated in accordance with the rotor rotation frequency.

The oscillator just described in relatively simple and highly reliable in its operation and is capable of producing a high-amplitude sonic output which automatically locks in at the resonant vibration frequency of the load being driven.

The device and method of this invention thus provide sonic means for enhancing the gravity flow of fluid material of both the liquid and granular variety. Both the cohesion of the particles of such material to each other and the adhesion of such material to the flow defining members are minimized. In addition, the sonic action improves the structure of the material and facilitates various forming processes for same.

While the device and method of this invention have been described and illustrated in detail, it is to be clearly understood that this is by way of illustration and example only, the spirit and scope of this invention being limited only by the terms of the following claims.

I claim:

1. A device for producing gravity flow of granular means in resonant flow defining means, comprising:

a sonic oscillator;

means for coupling the sonic vibration output of said oscillator to said flow defining means; and

means for driving said sonic oscillator at a frequency such as to set up resonant elastic vibration of said flow defining means and maintaining the amplitude of said resonant vibration at a value such as to cause the individual particles of said granular means to vibrate freely in random paths as an acoustic resistance,

whereby said fluid means is sonically vibrated and the friction between the particles of said fluid means and said particles and said flow defining means is minimized wherein said oscillator is as an orbiting-mass oscillator, said oscillator being adapted to automatically adjust it's frequency output to maintain resonant vibration of said flow defining means with changes in the effective impedance presented thereby.

2. In combination,

a chute, said chute having a gradual descent angle;

granular material contained in said chute;

means for vibrationally isolating said chute;

orbiting-mass oscillator means for generating vibratory energy at a sonic frequency; and

means for coupling the output of said oscillator to said chute to cause resonant elastic vibration thereof to cause the granules of said material to vibrate freely in random paths as an acoustic resistance,

whereby the friction between the granular material and the chute is minimized to induce the free flow of said material down said chute.

3. In combination,

a receptacle having a restricted orifice at one end thereof, said receptacle being oriented substantially vertically;

granular material contained in said receptacle;

orbiting mass oscillator means for generating vibratory energy at a sonic frequency; and

means for coupling the output of said oscillator to said receptacle to cause resonant elastic vibration thereof to cause the granules of said material to vibrate freely in random paths as an acoustic resistance,

whereby the sonic energy minimizes the friction between said material and the sides of said receptacle thereby enhancing the gravity flow of said material through said orifice.

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WALTER SOBIN, Primary Examiner

U.S. Cl. X.R.

74—87; 198—220