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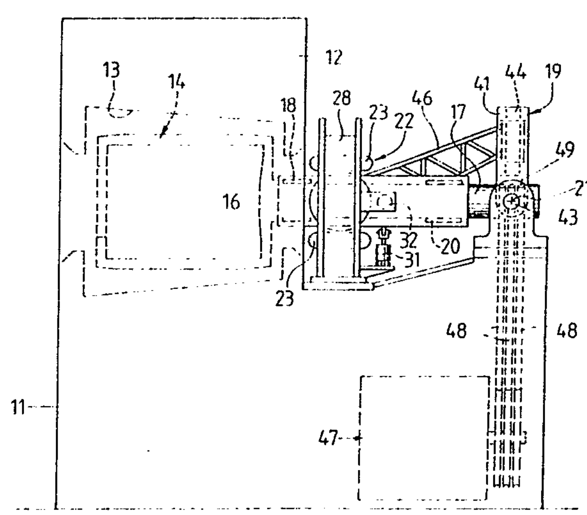
(54) Method and apparatus for extracting fluid from wet particulate matter.

(57) A method and apparatus for centrifugally removing fluid from wet matter, in which the bowl of the centrifuge (14) has a shaft (17) extending from a closed end (16) thereof, the other end of the shaft being mounted in a gimbal-like system (19) to provide a vertex (21) of precession of the bowl and shaft which is maintained in a well-defined locus, resilient means (22-28) such as air bags (23) supporting the shaft on bearings (18,20,26) which are located between the vertex (21) and the base (16), the resilience of the resilient means being variable whereby the natural frequency of the shaft and bowl may be varied in accordance with the frequency of rotation of the shaft and the bowl.

Fig. 1.



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The present invention relates to a method and apparatus for centrifugal removal of fluids from wet particulate matter including solid fines, such as ore slurries, industrial wastes, coal, and the like.

In the art to which this invention relates, the problems of operating batch-type centrifuges with their less than perfectly balanced loads of fine particulate at the very high speeds necessary for drying to extremely low moisture levels have not been solved. Prior apparatus has been unsafe or too expensive for use at the high production rates and at the very high speeds necessary to dry fine particulate to very low moisture levels for practical costs.

By way of example, the coal industry has an urgent need for an improved means for drying coal fines smaller than 100 mesh size in an economical manner with minimal pollution and safety problems. Prior commercial centrifuges for this service fall into three principal categories:

(1) Solid bowl decanters with screws for advancing the solids through the bowls;

(2) Screen bowl centrifuges with screws for advancing the solids through the bowls; and

(3) Batch centrifuges, similar to that shown in U.S. Patent No. 2,271,493 which receive moist particulate at low speeds, raise the bowl speed to a higher speed for drying, and then slow down again for removal of the dried solids. Some of the prior batch-type centrifuges have crude resilient suspension means, U.S. Patent 3,275,152 for example, but they have been unsuitable for the very high speeds and high production rates needed to economically dry very fine coal.

None of these three types of existing centrifuges can obtain a high enough centrifugal force to dry sub 100 mesh size coal to below twenty to thirty per cent surface moisture. Furthermore, the screen bowl centrifuges lose most of the coal of less than 325 mesh size through the screen. Consequently, coal cleaning plant operators who want their fine coal dried to below twenty per cent moisture are left with the choice of using thermal dryers or press-type dryers. Both of these are expensive. Press-type dryers cannot dry very fine coal below fifteen to twenty per cent surface moisture. Thermal dryers, although unsafe and potentially environmentally pollutant, can dry fine coal below ten per cent surface moisture; however, they cannot handle very fine coal unless it is mixed with coarse coal and thermally dried coal fines are dusty and will blow away during transportation.

According to the present invention there is provided a centrifuge comprising an envelope, a bowl rotatably mounted within said envelope, a wide mouthed opening at one end of the bowl for introducing material to be dried, a plurality of apertures in said bowl for discharging fluid into said envelope, a base closing the other end of the bowl, a continuous shaft secured to the base at one end of the shaft for mounting the bowl for rotation, means for mounting the shaft for rotation about its axis, and drive means for rotating the shaft and the bowl therewith, the means for mounting the shaft comprising a gimbal-like system mounting the shaft at a second end, to maintain a vertex of precession of the shaft and bowl at said second end in a substantially well defined locus, resilient means, which support the shaft bearings, being located between the vertex and base, and said resilient means being of variable resilience, whereby the natural frequency of the shaft and the bowl may be varied in accordance with the frequency of rotation of the shaft and bowl.

Such a construction can dry moist fine particulate to lower moisture levels than has been possible with prior art large scale centrifuges and can do so without causing pollution problems, safety hazards or significant losses of particular material in the fluid extracted therefrom.

The centrifuge of the invention is capable of handling unbalanced loads at very high drying speeds, e.g. in excess of 90 metres/sec and of operating at speeds in excess of 22 metres/sec during cutting out of the dried solids.

According to another aspect of the invention there is provided a method for centrifugally removing fluid from wet particulate matter, comprising the steps of introducing said wet particulate matter into a batch-type centrifuge having a bowl with an opening at one end for receiving said wet particulate matter, a base at the other end thereof attached to a driven shaft rotatable at various speeds and a filter media liner proximal the inner surface of said bowl; accelerating the rotational speed of said centrifuge to a controlled drying speed to reduce the moisture content of said particulate matter to below a predetermined percentage, by centrifugal extraction of the fluids; decelerating rotational speed of said centrifuge; and removing the particulate matter from said centrifuge at controlled rotational speeds of said centrifuge, supporting said shaft on a gimbal-like unit at the end of the shaft remote from the bowl, to maintain a vertex of precession of said shaft and bowl within a well-defined locus and to constrain said shaft to pivotal motion about said vertex, such that the freedom of movement of the bowl and shaft is limited to directions transverse to the axis of rotation thereof; supporting said shaft between said bowl and said gimbal-like system on supports of the variable resilience; and controlling the natural radial frequency (fn) of said centrifuge by varying the resilience of the supports in accordance with the rotational speed (f) of said centrifuge, such that the ratio (f/fn) becomes 1.0 only during said accelerating and decelerating steps, whereby the interval of time during which the condition f/fn = 1.0 is insufficient to induce successive radial vibration of said centrifuge.

The method and centrifuge of the invention use a mounting arrangement which takes advantage of the natural physical tendencies of rotating elastic bodies. An elastic body, namely, the bowl and shaft of a centrifuge, will vibrate freely at one or more of its natural frequencies if its equilibrium is momentarily disturbed by an external force. If the external force is applied repeatedly the elastic body will vibrate at the frequency of the external excitation. A rotating elastic system will have critical operating speeds at which objectionable vibrations are likely to occur. These speeds correspond to the various natural frequencies of the system. Since imbalances will always exist in the system, there will always be an excitation force with a frequency corresponding to the operating speed. When one of the system's natural frequencies coincides with the rotational frequency of the system, resonance results with maximum vibration of the system. The natural frequencies and consequently the critical speeds are not merely a property of the rotating shaft alone, rather they are also affected by the bearings, the supports, and the foundation; thus variation in these contributing factors will result in a variation of the natural frequencies and the critical speed.

The invention utilizes support members of variable resilience to alter the natural radial frequency of the system. A batch-type centrifuge by design rotates at a variable speed which ranges from a relatively low cut-out speed for removal of the dried fines, a moderately higher loading speed and a very high drying speed. Consequently, the rotational speed of the centrifuge will pass through a critical speed or be required to operate for a time at a critical speed corresponding to the natural radial frequency. By varying the resilience of support members, it is possible to shift the natural radial frequency so that the transition across the critical speed is almost instantaneous. Alternatively, the radial natural frequency can be shifted so that the centrifuge may operate for a period of time, such as at cut-out, at a speed corresponding to a frequency below the natural radial frequency.

The operating speed is not the only factor contributing to the amplitude of the vibration at resonance. Another very important factor is the damping of the system. Damping, however, is both friend and foe to a system which must operate over a wide range of speeds. At resonance, it is desirable for the actual damping to approach the critical damping of the system, thereby taking energy from the shaft and decreasing the amplitude of the vibration of the system. At the much higher drying speeds, it is desirable for actual damping to be minimal in order efficiently to utilize the energy of the system in rotating the shaft and bowl. Therefore, preferably a variable rate energy absorption means is used as a damper to stabilize the bowl against excessive radial excursions during cut-out at speeds near resonance, and to allow the system to vibrate freely at the higher drying speeds.

Since the centrifuge of the invention utilizes an overhung bowl, in order accurately to control the radial vibration of the system, there must be a means of maintaining the vertex of the system within a well defined locus. This is accomplished using at the end of the shaft opposite the bowl attachment, a gimbal-like system and the utilization of a drive means inputting rotational force proximal the vertex minimizes the radial vibration at the vertex and the external excitation to the rotating elements and isolates the support structure from receiving radial vibration transmitted at the vertex of the system.

In order that the invention may more readily be understood, the following description is given, merely by way of example, reference being made to the accompanying drawings, in which:-

Figure 1 is a side elevational of one embodiment of apparatus according to the invention;

Figure 2 is an enlarged sectional view along the axis of the shaft of the apparatus of Figure 1, showing the bowl, envelope and a portion of the resilient support;

Figure 3 is a sectional view along line 3-3 of Figure 2;

Figure 3a is a fragmentary view, similar to a portion of Figure 3, showing a modified construction;

Figure 4 is an end view of the drive means including the gimbal-like mount for the rotating shaft;

Figure 5 is a partial sectional view along the axis of the shaft and bowl showing the pin construction of a metallic bowl;

Figures 6a and 6b are graphs showing the response amplitude and phase angle of an elastic body at various frequency ratios; and

Figure 7 is an elevational view partially in section showing a flexible coupling of the motor to the shaft.

The apparatus shown in Figure 1 includes a base frame member 11 having an upper housing 12 which carries an envelope 13 therewithin which encases a bowl 14. The envelope 13 is used to confine and remove fluids extracted from the fines within the bowl 14 as is well known in the art. The bowl 14 has a base support 16 affixed conventionally to a continuous rotatable shaft 17 which rotates within longitudinally spaced bearings 18 and 20. The end of the shaft 17 opposite the bowl 14 is mounted for rotation on a gimbal-like system 19, which is affixed to and supports the shaft 17 whereby there is maintained a vertex of precession 21 of the shaft 17 and bowl 14.

As shown in Figures 2 and 3, supporting the bearings 18 intermediate the bowl 14 and the vertex 21 proximal the bowl is a resilient support structure 22, which has two principal types of components, with one being in the form of air bags 23 and the other in the form of semi-rigid supports 24. The air bags 23 and semi-rigid supports 24 are symetrically positioned about a bearing sleeve 26 containing the bearings 18 and the shaft 17 so that the structure 22 supports the bearings 18 at an area near the bowl 14. As illustrated, the semi-rigid supports 24 are placed intermediate each pair of air bags 23, but they could be integrated within the air bags 23, if the latter provide the sole support to the bearing sleeve 26 when they are fully inflated. The supports 24 may also be mounted on fluid actuated cylinders 25, as shown in Figure 3a. The air bags are mounted on the base frame 11 by connecting members 27 extending radially inwardly from a mounting collar 28 affixed to the base frame 11. A source of compressed air, not shown, is used individually to control the inflation of each air bag 23. The semi-rigid supports 24 are also mounted on the collar 28 and extend radially inwardly therefrom, as shown in Figure 3. The supports 24 include rubber pads 29 on the inwardly facing ends thereof, with the pads 29 being separated from the sleeve 26 when the air bags 23 are inflated and with the lower pads 29 abutting the sleeve 26 upon deflation of some or all of the air bags 23.

Also shown in Figures 1 and 2 are a pair of radially extending shock absorbers 31 and 32 which are mounted between the sleeve 26 and the collar 28 at angularly spaced locations relative to each other. The shock absorbers 31 and 32 are used to dampen the system from excessive radial motion such as may occur at resonance. It is preferable that the energy absorption capabilities of these shock absorbers be variable so that they may stabilize the bowl 14 at cut-out speeds for the removal of the dried particulate and yet absorb minimal energy at the drying speeds; however standard industrial shock absorbers may be used. Figure 2 shows one such variable shock absorber 31, which uses a flat bar 33 operatively connected to the sleeve 26 and extending into a housing 34 within which a hydraulically actuated clamp 36 is positioned to open and close about the bar 33. The pressure exerted on the bar 33 is determined by the hydraulic pressure provided to a hydraulic line 37 and cylinder 38 from an external hydraulic source, not shown.

The gimbal-like system 19 includes a yoke 41 having transverse pins 42 and 43 pivotally secured to the base frame 11. A vertical pin 44 extends downwardly from the yoke 41 and supports one end of a truss 46 which is connected at its opposite end to the sleeve 26 to support the shaft 17, which is restrained from axial movement within the sleeve 26. This gimbal-like system 19 allows the bowl 14 and shaft 17 to be displaced vertically and horizontally within the restriction placed on the shaft 17 by the resilient support structure 22 while maintaining the vertex 21 of precession of the shaft 17 at a substantially well defined locus. A variable speed drive 47, such as a variable frequency alternating current drive, is coupled to the shaft 17 by at least one drive belt 48 which transfers rotational force to the shaft 17 at a belt receiving groove 49 located at the locus of the vertex 21. Alternatively (Figure 7) the drive means may be directly coupled to the shaft 17 with a flexible coupling 63 such as a gear-type flexible coupling which is well known in the art. Alternative drive means such as variable speed direct current drives or hydraulic variable speed drives may also be used. The use of the flexible coupling 63 requires the use of a gimbal fork 64 and gimbal ring 66 rather than the aforementioned yoke 41 and truss 46, but they operate in the same way to isolate the rotating elements from the remainder of the centrifuge and to maintain the vertex 21 in a well defined locus.

The use of the gimbal-like system 19 resolves the three-dimensional vibration problem into a two-dimensional problem at the mounting collar 28 while isolating the base frame 11 from receiving excessive vibration which would result if a fixed bearing support system were used to support the shaft 17. This allows for the use of a very high rate of rotation which places very high centrifugal stresses on the loaded bowl 14. Therefore the bowl construction merits discussion in that the preferable construction of bowl 14 utilizes a composite material, such as a carbon fibre reinforced epoxy, due to its combined strength, stiffness, and durability. Such composite materials have a very high strength-to-weight ratio and thus give marked advantages over other materials.

In some applications it may be useful to use an expandable metallic bowl, as shown in Figure 5, which utilizes an expandable shell 51 attached to a base support 52 by a plurality of radially extending pins 53 which allow the shell to expand under stress as is well known in the art and exemplified in U.S. Patent No. 3,282,498.

Regardless of the bowl construction materials, the bowl 14 is substantially circular in cross-section and has a plurality of generally outwardly directed angularly spaced apertures 54 which allow the extracted fluids to exit the bowl into the envelope 13 from whence the fluids are conventionally removed. In the metallic bowl an imperforate shell 51 with substantially axially directed ports 54′ at the ends of the bowl are preferred, while in the composite bowl construction radially directed ports 54 are preferred. In order to prevent the unintentional discharge of fluids from the envelope 13 into the bowl or along the shaft, ring seals 56 are carried between the bowl 14 and the housing 12. The bowl 14 has a radially and inwardly extending annular lip 57 of a radial dimension substantially equal to the thickness of the particulate material deposited in the bowl adjacent the lip 57, which carries one set of ring seals 56 and defines a generally unobstructed opening 58 into the bowl 14. This opening 58 allows both ingress and egress for the particulate matter which may be introduced and removed by any number of conveyors, sprayers, scrapers, blades and the like as may be convenient with the particulate matter being dried and as is indicated schematically at 59 in Figure 2. The bowl contains an appropriate mesh size filter media 61, mounted on a filter media support 62 which allows extracted fluid to exit the bowl 14. In the metallic bowl construction, as shown in Figure 5, and in the bowl utilizing the composite material the filter media 61 and filter media support 62 may be peaked near the centre of the shell 51 and flare outwardly toward each end to bias the flow of extracted fluids toward the axially directed ports 54′ under enhanced radial force.

The wet particulate matter is introduced into the bowl 14 while it is rotating and is cut-out or removed from the bowl 14 while it is rotating. Between the time the particulate is introduced and the time the dried particles are removed, the bowl is accelerated to the drying speed. The centrifuge can operate at higher speeds than conventional batch centrifuges with the outer surface having a linear speed during cut out in excess of 22.8 metres/sec, during loading in excess of 55.8 metres/sec and during drying in excess of 91 metres/sec.

It will be appreciated that removing the particulate from the bowl at this high cut-out speed requires the bowl 14 to be relatively stable. However, the natural radial frequency of the system when supported on the air bags 23 is about 700 to 800 cycles per minute, 27.4 to 31.5 metres/sec outer surface speed, when a 0.75 metre outside diameter bowl is being used. Thus, it can be seen that the cut-out speeds will include a rotational speed corresponding to the natural radial frequency and resonance will result.

Figures 6a and 6b derived from Fan Engineering, edited by Robert Jorgenson and published by Buffalo Forge Co, illustrates the problem associated with rotating an elastic system with an unbalanced load at resonance. At drying speeds the rotational frequency f for a 0.75 m outside diameter bowl, for example, is usually 2400 rpm or greater and the shaft is supported on the air bags 23, thus the natural radial frequency fn is 700-800 cycles per minute, so that the frequency ratio f/fn is approximately 3.0 or greater. At this ratio the amplitude of the non-dimensional response Mx/me for the forced vibration of a system resulting from rotating imbalance is approximately 1.0. The total vibrating mass M includes the rotating mass m which has an eccentricity of e, the system amplitude is x and the phase angle or lag of the response behind the imbalance is ϕ. The curved lines on the Figures correspond to the response and phase angles at various ratios $\underline{C}$ between the actual damping on the system c, and the critical damping cc of the system. As will be noted at the drying speed the response will be approximately equal in amplitude to the imbalance and lag behind the imbalance by nearly 180°; thus the system will be self-balancing at the drying speed, particularly if the system has a damping ratio which is very small, such as 0.05. Therefore, at drying speeds it is desirable that the shock absorbers 31 influence the system minimally.

In contrast to this, for example, at cut out speeds for a 0.75 m outside diameter bowl of between 600 and 1000 rpm the frequency ratio f/fn with air bag support will at some point become 1.0 and the response Mx/me, with a minimal damping ratio $\underline{C}$ of 0.05, will increase well above the scale of the graph. Also the phase angle approaches 90°. The result is that the system undergoes tremendous vibration, which is totally undesirable in that the removal/loading element 59 may impact and damage the filter media 61.

In order to aleviate the problem, one of the air bags 23a is deflated as the rotational speed of the bowl 14 is reduced from the drying speed, and the bearing is then supported by the semi-rigid supports 24. Alternatively, supports 24 are moved into engagement with the bearing by a fluid pressure operated cylinder 25 as shown in Figure 3A. The support structure 22 is thereby changed to a less resilient or stiffer support which increases the natural radial frequency fn of the system and increases the hysteresis of the supports. That is to say, the rubber pads 29 and support 24 remove energy from the system. Inasmuch as the rate of rotation of the shaft is decreasing rapidly during the cutting out operation and the change in natural radial frequency is also quite rapid the transition through the rotational speed f corresponding to the natural radial frequency fn is quite rapid and the effects of resonance are minimal. During removal of the particulate, fn is above cut-out speed, thus the frequency ratio f/fn is less than 1.0; thus the amplitude of the response Mx/me is not as severe and the phase angle is less than 90°. At this point the shock absorbers 31 interact with the shaft to increase the damping ratio C which further reduces the amplitude of the response Mx/me by taking energy out of the system. The bowl 14 is thus stabilized against excessive radial movement and the cutting out of the dried particulate can proceed safely. It is noteworthy to mention that the dried particulate removed is not dusty but, rather, has a consistency somewhat like table salt; therefore it is not as subject to the same transportation losses due to dusting as thermally dried particulate would be.

In completing the cycle, upon completion of the cut-out operation, the bowl's rotational speed is increased. For example, with a 0.75 m outside diameter bowl the speed is increased to above 1400 rpm and wet particulate is introduced. As the speed increases the air bag 23a is reinflated and thus the natural radial frequency fn is decreased, such that the transition across the resonance speed is again quite brief, thereby causing no problems with excessive radial excursions. The bowl is then accelerated to drying speeds, usually in excess of 2400 rpm for a 0.75 m outside diameter bowl. The entire cycle takes as little as 90 seconds. It will be noted that the resilient support 22 incorporates a built-in safety feature due to its double support system. In the event of a failure of an air bag 23, the bearing sleeve 26, bearing 18, and shaft 17 will be engaged by the lower semi-rigid supports 24 and the centrifuge may be safely stopped.

It is to be understood that the curves of Figures 6a and 6b are idealized curves for a system having one degree of freedom; however the gimbal-like system 19 has only two degrees of freedom which are both radial to the bowl; thus the principles involved yield the same results, so that by virtue of its ability to vary the natural radial frequency of the system in a controlled manner coupled with its ability to vary the rotational speed of the system can control the duration of the transition across a critical speed and thus minimize excessive vibration. It can operate at cut-out speeds higher than prior art centrifuges and can pass from cut-out speeds to drying speeds and back more smoothly and more efficiently than prior centrifuges. The centrifuge of the invention can use lighter-weight materials for the shaft due to the reduction of vibratory stress, can process particulate matter more rapidly and economically; is less subject to fatigue or wear due to excessive vibration and is simpler and cheaper to construct and operate than are prior centrifuges.

Claims

1. A centrifuge comprising an envelope (13), a bowl (14) rotatably mounted within said envelope (13), a wide mouthed opening (58) at one end of the bowl for introducing material to be dried, a plurality of apertures (54) in said bowl for discharging fluid into said envelope (13), a base (16) closing the other end of the bowl, a shaft (17) for mounting the bowl for rotation, means (18-28) for mounting the shaft for rotation about its axis, and drive means (47-49) for rotating the shaft (17) and the bowl (14) therewith, characterised in that the shaft (17) is a continuous shaft, secured to the base (16) at one end of the shaft, in that the means (18-28) for mounting the shaft comprises a gimbal-like system (19,41-44) mounting the shaft (17) at a second end, to maintain a vertex (21) of precession of the shaft and bowl at said second end in a substantially well defined locus, in that resilient means (22-28), which support the shaft bearings (18,20,26), are located between the vertex (21) and base (16), and in that said resilient means (18-28) are of variable resilience, whereby the natural frequency of the shaft (17) and the bowl (14) may be varied in accordance with the frequency of rotation of the shaft (17) and bowl (14).

2. A centrifuge according to claim 1, characterised in that a filter media liner (61,62) is mounted within the bowl (14) proximal the inner surface thereof.

3. A centrifuge according to claim 1 or 2, characterised in that the bowl is a metal drum (51) with an expandable outer shell.

4. A centrifuge according to claim 1, 2 or 3, characterised in that the resilient means (18-28) is adapted to provide a high natural radial frequency, when said shaft (17) is rotating at low speeds suitable for removing dried solids from the bowl (14), and a low natural frequency, when said shaft is rotating at high, drying speeds.

5. A centrifuge according to any preceding claim, characterised in that the resilient means comprise a plurality of air bags (20,23) mounted about said bearing (18,20,26) and a plurality of movable support members (24,29) having a lower resilience than said air bags (23), mounted about said bearings in cooperation with said air bags (23), whereby said support members (24,29) and bearings (18,20,26) may be urged towards one another.

6. A centrifuge according to claim 5, characterised in that the bearings (18,20,26) may be urged against selected ones of support members (24,29) by varying the inflation of selected ones of the cooperating air bags (23).

7. A centrifuge according to any preceding claim, characterised in that energy absorption means (31-38) are operatively connected to the bearing (18,20,26) intermediate the bowl (14) and the gimbal-like system (19,41-44), for absorbing energy from the shaft and bowl, when they are rotating near the natural frequency, to stabilize the bowl at low rotational speeds.

8. A centrifuge according to claim 7, characterised in that said energy absorption means (31-38) include a plurality of shock absorbers (31,32) extending radially of the bearing (18,20,26) and attached thereto, and means to vary the energy absorption capability of the shock absorbers (31,32).

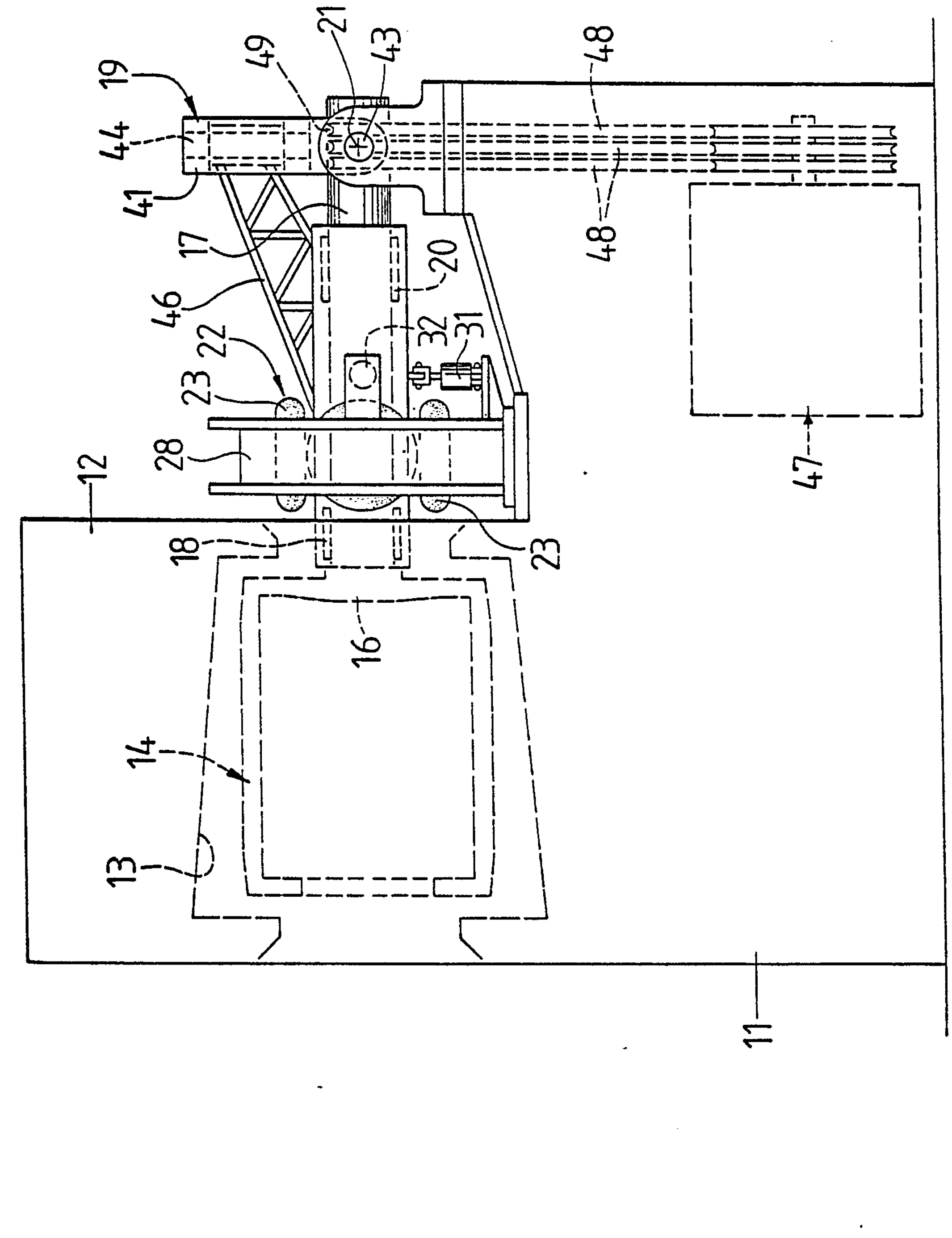
9. A method for centrifugally removing fluid from wet particulate matter, comprising the steps of introducing said wet particulate matter into a batch-type centrifuge having a bowl (14) with an opening (58) at one end for receiving said wet particulate matter, a base (16) at the other end thereof attached to a driven shaft (17) rotatable at various speeds and a filter media liner (61,62) proximal the inner surface of said bowl (14); accelerating the the rotational speed of said centrifuge to a controlled drying speed to reduce the moisture content of said particulate matter to below a predetermined percentage; by centrifugal extraction of the fluids; decelerating rotational speed of said centrifuge; and removing the particulate matter from said centrifuge at controlled rotational speeds of said centrifuge, characterised by the steps of supporting said shaft on a gimbal-like unit (19, 41-44) at the end of the shaft (17) remote from the bowl (14), to maintain a vertex (21) of precession of said shaft (17) and bowl (14) within a well-defined locus and to constrain said shaft to pivotal motion about said vertex, such that the freedom of movement of the bowl and shaft is limited to directions transverse to the axis of rotation thereof; supporting said shaft between said bowl (14) and said gimbal-like system (14,41-44) on supports (21-28) of the variable resilience; and controlling the natural radial frequency (fn) of said centrifuge by varying the resilience of the supports (22-28) in accordance with the rotational speed (f) of said centrifuge, such that the ratio (f/fn) becomes 1.0 only during said accelerating and decelerating steps, whereby the interval of time during which the condition f/fn = 1.0 is insufficient to induce successive radial vibration of said centrifuge.

10. A method according to claim 9, characterised by the step of damping said centrifuge during said removing and introducing steps, whereby said bowl is stabilized against excessive radial movement.

11. A method according to claim 9 or 10, characterised in that said removing step occurs at outer surface speeds above about 22.8 metres per second.

12. A method according to claim 9, 10 or 11, characterised in that the outer surface speed during the drying step is in excess of 91 metres per second.

Fig. 1.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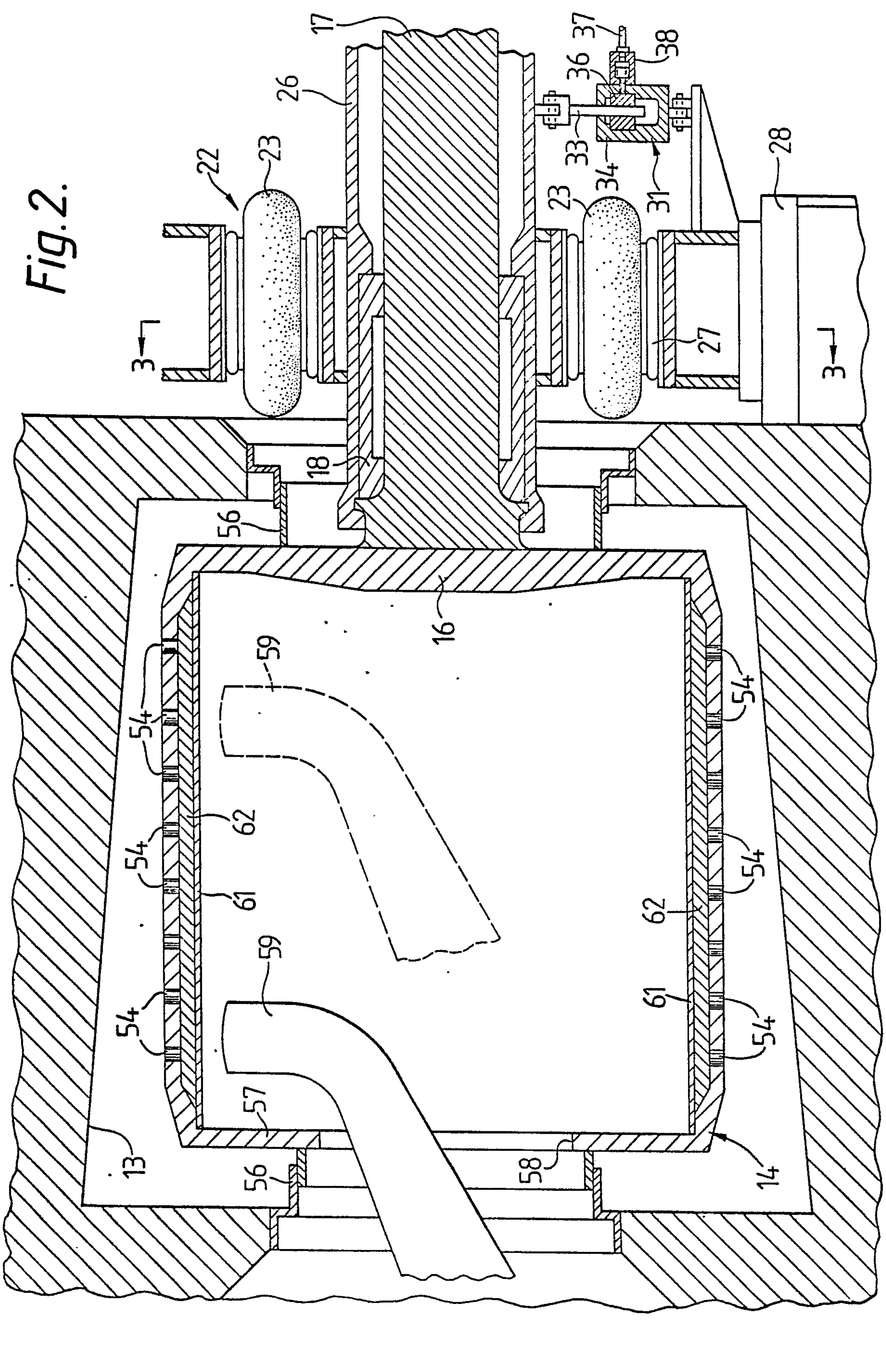
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Fig. 2.

Fig. 3.

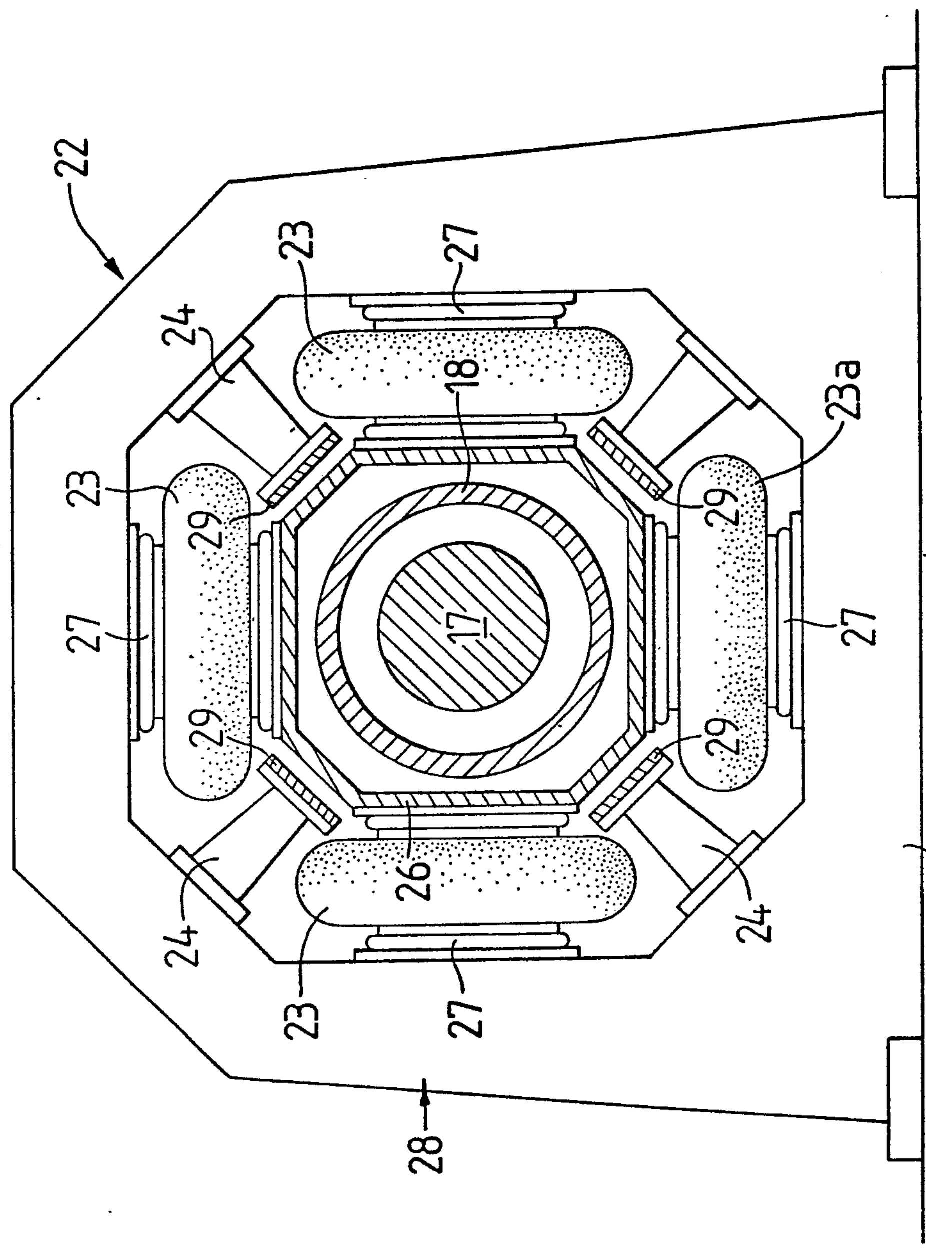


Fig.3A.

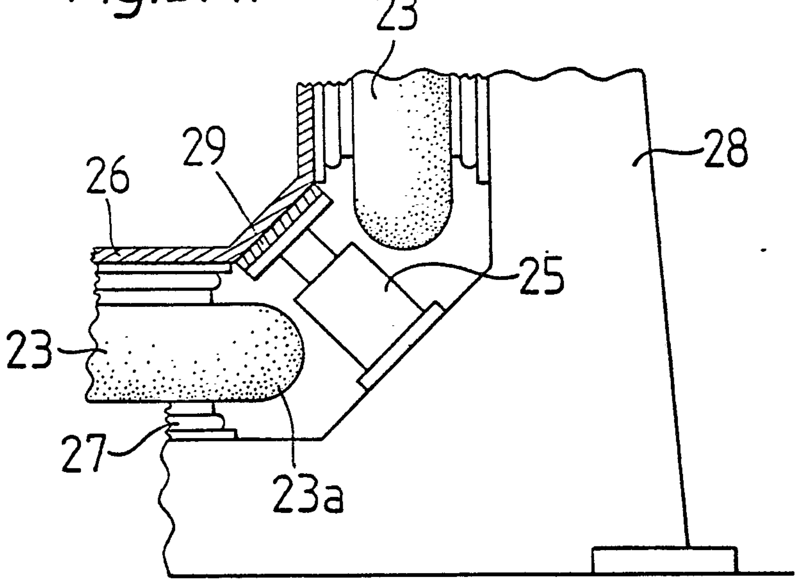


Fig.7.

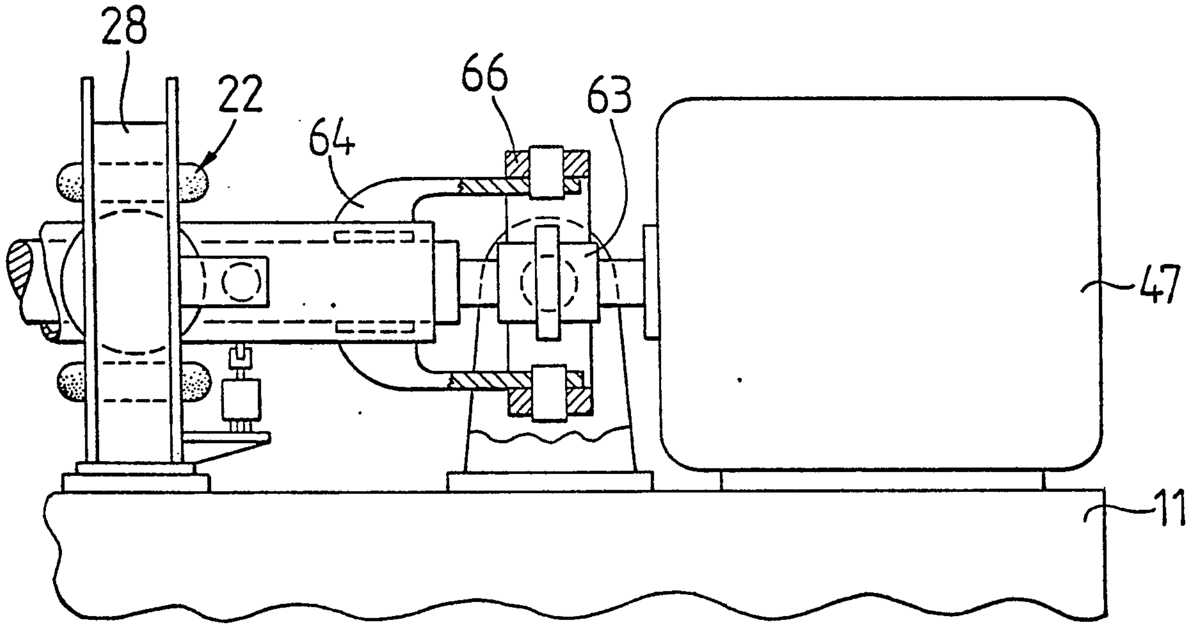


Fig.5.

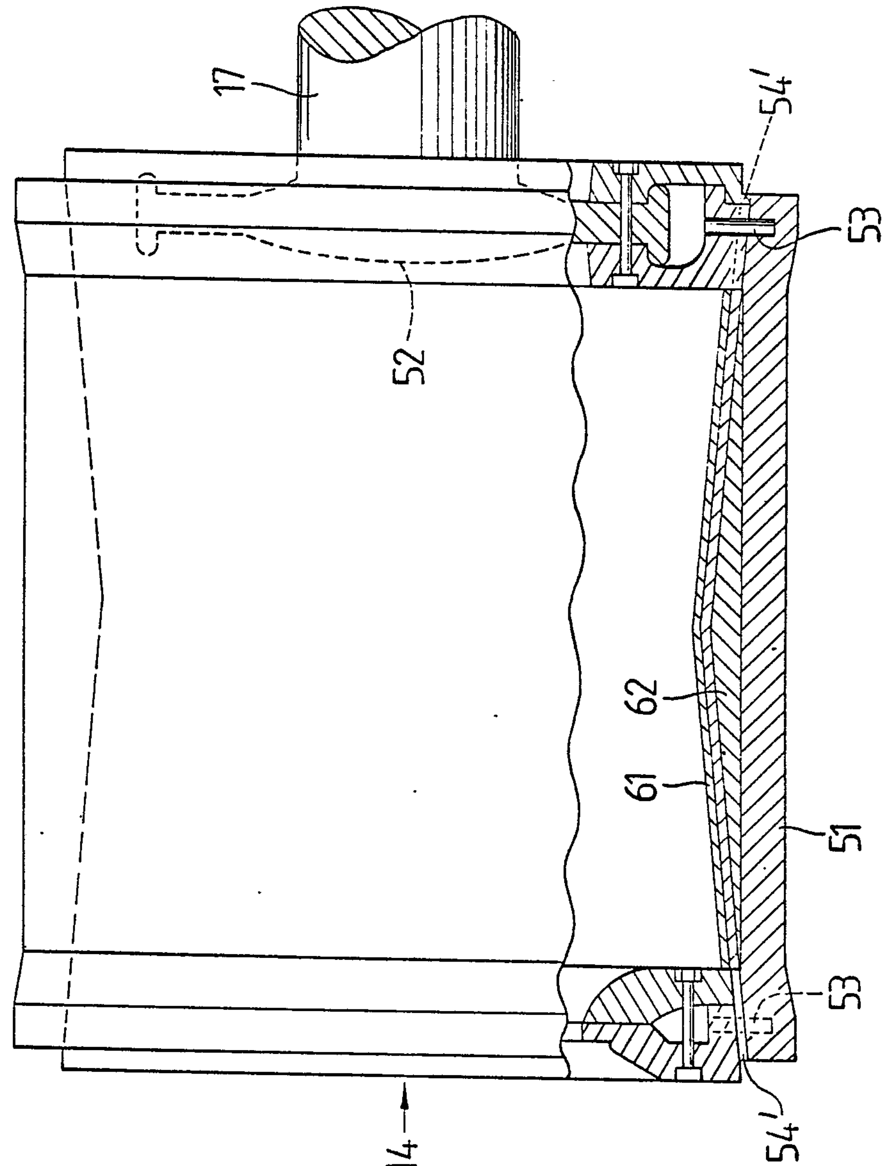


Fig.4.

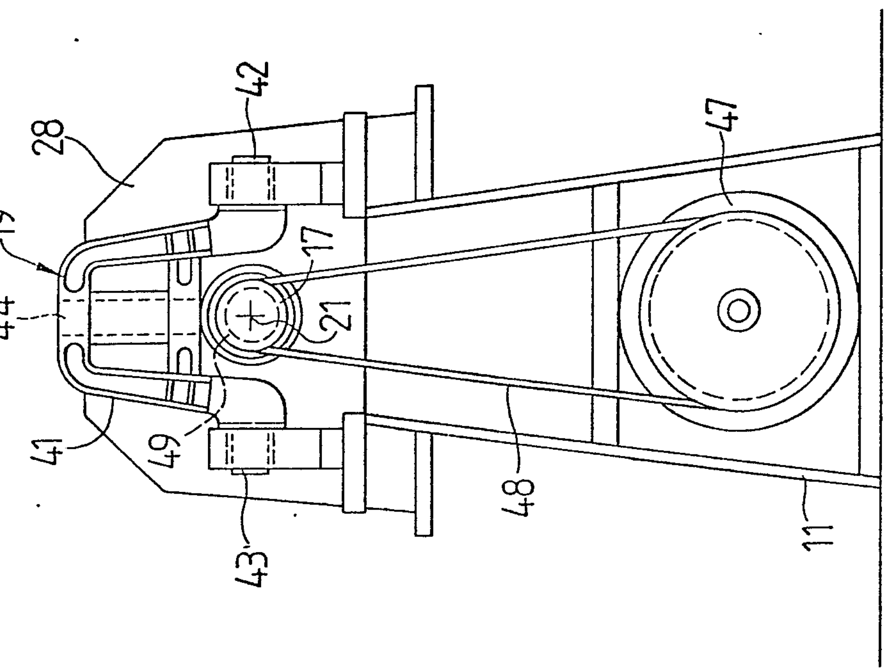
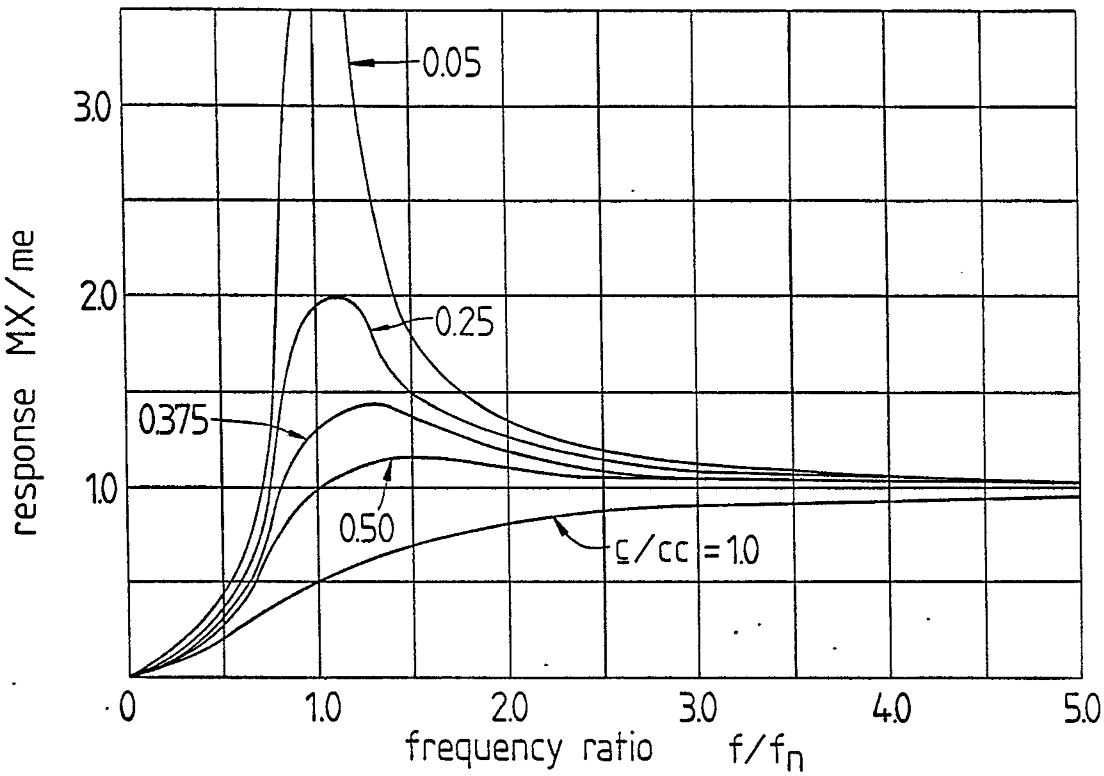


Fig.6A.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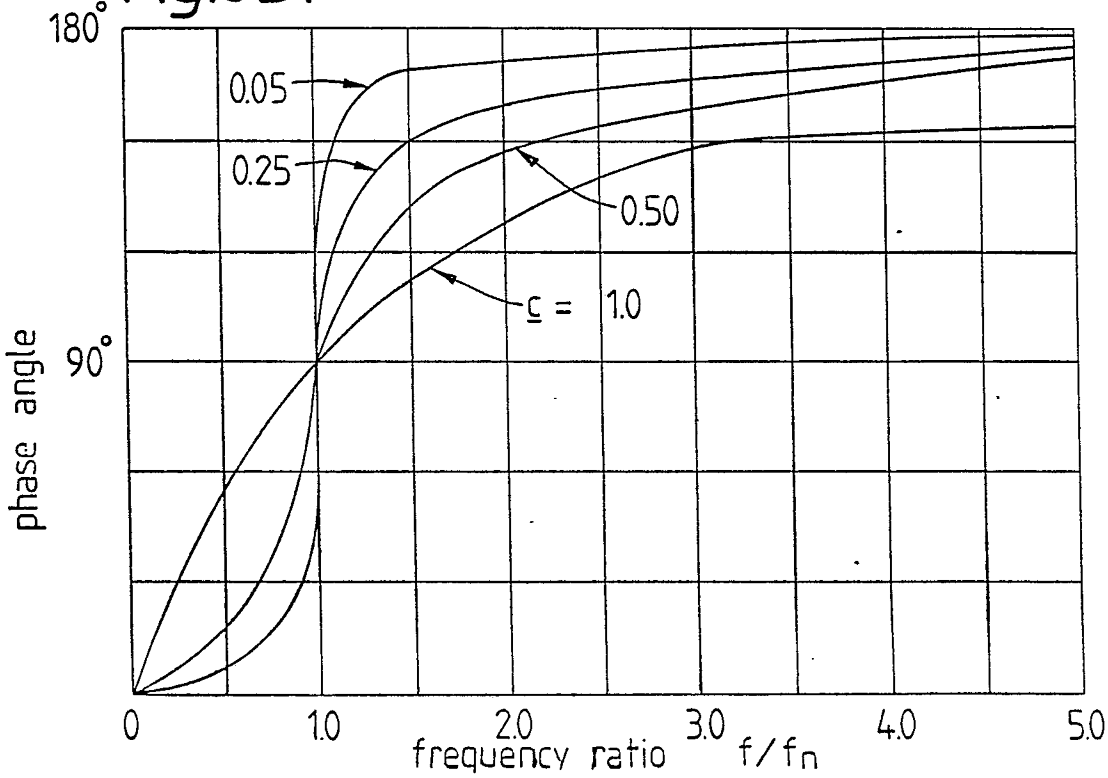
frequency ratio f/fn

Fig.6B.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