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(54) **VALVE ASSEMBLY, METHOD**

(57) A valve assembly suitable for controlling the flow of particulate material includes a chamber for storage of the material with an inlet and an outlet. The particulate material is dispensed from the outlet and builds up on an outlet control member that is located under the outlet. Sufficient build-uρ of the material acts to at least partially block the outlet and resist further material flow. The outlet control member and the chamber are movable relative to each other to disrupt the accumulated particulate material on the outlet control member and unblock the outlet of the chamber to permit the flow of particulate material to resume.

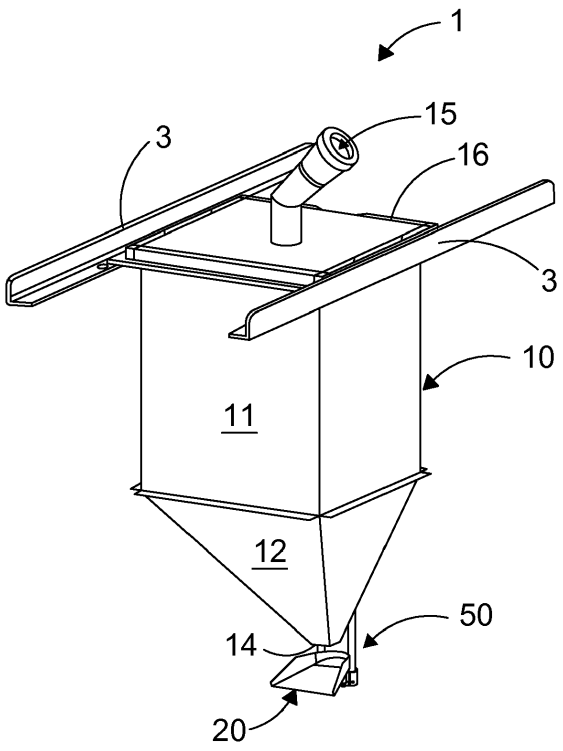


FIG. 1

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Description

[0001] The present application relates to a valve assembly. In particular, the present application relates to a valve assembly for controlling flow of particulate material.

[0002] Conventional mechanical valves, for example gate valves or ball valves, can have problems with rapid erosion and shortened life spans when particulate material such as sand is flowed through them, leading to failure to seal effectively or jamming of moving parts among other detrimental effects.

[0003] Research papers *Characterization of powder flowability using measurement of angle of repose* (Geldart D., Abdullah, E. C., Hassanpour A., Nwoke L. C., and Wouters, I., China Particuology 4 (2006) 104-107); *Characterisation of dry powders* (Geldart D., Abdullah E. C., and Verlinden A., Powder Technology 190 (2009) 70-74); and *Measuring the flowing properties of powders and grains* (Lumay, G., Boschini, F., Traina K., Bontempi S., Remy J-C., Cloots R., and Vandewalle N., Powder Technology 224 (2012) 19-27) are useful for understanding the invention.

SUMMARY OF THE INVENTION

[0004] According to the present invention there is provided a valve assembly for controlling flow of particulate material, the valve assembly having a storage chamber adapted to retain particulate material, said storage chamber having an inlet to receive particulate material and an outlet to dispense the particulate material from the storage chamber; wherein the valve assembly comprises an outlet control member adapted to receive and retain particulate material dispensed from the outlet of the storage chamber, said outlet control member being spaced apart from the outlet of the storage chamber; wherein particulate material dispensed from the outlet of the storage chamber is adapted to accumulate on at least one surface of the outlet control member and to at least partially block the outlet of the storage chamber, resisting flow of particulate material from the outlet; wherein the outlet control member and the storage chamber are movable relative to one another to disrupt accumulated particulate material on the outlet control member and unblock the outlet of the storage chamber.

[0005] Optionally the disruption of the accumulated material on the outlet control member disrupts the particulate material occluding the outlet and clears the outlet so that particulate material can flow more freely from the storage chamber through the outlet. Thus the outlet can be blocked and unblocked by switching the outlet control member and the storage chamber between different states of relative movement. This allows more reliable switching between open (when the outlet is unblocked and the particulate material flows freely) and closed (when the outlet is at least partially blocked and the particulate material has at least some resistance to flow) states of the storage chamber.

[0006] Optionally the storage chamber and the outlet control member are separated from one another, optionally by a clear space between them whether the outlet of the valve is blocked or unblocked, and thus are not directly connected, but optionally the storage chamber and the outlet control member may be indirectly connected. The clear space between the storage chamber and the outlet control member when the valve outlet is both blocked and unblocked allows the accumulation of the particulate material on the outlet control member while the outlet of the storage chamber is clear, until the accumulation of the particulate material on the outlet control member has occluded the outlet of the storage chamber.

[0007] Optionally the storage chamber comprises walls that are at least partially inclined. Optionally the walls of the storage chamber are flat. Optionally the walls of the storage chamber are curved. Optionally the storage chamber comprises a funnel, optionally leading to the outlet. Optionally the inlet of the storage chamber comprises a larger cross-sectional area than the outlet of the storage chamber, or optionally the inlet comprises a smaller cross-sectional area than the outlet. The ratio between the cross-sectional area of the inlet relative to the outlet can be adjusted to suit the particulate material that is being flowed through the storage chamber, and optionally to further control the flow rate of the particulate material through the storage chamber. Optionally the two cross-sectional areas are equal. Optionally the storage chamber comprises a hopper. Optionally the particulate material flows from the outlet of the storage chamber to the outlet control member under gravity. Optionally the particulate material is at least partially fluidised. Optionally the storage chamber is manufactured from metal, or optionally from a composite or ceramic material.

[0008] Optionally the storage chamber comprises an outlet compartment, optionally in the form of a shroud disposed at the lower end of the storage container, optionally a rectangular shroud, but this may be formed in any suitable shape. Optionally the outlet control member is contained within the shroud. Optionally the outlet control member is movable within the shroud, optionally relative to the shroud. Optionally the shroud is made of the same material as the storage chamber, or optionally the shroud is made of a different material. Optionally the shroud is insulated, and the thickness of the insulation is optionally selected taking into account parameters such as the conductivity of the insulating material, and the temperature gradient from inside the storage chamber to outside the storage chamber. Optionally, one possible example of the insulation is 50mm thick ceramic fibre insulation. Optionally the shroud is connected to the storage chamber with fixings such as bolts, or optionally rivets, or optionally by welding, or optionally any combination thereof.

[0009] Optionally the shroud comprises an outlet tube connected to a base portion of the shroud. Optionally particulate

material that is disrupted and released from the outlet control member as a result of relative movement of the outlet control member and the storage chamber falls under gravity to the base of the shroud and into the outlet tube. Optionally the outlet tube is angled. Optionally the outlet tube dispenses the particulate material for further processing or optionally for recycling back into the system. Optionally the outlet tube extends at least partially into the shroud. Optionally the outlet tube is attached to the external surface of the base of the shroud, optionally by welding, riveting, bolting, or any other suitable fixing.

[0010] Optionally the outlet control member has an at least partially concave shape. Optionally the outlet control member comprises a base and at least one wall. Optionally the outlet control member has at least one channel for directing flow of particulate material off the outlet control member; optionally the channel can comprise an edge that does not comprise a wall, or that comprises a lower wall than other edges. Optionally the channel faces away from the storage chamber and is adapted to direct flow of particulate material away from the outlet control member. Optionally at least a portion of the base of the outlet control member comprises a plate. Optionally the outlet control member comprises a bed, which may comprise a partially walled plate.

[0011] Optionally at least a portion of the base of the outlet control member is inclined relative to a horizontal axis. Optionally at least a portion of the base of the outlet control member is inclined downwards, for example, at an angle between 0°-90° relative to a horizontal axis. Optionally at least a portion of the base of the outlet control member is inclined downwards at an angle in the range of 0°-40° relative to a horizontal axis. Optionally at least a portion of the base of the outlet control member is inclined downwards at an angle in the range of 10°-20° relative to a horizontal axis.

[0012] Optionally the outlet control member comprises a first plate and a second plate, wherein the first and second plates are optionally inclined (optionally downwards) at different angles relative to a horizontal axis. Optionally the first plate of the outlet control member is inclined at a steeper angle than the second plate relative to the horizontal axis. Optionally the first plate is inclined at a more shallow angle than the second plate relative to the horizontal axis. Optionally the second plate of the outlet control member has a greater surface area than the first plate of the outlet control member.

[0013] Optionally the interface or transition between the first plate and the second plate of the outlet control member is disposed beneath the outlet of the storage chamber, optionally centrally relative to the outlet of the storage chamber.

[0014] Optionally, where the first plate is inclined at a shallower angle than the second plate relative to the horizontal axis, the interface or transition between the two plates is convex. Utilising a convex arrangement leads to a reduction in mass of accumulated particulate material on the plate, which allows a given vibrating power to produce a larger amplitude of vibration. This enhances the rate of flow of particulate material off the plate, and reduces the energy required to flow the particulate matter. By minimising the energy consumption, the overall effect of the renewable energy harvesting is maximised.

[0015] Optionally the outlet control member comprises a single flat plate, optionally forming a base for receiving and retaining particulate material. Optionally the flat plate is surrounded at least partially by a vertical wall or walls. Optionally the flat plate is not inclined relative to the horizontal axis. Optionally the flat plate is surrounded on two parallel sides by walls adapted to retain particulate material received by the flat plate. Optionally the flat plate is surrounded by walls such that there is a single channel for directing flow of particulate material off the outlet control member.

[0016] Optionally the outlet control member comprising a single flat plate has at least one channel, optionally two channels, for directing flow of particulate material off the outlet control member; optionally the channel or channels can comprise an edge that does not comprise a wall, or that comprises a lower wall than other edges. Optionally the channel or channels face away from the storage chamber and is/are adapted to direct flow of particulate material away from the outlet control member. Optionally the outlet control member comprises two channels on opposite sides of the flat plate. Optionally the flat plate does not comprise walls and particulate material can flow from the flat plate in any direction.

[0017] Optionally at least a portion of the flat plate is inclined at an angle, optionally downwards, relative to the horizontal axis. Optionally the whole plate is inclined at the same angle. Optionally the plate is inclined at an angle between 0-30° relative to the horizontal axis, optionally approximately 15°.

[0018] Inclining the plate offers the advantage that resistance to flow of the particulate material is lowered due to the inclination of the plate, and any movement of the plate results in an "avalanche" effect, giving rise to high flow of particulate material relative to the energy expended.

[0019] Optionally the outlet control member is in the form of a plurality of plates, optionally vertically stacked one above another, optionally in a mutually parallel arrangement. Optionally at least one, and optionally each, of the plurality of stack plates is flat. Optionally at least a part of at least one or more of the plates is arranged on the horizontal axis. Optionally at least one plate comprises a flat solid plate with no edges. Optionally at least one plate comprises a convex plate with no edges, optionally the plate at the base of the vertical stack of plates. Optionally the base plate comprises a conical or similar shape.

[0020] Optionally at least one plate incorporates at least one aperture to permit flow of particulate material through the plate to the plate directly underneath it under gravity.

[0021] Optionally each stack plate above the base plate comprises an aperture, optionally more than one aperture.

[0022] Optionally the aperture in the or each plate comprises a large cross-sectional area relative to the cross-sectional

area of the plate. Optionally the or each aperture is arranged directly underneath the outlet of the storage chamber, and optionally centrally to the or each plate. Optionally the apertures in adjacent plates are aligned. Optionally the or each plate comprises at least one edge with no raised walls or barriers to the flow of particulate material. Optionally particulate material can flow off the or each plate in all directions, i.e. substantially 360° around the or each plate.

[0023] Optionally the edge of the mound of particulate material flowing from the storage chamber onto the plurality of plates comes to rest at or very close to the edge of each plate. The proximity of the particulate material to the edge of each plate results in less energy being required to flow the particulate material off each plate. Optionally the edge of the plate from which the particulate material drops is spaced from the edge of the mound of particulate material when the outlet is occluded. Spacing the edge of the plate or plates from the edge of the mound of particulate material, such that there is a margin between the edge of the particulate material and the edge of the plate or plates, assists with rapid occlusion of the valve outlet when it is necessary to stop the flow of particulate material through the outlet.

[0024] The particulate material optionally accumulates on the outlet control member in a mound with an apex and with sides of the mound adopting a resting angle of repose, at which the mound is stable on the outlet control member and wherein the apex of the mound gradually builds up to occlude the outlet of the storage chamber. The angle of repose of the particulate material is dependent on various parameters of the material and the system, for example, frictional coefficient of the powder, mass of the powder, angle of the base of the outlet control member etc. The angle of the base of the outlet control member is usefully less than the corresponding angle of repose for the particular powder material, so that the sides of the mound build up at a steeper angle than the base of the outlet control member.

[0025] The arrangement of the plurality of plates with central apertures offers a greater flow area with a smaller mass of particulate material around the edges of each plate acting to restrict flow of particulate material disposed further towards the centre of the plate arrangement. The total mass of particulate material accumulated on the plate arrangement may optionally be equal to or optionally greater than the total mass accumulated on one of the other examples of the apparatus, however, as this mass is distributed across multiple plates, this reduces the resistance of the particulate material to disruption and flow off each plate. This offers the advantage that for an equivalent mass of particulate material, lower vibrational power is required to disrupt the accumulated material. As lower power is required, this results in lower consumption of energy.

[0026] Optionally the particulate material is hot particulate material, which can be heated before being received in the storage chamber. Optionally the particulate material is heated by a heating system that is powered by renewable energy, supplying intermittent power, optionally harvested by a photovoltaic system, or optionally by wind, tidal, or wave systems. Optionally the heating system is electrically connected to an array of solar cells and/or modules. Optionally the heating system is electrically connected to at least one wind or tidal turbine, or at least one other form of hydroelectric energy harvesting. Optionally the particulate material is heated to several hundred degrees Celsius, for example 500-700°C dependent on the material being used. Optionally at least a part of the storage chamber is at least partially insulated, and is adapted to resist heat exchange or loss between the heated particulate material and the environment surrounding the valve assembly. Optionally the particulate material stacks on the or each outlet control member at an angle of repose of approximately 30°.

[0027] Optionally the particulate material is heated by solar energy, and can be directly heated in a concentrated solar power system having mirrors or lenses to concentrate solar energy on a small area containing the particulate material (or through which the particulate material passes) to heat up the particulate material prior to passage through the valve. The valve is thus optionally used to control the distribution of heated particulate material, e.g. sand, which can then be routed to a heat engine such as a steam turbine, to recover heat from the hot particulate material. Hence, in certain aspects the particular material is used as a medium for the transfer of renewable heat energy from the concentrated solar power system to the heat exchanger for recovery of the heat energy contained in the particulate material.

[0028] Accordingly the invention also provides a concentrated solar power system incorporating a valve assembly as defined herein.

[0029] Optionally the first plate of the outlet control member forms a connection with at least one shaft optionally connected to the valve and optionally adapted to support at least a portion of the valve. Optionally the storage chamber and the outlet control member are mounted to different supports, and the storage member is optionally not directly connected to or is isolated from the shaft; thus movement of the outlet control member or the shaft is not directly transmitted to the storage member and vice versa. This enhances the relative movement between the outlet control member and the storage chamber when one of them is moved relative to the other. Optionally the storage chamber and the outlet control member can be remotely connected together or to the same support structure by the at least one shaft.

[0030] Optionally the valve assembly comprises at least one movement device, configured to move the outlet control member relative to the storage member. Optionally the at least one shaft connects the movement device and the storage device, and optionally the shaft transmits movement between the movement device and the outlet control member.

[0031] Optionally, the movement is cyclic, and the movement device optionally comprises an oscillatory device, optionally adapted to cyclically move one of the outlet control member and the storage chamber relative to the other, and disrupt particulate material that has accumulated on the outlet control member, and optionally that has occluded the

outlet of the storage chamber. Optionally the movement is elliptical. Optionally the movement of the outlet control member is vibration. Optionally the movement device is adapted to cyclically move, and optionally vibrate, the outlet control member in one or more than one scenario and which may include:--

i) when the outlet is clear, and optionally when particulate material is flowing through the outlet to the outlet control member; and/or
ii) when the outlet is blocked (to clear it).

[0032] Alternatively, the outlet control member remains static when the outlet is clear, optionally when particulate material is flowing through the outlet, optionally so that the particulate material accumulates on the outlet control member to block the outlet. Optionally the connection of the outlet control member to either the at least one shaft or to the movement device comprises a cantilever connection, and optionally the second plate of the outlet control member is connected only to the first plate of the outlet control member.

[0033] Optionally the outlet control member and optionally the movement device are connected to at least one shaft. Optionally the shaft is flexible and optionally comprises a flexible beam. Optionally the shaft extends from a fixed, optionally rigid foundation disposed above, or optionally beside, or optionally beneath the storage chamber. Optionally the shaft extends from the foundation and along the full height of the storage chamber. Optionally the foundation is located beneath the storage chamber and the shafts extend vertically upwards. Optionally the shaft is flexible and supports the outlet control member so that the shaft can flex and the outlet control member can move. Optionally the valve assembly comprises more than one shaft, optionally two. Optionally the shafts incorporate or support conduits and supply power to move the movement member. Optionally the free ends of the shafts, that is the ends that are not connected to the movement member, are rigidly constrained by the foundation. Optionally the storage chamber is also rigidly constrained, optionally by attaching at least a portion of the shaft or shafts to the storage container.

[0034] Optionally the movement device is pneumatically powered, and the shafts optionally comprise or support a fluid inlet tube and a fluid outlet tube. Optionally the outlet control member is connected to the movement device, and the movement device is connected to the at least one shaft.

[0035] Rigid constraint of the shafts ensures that the greatest proportion of the kinetic energy present in the fluid as it is being flowed to the movement device is transferred to the movement device itself.

[0036] Optionally the fluid inlet and fluid outlet tubes are connected to the movement device. Optionally fluid, for example air, nitrogen gas, or vapours, e.g. steam, is flowed into the movement device through the fluid inlet tube and out of the movement device through the fluid outlet tube. Optionally the fluid inlet and outlet tubes are connected to the movement device on its upper surface, but the tubes can also be connected in other ways, for example, to a side or to the lower surface of the movement device according to the internal configuration of the movement device. Optionally the fluid inlet and outlet tubes are arranged with one tube connected to the movement device on one side of the outlet control member, and one tube connected to the movement device on the other side of the outlet control member. Optionally the air outlet tube comprises an exhaust.

[0037] Optionally the movement device comprises a turbine. Optionally the turbine comprises an out of balance weight. Optionally the movement device comprises at least one bearing in a race, optionally a ball bearing, forming a bearing assembly. Optionally the movement device is manufactured from metal, optionally stainless steel. Optionally the movement device comprises a ceramic material; for example zirconia, silicon nitride, silicon carbide. Optionally fluid flow into the movement device sets up an eccentric movement within the device. Optionally fluid flow into the movement device causes cyclic rotational movement of the air turbine or of the bearing. Optionally fluid flow into the movement device drives the turbine and generates eccentric movement. Optionally fluid flow into the movement device pushes the bearing around the race and leads to eccentric movement of the movement device. Optionally the race is circular, or elliptical. Optionally the race is arranged in a horizontal plane. Optionally the movement device generates vibrations in a horizontal plane. Optionally the movement device generates vibrations off the horizontal plane, optionally at an angle less than 30°. Optionally the movement device is angled off the horizontal plane.

[0038] Optionally the movement device comprises a port, optionally in the wall of the connection of the fluid inlet tube. Optionally fluid flows through the port and into the body of the movement device. Optionally the moving part of the movement device, for example the bearing, or the fluid turbine, is contained within at least a portion of the movement device. Optionally the portion of the movement device restrains movement of the moving part in a cyclic (e.g. a circular) path, or optionally an elliptical path. Optionally the portion of the movement device comprises apertures to permit exit of fluid flow away from the moving part of the movement device, optionally to maintain the fluid within the device at a given pressure value, and flowing in a given direction.

[0039] Optionally the apertures pass through a wall, optionally a horizontal wall, of the movement device, into a circular or optionally elliptical air outlet manifold. Optionally fluid flows into the manifold and exits the movement device through a port in the wall of the connection of the fluid outlet tube.

[0040] Optionally the movement of the movement device moves the outlet control member relative to the storage

member, which optionally remains static, but the in other examples this arrangement can be reversed, or both the outlet control and the storage member can be moved. Optionally the movement is vibration or oscillation. Optionally the movement of the outlet control member is in one plane, for example towards and away from the at least one shaft, or backwards and forwards. Optionally the movement of the outlet control member is side to side. Optionally the movement of the outlet control member can be in more than one plane. Optionally the movement of the outlet control member disrupts the particulate material, and the particulate material optionally falls from one end of the outlet control member, for example, via a low side of the outlet control member, optionally onto the base of the shroud, or optionally into a further container, or optionally the particulate material is directly dispensed from the outlet control member. Optionally the particulate material is adapted to flow or fall from more than one end or side of the outlet control member. Optionally the particulate material is adapted to flow or fall from the full perimeter of the outlet control member.

[0041] Optionally the movement device is arranged in close proximity to the outlet control member. Optionally in the example of the apparatus where the outlet control member comprises a plurality of plates, the movement device is optionally arranged in close proximity to the plurality of plates. Optionally the movement device and the outlet control member (e.g. the plurality of plates) are constrained to move together. Optionally this effectively creates a point load, which advantageously reduces stress on the connections between the movement device and the supporting structure for said movement device. Optionally the movement device and the plurality of plates are held in a proximal arrangement by an upper and a lower plate, the upper and lower plates optionally adapted to vertically restrain the movement device and the plurality of plates while optionally permitting horizontal movement. Optionally the movement device, plurality of plates, and upper and lower plates are adapted to move as one unit. Optionally in the example of the apparatus where the outlet control member comprises a single plate, or optionally a first and second plate connected together at an interface, the movement device is optionally connected to both the plate and the shaft. Optionally the outlet control member (e.g. the plate) is connected to the movement device by a threaded fixing. Optionally the connection of the plate and the movement device maintains the movement device in close proximity to the plate and optionally adapts the plate and the movement device arrangement to move as a single unit. The close proximity of the movement device to plates reduces the overhang of mass from the shafts and acts to resist fatigue in the metal or other material used to manufacture the apparatus and its fixings.

[0042] Optionally at least one movement device is connected to the storage chamber. Optionally the movement device vibrates the storage chamber and disrupts the particulate material therein, for example to release or disperse clumps or agglomerations of particulate material supported on the outlet control member. Optionally at least one movement device is connected to the storage chamber and at least one movement device is connected to the outlet control member. Optionally the movement devices on the storage chamber and on the outlet control member are operated at different times, or optionally at the same time, according to the required flow rate of particulate material. For example, operating both movement devices at the same time will increase the flow rate of particulate material through the outlet of the storage chamber, into the outlet control member, and away from the outlet control member. Optionally the movement devices are operated in a synchronised manner, optionally in an asynchronous manner. Optionally the storage member and the outlet control member can be moved at the same time in different planes, or directions.

[0043] Optionally fluid flowing through the fluid inlet and outlet tubes and through the movement device can be heated, for example, by the heat from the heated particulate material. Optionally the heated fluid passes from the fluid outlet tube into a heat exchanger device. Optionally the heat exchanger device comprises at least one cool fluid intake. Optionally the cool fluid intake is separated from the intake of hot fluid from the fluid outlet tube. Optionally as the cool fluid passes through the heat exchanger, at least a portion of the heat from the hot fluid stream is transferred to the cool fluid. Optionally the transfer of heat from the hot fluid stream creates two separate warm fluid streams. Optionally one warm fluid stream is directed to the valve for input into the movement device, and one warm fluid stream is output to, for example, a heat engine such as a Stirling engine, where the heat from the fluid is used to power the engine. Optionally the heat from the fluid is used to heat water and create steam to provide power to an engine.

[0044] Pre-heating the warm fluid stream that is directed to the movement device reduces the loss of thermal energy from the particulate material on the outlet control member to the fluid, in turn reducing the energy that is required to be input into the system to heat the particulate material.

[0045] According to the present invention there is also provided a method of controlling flow of particulate material through a valve assembly, the method including flowing the particulate material into a storage chamber through an inlet formed in said storage chamber, wherein the storage chamber is adapted to retain particulate material; dispensing the particulate material from the storage chamber through an outlet formed in the storage chamber onto an outlet control member adapted to receive and retain particulate material, the outlet control member being spaced apart from the outlet of the storage chamber; accumulating particulate material on at least one surface of the outlet control member; and at least partially occluding the outlet of the storage chamber with particulate material that has accumulated on at least one surface of the outlet control member; wherein the method includes moving one of the outlet control member and the storage chamber relative to the other to disrupt accumulated particulate material on the outlet control member and unblock the outlet of the storage chamber.

[0046] The various aspects of the present invention can be practiced alone or in combination with one or more of the other aspects, as will be appreciated by those skilled in the relevant arts. The various aspects of the invention can optionally be provided in combination with one or more of the optional features of the other aspects of the invention. Also, optional features described in relation to one aspect can typically be combined alone or together with other features in different aspects of the invention. Any subject matter described in this specification can be combined with any other subject matter in the specification to form a novel combination.

[0047] Various aspects of the invention will now be described in detail with reference to the accompanying figures. Still other aspects, features, and advantages of the present invention are readily apparent from the entire description thereof, including the figures, which illustrates a number of exemplary aspects and implementations. Any subject matter described in the specification can be combined with any other subject matter in the specification to form a novel combination. The invention is also capable of other and different examples and aspects, and its several details can be modified in various respects, all without departing from the scope of the present invention. Accordingly, the drawings and descriptions are to be regarded as illustrative in nature, and not as restrictive. Furthermore, the terminology and phraseology used herein is solely used for descriptive purposes and should not be construed as limiting in scope. Language such as "including", "comprising", "having", "containing", or "involving" and variations thereof, is intended to be broad and encompass the subject matter listed thereafter, equivalents, and additional subject matter not recited, and is not intended to exclude other additives, components, integers or steps. Likewise, the term "comprising" is considered synonymous with the terms "including" or "containing" for applicable legal purposes. Thus, throughout the specification and claims unless the context requires otherwise, the word "comprise" or variations thereof such as "comprises" or "comprising" will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

[0048] Any discussion of documents, acts, materials, devices, articles and the like is included in the specification solely for the purpose of providing a context for the present invention. It is not suggested or represented that any or all of these matters formed part of the prior art base or were common general knowledge in the field relevant to the present invention.

[0049] In this disclosure, whenever a composition, an element or a group of elements is preceded with the transitional phrase "comprising", it is understood that we also contemplate the same composition, element or group of elements with transitional phrases "consisting essentially of", "consisting", "selected from the group of consisting of", "including", or "is" preceding the recitation of the composition, element or group of elements and vice versa. In this disclosure, the words "typically" or "optionally" are to be understood as being intended to indicate optional or non-essential features of the invention which are present in certain examples but which can be omitted in others without departing from the scope of the invention.

[0050] All numerical values in this disclosure are understood as being modified by "about". All singular forms of elements, or any other components described herein are understood to include plural forms thereof and vice versa. References to directional and positional descriptions such as upper and lower and directions e.g. "up", "down" etc. are to be interpreted by a skilled reader in the context of the examples described to refer to the orientation of features shown in the drawings, and are not to be interpreted as limiting the invention to the literal interpretation of the term, but instead should be as understood by the skilled addressee.

BRIEF DESCRIPTION OF THE DRAWINGS

[0051] In the accompanying drawings:

Figure 1 shows a perspective view of the valve assembly;
Figure 2 shows a close-up view of the outlet control member underneath the outlet of the storage chamber;
Figure 3 shows a side view of the valve assembly with lower section A circled;
Figure 4 shows a close-up view of the lower section A as highlighted in Figure 3;
Figure 5 shows the valve assembly of Figure 1 with a shroud attached to the lower portion of the storage chamber;
Figure 6 shows a side view of the outlet control member and shaft assembly without the storage chamber;
Figure 7 shows a perspective view of Figure 6;
Figure 8 shows a close-up view of an example of the movement device;
Figure 9 shows a close-up view of a horizontal cross-section of the movement device of Figure 8;
Figure 10 shows a vertical cross-section of the movement device of Figures 8 and 9; and
Figure 11 shows a fluid flow pathway through the movement device of Figures 8-10 and flowing through a heat exchanger
Figure 12 shows a side view of a further example of the outlet control member in the form of a flat plate parallel to the horizontal axis;
Figure 13 shows a side view of a further example of the outlet control member in the form of a flat plate incline relative to the horizontal axis;

Figure 14 shows a side view of a further example of the outlet control member in the form of two plates joined together at a convex angle, both plates inclined relative to the horizontal axis;

Figure 15 shows a side view of a further example of the outlet control member in the form of a plurality of flat plates disposed parallel to the horizontal axis;

Figure 16 shows a perspective view of an example of the outlet control member with multiple plates;

Figure 17 shows an exploded view of the example of Figure 16;

Figure 18 shows a close-up view of the outlet control member with multiple plates, in position next to the movement member; and

Figure 19 shows the calculation of curtain area for the example of the outlet control member illustrated in Figure 14.

DETAILED DESCRIPTION OF EXAMPLES OF THE INVENTION

[0052] Referring now to the drawings, a valve assembly 1 comprises a storage chamber, in this example in the form of a hopper 10, adapted to retain particulate material, in this example powder 28, but sand, grit, flour, granules, grains, or other particulate materials can be used, and "powder" is merely used here as a general term. The hopper 10 comprises an inlet 15, adapted to receive the powder 28 into the body 11 of the hopper 10, and an outlet 14 to dispense the powder 28 from the lower, funnelled section 12 of the hopper 10. The valve assembly 1 comprises an outlet control member, in one example, herein described, in the form of a bed 20 forming a platform underneath the outlet 14 of the hopper 10, adapted to receive and retain powder 28 dispensed from the outlet 14 of the hopper 10. Other examples of the outlet control member will be described in detail later in the description. The bed 20 is spaced apart from the outlet 14 of the hopper 10, with clearance between the outlet 14 and the bed 20 of around, for example, 5-50mm, but optionally greater or lesser spacing dependent on the parameters of the particulate material, the plates, and the relative angles thereof. Powder 28 dispensed from the outlet 14 of the hopper 10 accumulates on at least one surface of the bed 20, in this example on first 21 and second 22 sections of the base of the bed 20, which are each arranged at non-horizontal angles underneath the outlet 14. The first and second plates 21, 22 are canted at different angles; in this case, the first plate 21 is canted at a steeper angle than the second plate 22, as best seen in the side view of Figure 4. As the powder 28 accumulates on the first and second plates 21, 22, it is retained on the bed 20 by side wall 25 extending upwards from the first and second plates 21, 22 around a part of the circumference of the bed 20, but in this case, the wall 25 is not entirely continuous around the bed 20, and at one side the bed 20 has an outlet 20o which is not bounded by the wall 25, and at which the powder 28 is free to fall from the bed 20. In this example, the outlet 20o is at the open side of the second plate 22. The first and second plates 21, 22 of the base of the bed 20 are both canted downwards towards the outlet 20o of the bed 20, at different angles. The side walls 25 retain the powder on the bed 20, but at the outlet 20o, the powder is relatively unconstrained and so preferentially falls from the bed 20 at the outlet 20o. By this arrangement the powder 28 accumulating on the bed 20 gradually rises in a mound underneath the outlet 14 until the upper tip of the mound extends into and at least partially occludes the outlet 14 of the hopper 10. As the mound of powder 28 on the bed 20 grows and occludes the outlet 14, it reduces the open surface area of the outlet 14, and resists flow of further powder 28 from the outlet 14. The bed 20 and the hopper 10 generally remain static with respect to one another when powder 28 is supported by the bed 20, so in this phase, with the bed 20 accumulating powder 28 prior to occlusion, or with the outlet 14 blocked by the tip of the mound, the outlet control member does not move relative to the storage chamber or vice versa. When the outlet 14 is to be unblocked, the accumulated powder 28 is disrupted by relative movement of the bed 20 and the hopper 10, and the bed 20 relative to the ground, as will now be described.

[0053] Figure 1 shows the valve assembly 1 connected to a supporting structure comprising a parallel arrangement of rails forming a supporting frame 3, with the inlet 15 connected to a lid 16 covering over the hopper body 11. Here the lid 16 is bolted on to the hopper body 11. Optionally, if cold powder is being flowed into the hopper 10, it is not necessary to include a lid and the hopper 10 can be uncovered. Optionally when the powder is heated, a lid can be used, and optionally the lid can be insulated. The inlet 15 is in the form of a tube or a pipe in this example, which can comprise a straight or an angled connection to the powder input. The powder 28 flows into the hopper 10 via a supply line (not shown) connected to the inlet 15 into the body 11 of the hopper 10 and into a funnelled lower section 12, where at least one (and optionally more than one) of the hopper walls is inclined in a downwards direction, and is optionally generally flat. The funnelled section 12 is in this example a separate section from the body of the hopper 11, connected to the body 11 of the hopper by fixings such as bolts or rivets, but could alternatively be integral with the body 11. The bed 20 is positioned underneath the outlet 14, leaving a clearance between the upper edges of the bed 20 and the lower surfaces of the outlet 14, and provides a surface on which the powder accumulates after falling from the outlet 14. The bed 20 is spaced apart from the outlet 14 to allow the powder to build up into a heap or a mound, and thus the hopper 10 and the bed 20 are not connected.

[0054] In this example, and as best seen in Figure 1, the inlet 15 of the hopper 10 comprises a smaller cross-sectional area than the outlet 14 of the hopper 10. The powder 28 flows from the outlet 14 of the hopper 10 onto the bed 20 under gravity.

[0055] Figure 2 shows the bed 20 comprising a base having flat first plate 21 and flat second plate 22 forming the base of the bed 20. The first plate 21 is generally semicircular, and the second plate 22 is generally trapezoidal, with two parallel sides, the narrower of which transitions into the first plate 21, and the wider of which forms the outlet 20o at the lower side of the bed 20, unconstrained by the wall 25. The base of the bed 20 is inclined downwards relative to a horizontal axis x-x (best seen in Figure 4), at an angle in the range of 10°-20° with respect to the horizontal axis x-x, but the angle can be greater or smaller depending on the type of powder and its frictional coefficients, for example. The angle of the bed 20 with respect to the horizontal plane is usefully less than the angle of repose for the particular powder material. In this example, the angle of repose shown is 30°. The first plate 21 and the second plate 22 of the base of the bed 20 are each inclined at different angles relative to the horizontal axis x-x. The first plate 21 of the bed 20 is inclined at a steeper angle than the second plate 22 relative to the horizontal axis. The transition between the first plate 21 and the second plate 22 is in this example positioned directly underneath the outlet 14 of the hopper 10, optionally slightly off-centre, so that the central vertical axis of the outlet 14 is slightly in front of the transition between the first plate 21 and the second plate 22, closer to the outlet of the relative to the outlet 14, directly above the second plate 22 with the shallower angle. The first plate 21 has a greater surface area than the second plate 22. The wall 25 extends partially around the first 21 and second 22 sections of the base, leaving a space at the outlet 20o of the second plate 22 to form a channel for directing flow of accumulated powder 28 off the bed 20. The channel faces away from the hopper 10 and is adapted to direct the accumulated powder 28 away from the bed 20.

[0056] The bed 20 is connected to a movement device, which in this example comprises an oscillatory device driving the bed 20 in cyclic movements or vibrations, and here comprising a bearing assembly 40, but can instead comprise an air turbine or similar device. On one side of the connection there is a fluid inlet conduit in the form of an air inlet tube 51 which connects to the bearing assembly 40 and flows air into the bearing assembly 40. Any type of industrial air can be used to drive the bearing assembly 40. On the other side, there is optionally an air outlet conduit in the form of a tube 52 through which the air flows out of the bearing assembly 40. This will be discussed in more detail below. The outlet is not essential and can be omitted in some examples. However, it is useful to divert air flow away from the mound of powder on the outlet control member in some examples.

[0057] The hopper 10 is connected to a supportive brace 55, as seen in Figure 3. In this example, the two tubes 51,52 are fixed to the hopper 10 structure, but in other examples, they could alternatively be fixed to another supporting structure. The brace 55 is bolted to the hopper and provides a passageway for the fluid inlet and outlet tubes 51, 52, which are disposed within the brace 55, and pass up the external surface of the rear wall of the hopper 10, where the term "rear" is used here merely for clarity in relation to the drawings. In this example the rear wall of the hopper 10 is vertical for ease of fixing of the hopper 10 to the brace, and the remaining three walls of the funnelled section 12 are inclined downwards.

[0058] The area A circled in Figure 3 is shown close-up in Figure 4. Figure 4 shows a schematic illustration of the accumulation of a mound of powder 28 on the bed 20 and occlusion of the outlet 14 by the mound of powder 28. The powder 28 is funnelled by the funnelled lower section 12 of the hopper 10 out of the hopper 10 via the outlet 14. The clear space between the lower extent of the outlet 14 and the upper extent of the bed 20 allows space for the accumulation of the powder 28 on the bed 20 while the outlet 14 of the hopper 10 is clear. After a given period of time, the accumulated powder 28 builds up sufficiently to begin to occlude or block the outlet 14, and slow down or resist the flow of more powder 28 out of the hopper 10 and onto the bed 20.

[0059] The powder 28 can be heated before it is received by the hopper 10. The energy required for heating the powder 28 can be provided by renewable sources. For example, a photovoltaic system such as a solar array could be used to transfer electrical energy harvested by the array to a heating system. The powder 28 is optionally heated to temperatures of several hundred degrees Celsius, for example around 600°C, although this can be higher or lower depending on the properties of the materials involved. In order to maintain the temperature and to resist loss of heat from the powder 28 into the environment around the hopper 10, the hopper 10 is at least partially insulated. In this example, all walls of the hopper 10 and the lid of the hopper 16 comprise a layer of insulation. The hopper inlet 15 (and any pipes feeding it) can also be at least partly insulated for a portion of its length.

[0060] The bed 20 is connected to the bearing assembly 40 by a fixing which here comprises a nut and bolt 26, which passes through an orifice 49 in the body of the bearing assembly 40 (best seen in Figure 10). In other examples, the bed could be formed integrally with the bearing assembly, or it could be welded to at least a portion of the bearing assembly. The bolt optionally does not protrude into the base of the bed 20, and is instead welded or received into a blind threaded socket on the lower surface of the first portion 21 of the bed 20, thus avoiding interference with the accumulation of the powder 28 on the top of the bed 20 and the subsequent disruption thereof. The bed 20 is thus directly connected to the movement device at one end, by a cantilever connection, and this permits some minor flexing in a vertical direction, amplified by the weight of the powder 28 as it accumulates on the bed 20.

[0061] Optionally the bearing assembly 40 and bed 20 are contained within an outlet compartment that is attached to the lower end of the funnelled section 12 of the hopper 10. In this example, the outlet compartment is in the form of a shroud 18 with an outlet. The outlet here is in the form of an outlet pipe 19 connected to the base of the shroud 18,

however this can be another form of conduit. For example, the shroud could also comprise inclined walls and form a smaller funnel containing the bearing assembly 40 and bed 20. The outlet tube 19 can be angled or can be directed vertically downwards. The outlet tube 19 can extend at least partially into the shroud 18, or can be connected to the external surfaces of the shroud 18, for example by welding or another suitable type of fixing. The shroud 18 is connected to the funnelled section 12 of the hopper 10 with fixings such as bolts, or optionally rivets, or optionally by welding, or optionally another means of attachment. The shroud could be insulated in certain examples.

[0062] Figures 6 and 7 show the bed 20 and shaft assembly 50 comprising the air inlet 51 and outlet 52 tubes without the hopper 10 in place for clarity. The air inlet 51 and outlet 52 tubes can be contained within bores in one or two flexible beams that pass behind the rear wall of the hopper 10. The beams are secured at their top ends by a rigid foundation 57, and at their bottom ends to the movement device. The air inlet 51 and outlet 52 tubes can either be connected to the rest of the air flow conduit through apertures in the beams that permit connection or passage of tubes, or through connection points in the foundation 57. For example, the inlet and outlet tubes 51,52 can be rigidly fixed in a bulkhead fitting. Alternatively, the movement device can be connected to the foundation 57 via flexible beams and the air inlet and outlet tubes can be connected to the beams (e.g. by clips etc.).

[0063] When the outlet of the hopper is occluded by the mound of powder 28 accumulated on the bed 20, and is to be unblocked to resume flow of the powder 28 from the hopper 10, air is flowed through the air inlet tube 51 into the bearing assembly 40. The air moves the bearing eccentrically around the track, which is in a horizontal plane. The eccentric movement of the bearing around the horizontal track causes oscillations in the movement device, which moves cyclically. The cyclic movements are most pronounced (with the highest amplitude) in the horizontal plane parallel to the plane of the track constraining the bearing. These vibrations experienced by the movement device when the air flows are transmitted directly to the bed 20 by the bolt or other fixing between the movement device and the outlet control member, which vibrates the bed 20 back and forth in the horizontal plane as shown in Figure 6, although other planes of vibration can be evident; this will be discussed in greater detail below. Thus, the movement of the outlet control member can be in the form of vibrations. The beam or beams that contain the air inlet and outlet tubes 51, 52 flex with the movement of the movement device and the bed 20. The vibrations are not transmitted to the hopper 10 (or at least are not transmitted at the same intensity), as there is no direct connection between the movement device and the hopper 10. The cantilever connection of the movement device and bed 20 to the ends of the beams allows free cyclic oscillatory movement of the bed 20 in concert with the vibrations of the movement device.

[0064] The vibration of the bed 20 relative to the more static hopper 10 disrupts the stacked configuration of the accumulated powder 28, causing a collapse of the powder mound on the bed 20, as the grains of powder in the mound experience less friction tending to retain the structure of the mound. The grains of powder 28 that are liberated by the vibrations of the bed 20 fall under gravity towards the outlet 20o, and eventually some will drop off the edge of the bed 20. The collapse of the powder mound clears the occlusion of the outlet 14 and, if there is powder remaining within the hopper 10, resumes powder flow onto the bed 20. The outlet 14 can thus be occluded and cleared by switching the bed 20 and the hopper 10 between different states of relative movement, i.e. by switching on and off the movement device to vibrate the bed 20 relative to the hopper 10. The movement device is thus adapted to optionally move the outlet control member cyclically when the valve is unblocked, and optionally the cessation of the cyclic movement leads to occlusion of the valve by accumulated powder while the outlet control member is static. More cohesive powder types require greater vibrational displacement of the plate in order to encourage flow of the powder over the bed. The vibrational power of the bearing assembly is related to the displacement amplitude and the oscillating frequency of the assembly. The frequency of oscillation of the bearing may be adjusted according to the type of powder that is being flowed, to improve the flow performance, for example by reducing compaction of the powder on the plate.

[0065] Figures 8-10 show the bearing assembly 40, comprising a bearing 41 restrained in a circular race 42. The air inlet tube 51 is inserted into an inlet channel 51 a, which comprises a tangential port 44. The tangential port 44 is configured to direct the flow of air from the air inlet tube 51 into the bearing race 42, and thus drive the movement of the bearing 41 around the race 42 on an eccentric path. Optionally the bearing track can be circular, but in some examples, the track can be elliptical, to enhance the eccentric movement of the movement device. In this case the track is disposed in a horizontal plane, which amplifies the vibrations in parallel planes. On the opposite side of the bearing assembly 40, the air outlet tube 52 is also connected to the bearing assembly 40 by insertion into an outlet channel 52a, which comprises a port 48 disposed perpendicularly to the bearing assembly 40, and through which air flows out of the bearing assembly 40. The air inlet 51 and outlet 52 tubes can be inserted into the bearing assembly 40 in different locations as required.

[0066] The bearing assembly 40 comprises an outlet air manifold 46, in this example a circular cavity forming a substantially separate layer of the bearing assembly 40 while remaining in fluid communication with the bearing race 42. The manifold 46 includes apertures 47 which permit the flow of air out of the bearing race 42, and through the outlet port 48. The outlet port 48 is connected to the manifold 46, and not to the race 42, while the inlet port 44 is connected to the race 42 and not to the manifold 46.

[0067] When it is desirable to unblock the outlet 14 of the hopper 10, the air flow pathway is opened and air begins to

flow into the bearing race 42. The bearing 41 is driven around the race 42, and as the bearing 41 picks up speed, the vibration of the bed 20 intensifies and collapses the pile of powder 28 on the bed 20. The movement of the bearing 41 is cyclic, oscillatory, and due to the angle of the tangential port 44, eccentric, i.e. larger in one direction, so that the bed 20 moves substantially backwards and forwards in a shallow arc determined by the length of the tubes 51, 52. The oscillatory movement can be in a different arc, or in a single plane in other examples. The hopper 10, and optionally the shroud 18, remains static as the bed 20 moves.

[0068] Optionally air flowing through the air inlet 51 and outlet 52 tubes and through the bearing assembly 40 is heated, for example, by the heat from the hot powder. Optionally, the beam through which the air inlet 51 and outlet 52 tubes pass behind the hopper 10 is insulated, and optionally the portion of the rear wall of the hopper 10 that is proximal to the air inlet 51 and outlet 52 tubes is not insulated, to allow heat to flow towards the tubes 51,52 from the powder. The shroud 18 containing the bearing assembly 40 and the bed 20 is optionally insulated to retain heat and resist heat loss from the powder. The accumulation of hot powder in the bed 20 raises the ambient temperature within the shroud 18, optionally to several hundred degrees Celsius. Heat is absorbed by the inflowing air, and as the bearing assembly 40 is also within the hot inner cavity of the shroud 18, the temperature of the air within the bearing assembly 40 is maintained.

[0069] The air inlet and outlet tubes 51, 52 are connected to a heat exchanger 60 as shown in Figure 11. The heated air then passes out of the bearing assembly 40, through the air outlet tube 52, and into the heat exchanger 60. The heat exchanger 60 comprises at least one cool air intake. The heat exchanger 60 comprises at least two separate air flow layers 61, 62, with the hot air from the bearing assembly outlet tube 52 flowing through one layer 61, and the cooler input air flowing into the bearing assembly 40 flowing through the other layer 62. As the cooler air being directed to the bearing assembly 40 passes through the heat exchanger 60, at least a portion of the heat from the hot air stream is transferred to the cooler air, creating two separate warm air streams as best shown in Figure 11. One warm air stream is returned to the valve assembly 1 for input into the bearing assembly 40, where it is again heated by the hot powder, and the other warm air stream returning from the bearing assembly 40 is output from the heat exchanger 60 for use elsewhere. Examples of uses for the warm air stream from the heat exchanger 60 include powering a heat engine such as a Stirling engine, or heating water to create steam, optionally again to power an engine device.

[0070] Pre-heating the air before injecting it to the bearing assembly 40 results in less thermal energy being removed from the particulate material on the outlet control member in order to heat the incoming air powering the bearing assembly 40, meaning that the temperature of the powder and the system overall can be more efficiently maintained at the desired level.

[0071] Figures 12-18 show some further examples of the outlet control member. In each separate example, the reference numbers are increased by 100. The rest of the features of the following examples remain as described above, and for the sake of conciseness, the descriptions will not be repeated here; however, any of the following examples of outlet control member could be used in any of the preceding examples, and features of the preceding examples can be combined with any of the following examples of outlet control member, hence combinations thereof are specifically contemplated by the present disclosure.

[0072] Figure 12 shows an example of a valve assembly 101 in which the drawing is simplified to remove other features, but which shares some or all of the features of the previous examples. In the present example, the valve assembly 101 includes an outlet control member in the form of bed 120 disposed below the outlet of hopper funnel 112. Bed 120 is flat and in line with the horizontal axis x-x. Powder exits the outlet of the hopper funnel 112 and is received by the bed 120. The mound of powder 128 accumulated on the bed 120 is occluding the outlet of the hopper and is heaped on the bed 120. The edges of the powder 128 have an angle of repose of 30°, and the mound of powder stops just before the edges of the bed. In this example there is a spacing of approximately 5mm between the edge of the bed and the edge of the mound of powder, which stops the powder from falling from the outlet control member when the outlet to the storage chamber is occluded. The bed 120 does not have any surrounding walls. When the bed 120 is vibrated, powder falls from the full perimeter of the bed 120.

[0073] Figure 13 shows a further example of a valve assembly 201 in which the drawing is simplified to remove other features, but which shares some or all of the features of the previous examples with corresponding reference numbers prefixed by 2. The valve assembly 201 comprises an alternative outlet control member in the form of a flat bed 220, inclined downwards at an angle relative to the horizontal axis x-x. The angle of inclination can be between 0°-90°, optionally 10°-20°, to facilitate powder run-off. In this example, the bed 220 is angled at 15°. The bed 220 does not comprise walls, and thus powder can flow off both at the lower end of the bed 220 and from the sides when the mound of powder 228 is disrupted. In this example, the mound of powder is on the tipping point of collapse due to the angle of repose relative to the inclination of the bed 220 and the mass of the powder 228 on the bed 220. Any vibration of the bed 220 results in significant flow of powder off the bed 220.

[0074] Inclining the bed 220 offers the advantage that resistance to flow of the powder is lowered due to the inclination of the bed 220, and any movement of the bed, for example the vibration from the bearing assembly, results in an "avalanche" effect, giving rise to high powder flow relative to the energy expended.

[0075] Figure 14 shows a further example of a valve assembly 301 in which the drawing is simplified to remove other

features, but which shares some or all of the features of the previous examples with corresponding reference numbers prefixed by 3. The valve assembly 301 comprises an alternative outlet control member in the form of a convex example of a bed 320, with a first plate 321 and a second plate 322 joined at an interface that is centrally disposed under the outlet of the hopper funnel 312. Both the first plate 321 and the second plate 322 are inclined downwards relative to the horizontal axis x-x. The angle of repose in this case (α as indicated in Figure 19) is again 30°.The first plate 321 is inclined at a shallower angle than the second plate 322 relative to the axis x-x, thus creating a shallow apex at the interface between the plates, and therefore an overall convex shape. Bed 320 comprises a wall along one end of the first plate 321, which prevents powder run-off towards the rear of the bed 320, and instead directs the flow of powder off the lowest edge of the bed 320. The convex nature of the bed 320 reduces the mass of powder that is retained before the outlet is obstructed, which in turn means that a larger amplitude of vibration of the bed can be achieved for a given vibrational power exerted by the movement device. This design may be more suitable for powder with a higher frictional coefficient that is more cohesive or prone to accumulation in clumps and less adapted to flow from the bed 320.

[0076] An example of an alternative outlet control member in the form of a bed with a plurality of vertically stacked plates is shown in Figures 15-18, with features in common with previous examples prefixed by 4. In this example, there is a top plate 420t, comprising an aperture 420a that is centrally disposed beneath the outlet of the hopper funnel 412. This top plate 420t comprises an extension that is adapted to sit above the bearing assembly 440. The top plate 420t comprises two pairs of legs 471, 472. The legs 471 extend on either side of the stack of plates 420p, while the legs 472 extend on either side of the bearing assembly 440. At the end of each leg is a threaded hole for passing through a bolt or other fixing. The top plate 420t is bolted onto a base plate 420b, enclosing and securing the stack of plates 420p and the bearing assembly 440 together, as best shown in Figure 18. The base plate 420b in this example is flat, however it can take a conical or otherwise convex form in order to further reduce the mass of powder that is accumulated on it, and subsequently on the arrangement of plates as a whole.

[0077] The plates 420p each comprise a central aperture 420a aligned with the aperture in the top plate 420t and with the outlet of the hopper through which powder can flow from the hopper funnel 412 to the base plate 420b. As the powder builds up on the base plate 420b, it forms a mound with an apex and adopting a resting angle of repose of 30°. The resulting mound of powder obturates the aperture 420a of the next plate, and flows over onto the upper surface of each successive plate 420p, so that each of the plates 420p in the stack gradually accumulates a mound of powder on the surface area of the plate 420p between its aperture 420a and its outer perimeter, and accommodates the central mound within the aperture 420a. As powder continues to flow from the hopper, the mound of powder 428 increases in height and obturates each aperture 420a of each plate 420p in turn until it reaches and blocks the outlet 414 of the hopper.

[0078] The mound of powder 428 remains at rest and in a stable configuration close to the edge of each plate 420p, 420b, with a gap of approximately 5mm between the perimeter of each plate 420p, 420b, and the edge of the mounds of powder, with an angle of repose of 30°, until the outlet control member is vibrated by input of air or another fluid, for example nitrogen or steam, into the bearing assembly 440, transmitting vibrations along the plates 420p into different parts of the mound of powder 428. As none of the plates 420p have any walls around their perimeters, powder can flow from all points around the perimeter of the plates 420p, 420b, 420t. As the edges of the mound of powder are close to the edges of each of the plates, flow of powder occurs rapidly from each plate after disruption of the mound of powder by vibrations from the bearing assembly. Thus, the stacked arrangement of multiple plates allows faster run-off of powder from the outlet control member.

[0079] The angle of repose of the particulate material is dependent on various parameters of the material and the system, for example, frictional coefficient of the powder, mass of the powder, particle size, homo- or heterogeneity of the particle sizes etc. The angle of the base of the bed (20,120,220,320,420) is usefully less than the corresponding angle of repose for the particular powder material, so that the sides of the mound build up at a steeper angle than the base of the bed ; for example, a powder with good flowability may exhibit an angle of repose of less than 40° and a compressibility index of 1.0-1.25, and the valve may operate satisfactorily with a bed (20,120,220,320,420) that is inclined at an angle in the range of 0°-30°. A powder with fair-poor flowability may exhibit an angle of repose of 40°-55°, with a compressibility index of 1.25-1.5, and the valve may then operate with a bed (20,120,220,320,420) that is inclined at an angle in the range of 30°-40° to the horizontal axis x-x.

[0080] The arrangement of the bed 420 with the plurality of plates 420p with central apertures 420a offers a greater flow area with a smaller mass of powder around the edges of each plate 420p acting to restrict flow of powder disposed further towards the centre of the bed 420. The total mass of powder 428 accumulated on the bed 420 may optionally be equal to or optionally greater than the total mass accumulated on one of the other examples of the apparatus (20,120,220,320), however, as this mass is distributed across multiple plates 420p, this reduces the resistance of the powder to disruption and flow off each plate 420p. This offers the advantage that for an equivalent mass of powder, lower vibrational power is required to disrupt the accumulated material. As lower power is required, this results in rapid flow of powder from the outlet control member, yet low consumption of energy.

[0081] The type of bed to be used can be selected according to the characteristics of the powder to be flowed through the valve assembly, for example the flowability and the cohesiveness of the powder. A single inclined plate may be

better suited to a powder with poor flowability and cohesiveness, as the distance between the plate and the hopper can be selected accordingly. The plurality of plates 420p may be better suited to a powder with excellent flowability and no cohesiveness, as this arrangement 420 benefits from a greater curtain area and compact configuration.

[0082] Table 1 shows a comparison of some parameters of the examples of the outlet control members in the form of beds (120,220,320,420) shown in Figures 12-15. This shows the "curtain area" in mm^2, and the ratio of the curtain area to the area of the hopper outlet. In this example, the hopper outlet is square with sides of 40mm, therefore it has an area of $1600mm^2$. It should be understood that the curtain area is applicable for any dimension or shape of outlet and these examples are not limiting.

[0083] The curtain area refers to the window that is created by the distance between the bed (20,120,220,320,420) and the hopper outlet (14,114,214,314,414) when the powder is flowing, e.g. when the bearing assembly sets up vibrations in the bed that clear the hopper outlet and recommence flow of the powder. Effectively, the curtain area can be imagined as the area that a flat curtain would have if it were dropped from the perimeter of the hopper outlet down to the bed.

[0084] In these examples, the hopper aperture is square, and thus $l_1 = l_2 = l_3 = l_4 = l$. Thus, the simplest example of the curtain area can be calculated using the arrangement shown in Figure 12, where the distance d, or "lift", from the bed 120 to the hopper outlet 114 is constant across the bed 120. In this case:

$$\text{Curtain Area (Fig 12)} = 4 \times d \times l$$

[0085] For the parameters given in this example, d = 10mm, l = 40mm and thus the curtain area = $4 \times 10 \times 40 = 1600mm^2$.

[0086] This can effectively be extrapolated for the other examples of the bed and hopper outlet. For example, the example illustrated in Figure 15 with multiple plates is merely the above equation for a single plate, multiplied by the number of plates n in the arrangement:

$$\text{Curtain Area (Fig 15)} = 4 \times n \times d \times l$$

[0087] For the parameters in this example, d = 10mm, l = 40mm, n = 6, therefore the curtain area = $4 \times 6 \times 10 \times 40 = 4800mm^2$.

[0088] Where there is an inclined bed as in Figure 13, there are three different values of lift; a small one (i.e. d_1) where the bed is nearest the outlet, a large one (i.e. d_2) where the bed is inclined furthest away from the outlet, and two equally continuously changing distances on either side of the hopper perpendicular to both d_1 and d_2 (i.e. d_3). In this case, the average distance or lift between d_1 and d_2, $\langle d_3 \rangle$, can be used, giving the equation:

$$\text{Curtain Area (Figure 13)} = (2 \times (\langle d_3 \rangle \times l)) + (d_1 \times l) + (d_2 \times l)$$

[0089] Taking Figure 13 as an example, d1 = 10mm, d2 = 20.7mm $\langle d_3 \rangle = \frac{1}{2}(d_1 + d_2) = 15.35mm$; l = 40mm, thus:

$$\text{Curtain area (Figure 13)} = (2 \times (15.35 \times 40)) + (10 \times 40) + (20.7 \times 40)$$
$$= 1228 + 400 + 828 = 2456mm^2$$

[0090] In the example given in Figure 14, the curtain area is illustrated in Figure 19. There are four separate area calculations to be performed, which are then combined in order to calculate the curtain area.

[0091] In the example shown in Figure 14 with dimensions illustrated in Figure 19, there are three different values of lift; a small one (i.e. d_1) where the bed is nearest the outlet, a large one (i.e. d_2) where the bed is inclined furthest away from the outlet, and one at the point of intersection of the two plates (d_3).

$$d_3 = d_1 + l_3 \times \tan(\theta)$$

$$d_2 = d_3 + (l_1 - l_3) \times \tan(\varphi)$$

[0092] There are similarly three different length dimensions; l_1, l_2, and l_3. In this example, as the outlet is square, $l_1 = l_2$, and $l_3 = 0.5 \times l_1$. However this relationship is not restrictive and is merely exemplary.

[0093] Calculating each curtain area in turn:

$$\text{Area A} = d_1 \times l_3 + \tfrac{1}{2} \times l_3^2 \times \tan(\theta)$$

$$\text{Area B} = (d_1 + (l_3 \times \tan(\theta)))x(l_1-l_3) + \tfrac{1}{2} \times (l_1 - l_3)^2 \times \tan(\varphi)$$

$$\text{Area C} = d_2 \times l_2$$

$$\text{Area D} = d_1 \times l_2$$

[0094] Combining the calculated values for these areas into a formula for the total curtain area:

$$\text{Total Curtain Area} = 2(A+B) + C + D$$

[0095] An exemplary calculation for the curtain area illustrated in Figure 19 is as follows, where l_1 = 40mm; l_2 = 40mm; l_3 = 20mm; d_1 = 10mm; θ = 7.5°; and φ = 15°.

$$\text{Thus} \quad d_3 = d_1 + l_3 \times \tan(\theta) = 10 + 20 \times \tan(7.5^\circ) = 12.63\text{mm}$$

and

$$d_2 = d_3 + (l_1 - l_3) \times \tan(\varphi) = 12.63 + (40\text{-}20) \times \tan(15^\circ) = 17.99\text{mm}$$

$$\text{Area A} = d_1 \times l_3 + \tfrac{1}{2} \times l_3^2 \times \tan(\theta) = 10 \times 20 + \tfrac{1}{2} \times 20^2 \times \tan(7.5^\circ) = 226.3\text{mm}^2$$

$$\text{Area B} = (d_1 + (l_3 \times \tan(\theta)))x(l_1-l_3) + \tfrac{1}{2} \times (l_1 - l_3)^2 \times \tan(\varphi)$$
$$= (10 + (20 \times \tan(7.5^\circ)))x(40\text{-}20) + \tfrac{1}{2} \times (40 - 20)^2 \times \tan(15^\circ) = 306.3\text{mm}^2$$

$$\text{Area C} = d_2 \times l_2 = 17.99 \times 40 = 719.6\text{mm}^2$$

$$\text{Area D} = d_1 \times l_2 = 10 \times 40 = 400\text{mm}^2$$

[0096] The total curtain area for these exemplary dimensions for the example shown in Figure 19 is therefore:

$$\text{Total Curtain Area (Fig 19)} = 2(A+B) + C + D$$
$$= 2(226.3 + 306.3) + 719.6 + 400 = 2184.8\ \text{mm}^2$$

[0097] Increasing the curtain area of the valve allows faster flow through the valve when the valve is unblocked. The curtain area can be adjusted to account for desired flow rates and flow characteristics of the particulate material and particle size. For example, a small curtain area would suffice for a free-flowing powder. A smaller curtain area in this example would also permit rapid closure of the outlet when required. If the outlet control member was located too far away from the outlet, it could be the case that the powder would not stack sufficiently well to reach the outlet to occlude it, and would instead be prone to flowing off the sides of the mound of powder. For example, the mound of powder may

not achieve the exemplary 5mm border around the perimeter of the surface of the outlet control member. This can be overcome by increasing the size of the plate or plates forming the base of the outlet control member, offering a greater cross-sectional area for the powder to accumulate on.

[0098] However for e.g. cohesive aggregate, which comprises larger clumps and may not flow so freely, a larger curtain area may be advantageous to encourage flow of the particulate material when the valve is unblocked. This would allow stacking of the particulate material to occlude the valve, while providing enough space for the material to flow. Spacing the outlet control member too close to the outlet, in this example, could result in difficulties in unblocking the valve.

[0099] It is therefore understood that the curtain area can optionally be adjusted to account for the outlet shape, the inclination of the outlet control member, and the type of particulate material that will be flowed through the valve.

[0100] In one example of a practical application for the valve assembly particulate material in the form of sand is heated directly by solar energy in a concentrated solar power system having mirrors or lenses to concentrate solar energy on a small area such as a section of a conveyor belt conveying the sand. The concentrated solar energy heats up the sand prior to passage of the sand through the valve assembly, which is used to control the distribution of the hot sand, and to rout it to a heat engine such as a steam turbine, to recover heat from the hot sand, which functions as a medium for the transfer of renewable heat energy from the concentrated solar power system to the heat exchanger for recovery of the heat energy.

Table 1: A comparison of exemplary parameters for the examples of the apparatus given in Figures 12-15

Comparison of Examples		
Type	Curtain Area (mm^2)	Ratio Curtain/Hopper outlet
Flat Plate (Figure 12)	1600	1.00
Inclined Plate (Figure 13)	2456	1.56
Convex Inclined Plate (Figure 14)	2178	1.36
Stacked Plates (Figure 15)	4800	3.00
Hopper (10) outlet area = 40 x 40 = 1600 mm^2		
Curtain area indicates the flow area available to the powder travelling away from beneath the hopper outlet		

Claims

1. A valve assembly for controlling flow of particulate material (28, 128, 228, 328, 428), the valve assembly (1, 101, 201, 301, 401) having a storage chamber (10) adapted to retain particulate material (28, 128, 228, 328, 428), said storage chamber (10) having an inlet (15) to receive particulate material (28, 128, 228, 328, 428) and an outlet (14, 114, 214, 314, 414) to dispense the particulate material (28, 128, 228, 328, 428) from the storage chamber (10); wherein the valve assembly (1, 101, 201, 301, 401) comprises an outlet control member (20, 120, 220, 320, 420) adapted to receive and retain particulate material (28, 128, 228, 328, 428) dispensed from the outlet (14, 114, 214, 314, 414) of the storage chamber (10), said outlet control member (20, 120, 220, 320, 420) being spaced apart from the outlet (14, 114, 214, 314, 414) of the storage chamber (10); wherein particulate material (28, 128, 228, 328, 428) dispensed from the outlet (14, 114, 214, 314, 414) of the storage chamber (10) is adapted to accumulate on at least one surface of the outlet control member (20, 120, 220, 320, 420) and to at least partially block the outlet (14, 114, 214, 314, 414) of the storage chamber (10), resisting flow of particulate material (28, 128, 228, 328, 428) from the outlet (14, 114, 214, 314, 414); wherein the outlet control member (20, 120, 220, 320, 420) and the storage chamber (10) are movable relative to one another to disrupt accumulated particulate material (28, 128, 228, 328, 428) on the outlet control member (20, 120, 220, 320, 420) and unblock the outlet (14, 114, 214, 314, 414) of the storage chamber (10).

2. A valve assembly as claimed in claim 1, wherein at least a portion of the outlet control member (20, 120, 220, 320, 420) is disposed beneath the outlet (14, 114, 214, 314, 414) of the storage chamber (10).

3. A valve assembly as claimed in claim 1 or claim 2, wherein the outlet control member (20, 120, 220, 320, 420) is disposed within a shroud (18) connected to the storage chamber, wherein the shroud (18) is connected to the lower portion of the storage chamber (10); wherein the shroud (18) comprises an outlet tube (19) for dispensing particulate material (28, 128, 228, 328, 428) that has been disrupted and fallen from the outlet control member (20, 120, 220, 320, 420) as a result of relative movement of the outlet control member (20, 120, 220, 320, 420) and the storage

chamber (10).

4. A valve assembly as claimed in any one of claims 1-3, the outlet control member (20, 120, 220, 320, 420) having a base wherein at least a portion of the base of the outlet control member (20, 120, 220, 320, 420) comprises at least one plate, wherein at least a portion of the base of the outlet control member (20, 120, 220, 320, 420) is aligned parallel to a horizontal axis.

5. A valve assembly as claimed in claim 4, wherein at least a portion of the base of the outlet control member (20, 120, 220, 320, 420) is inclined relative to a horizontal axis.

6. A valve assembly as claimed in claim 5, wherein the outlet control member (420) comprises a plurality of plates (420p, 420t, 420b), wherein the plurality of plates (420p, 420t, 420b) are vertically stacked in a parallel arrangement relative to each other, and wherein at least one plate (420p, 420t) comprises an aperture (420a) through which particulate material (428) can pass, when said particulate material (428) is dispensed from the outlet (414) of the storage chamber; wherein said particulate material (428) flows from the outlet (414) of the storage chamber through the apertures (420a) in the plates (420p, 420t) under gravity; and wherein at least one plate (420b) is a solid plate with no aperture, wherein said solid plate (420b) is adapted to be a base plate, and wherein the base plate (420b) is adapted to initiate accumulation of particulate material (428) within the stack of plates (420p, 420t, 420b) as particulate material (428) flows through the apertures (420a) of the plates (420t, 420p) disposed proximal to the storage chamber.

7. A valve assembly as claimed in any one of claims 1-6, wherein the spacing between the outlet control member (20, 120, 220, 320, 420) and the outlet (14, 114, 214, 314, 414) of the storage chamber (10) creates a curtain area, wherein the curtain area is the vertical two-dimensional area defined in a first plane by the perimeter of the outlet (14, 114, 214, 314, 414), and in a second plane by the distance between the outlet control member (20, 120, 220, 320, 420) and the outlet (14, 114, 214, 314, 414), wherein the second plane is perpendicular to the first plane, wherein when the valve outlet (14, 114, 214, 314, 414) is unblocked, the dimensions of the curtain area at least partially influence the rate of flow of particulate material (28, 128, 228, 328, 428) through the valve outlet (14, 114, 214, 314, 414).

8. A valve assembly as claimed in any one of claims 1-7, wherein the (20, 120, 220, 320) outlet control member comprises a first section (21, 321) and a second section (22, 322), wherein the first (21, 321) and second (22, 322) sections are inclined at different angles relative to a horizontal axis; wherein the first section (21, 321) of the outlet control member (20, 120, 220, 320) forms a connection with at least one shaft (50) of the valve, wherein the connection comprises a cantilever connection, and wherein the second section (22, 322) of the outlet control member (20, 120, 220, 320) is connected only to the first section (21, 321) of the outlet control member (20, 120,220,320).

9. A valve assembly as claimed in claim 8, wherein the interface between the first (21, 321) and second (22, 322) sections of the outlet control member (20, 120, 220, 320) is disposed beneath the outlet (14, 314) of the storage chamber (10).

10. A valve assembly as claimed in claim 8 or claim 9, wherein the second section (22, 322) of the outlet control member (20, 120, 220, 320) has a greater surface area than the first section (21, 321) of the outlet control member (20, 120, 220, 320).

11. A valve assembly as claimed in any one of claims 1-10, comprising at least one movement device (40, 440) adapted to cyclically move one of the outlet control member (20, 120, 220, 320, 420) and the storage chamber (10) and disrupt accumulated particulate material (28, 128, 228, 328, 428).

12. A valve assembly as claimed in claim 11, wherein the movement of the movement device (40, 440) causes a corresponding vibration of the outlet control member (20, 120, 220, 320, 420) and/or the storage chamber (10).

13. A valve assembly as claimed in claim 11 or claim 12, wherein the movement device (40, 440) comprises at least one bearing (41) contained within a race (42), forming a bearing assembly (40, 440), wherein the bearing assembly (40, 440) comprises an inlet (51) and outlet (52) adapted to provide a flow of fluid within the bearing assembly (40, 440), wherein the flow of fluid moves the bearing (41) rotationally in the race (42), wherein rotational movement of the bearing (41) in the race (42) causes cyclic rotational movement of the bearing assembly (40, 440), and wherein the fluid passing into the bearing assembly (40, 440) is heated and heat is extracted from fluid passing out of the

bearing assembly (40, 440).

14. A method of controlling flow of particulate material (28, 128, 228, 328, 428) through a valve assembly (1, 101, 201, 301, 401), the method including flowing the particulate material (28, 128, 228, 328, 428) into a storage chamber (10) through an inlet (15) formed in said storage chamber (10), wherein the storage chamber (10) is adapted to retain particulate material (28, 128, 228, 328, 428); dispensing the particulate material (28, 128, 228, 328, 428) from the storage chamber (10) through an outlet (14, 114, 214, 314, 414) formed in the storage chamber (10) onto an outlet control member (20, 120, 220, 320, 420) adapted to receive and retain particulate material (28, 128, 228, 328, 428), the outlet control member (20, 120, 220, 320, 420) being spaced apart from the outlet (14, 114, 214, 314, 414) of the storage chamber (10); accumulating particulate material (28, 128, 228, 328, 428) on at least one surface of the outlet control member (20, 120, 220, 320, 420); and at least partially blocking the outlet (14, 114, 214, 314, 414) of the storage chamber (10) with particulate material (28, 128, 228, 328, 428) that has accumulated on at least one surface of the outlet control member (20, 120, 220, 320, 420); wherein the method includes moving one of the outlet control member (20, 120, 220, 320, 420) and the storage chamber (10) relative to the other to disrupt accumulated particulate material (28, 128, 228, 328, 428) on the outlet control member (20, 120, 220, 320, 420) and unblock the outlet (14, 114, 214, 314, 414) of the storage chamber (10).

15. A method as claimed in claim 14, including heating the particulate material (28, 128, 228, 328, 428) before said particulate material (28, 128, 228, 328, 428) is received in the storage chamber (10).

16. A method as claimed in claim 14 or claim 15, including connecting at least one of the storage chamber (10) and the outlet control member (20, 120, 220, 320, 420) to a shaft (50), wherein the shaft (50) is connected to at least one movement device (40, 440), and including flowing fluid into an inlet (51) in the movement device (40, 440), and out of an outlet (52) in the movement device (40, 440), wherein the movement device (40, 440) comprises a bearing (41) on a race (42), and wherein the fluid flow within the movement device (40, 440) moves the bearing (41) around the race (42).

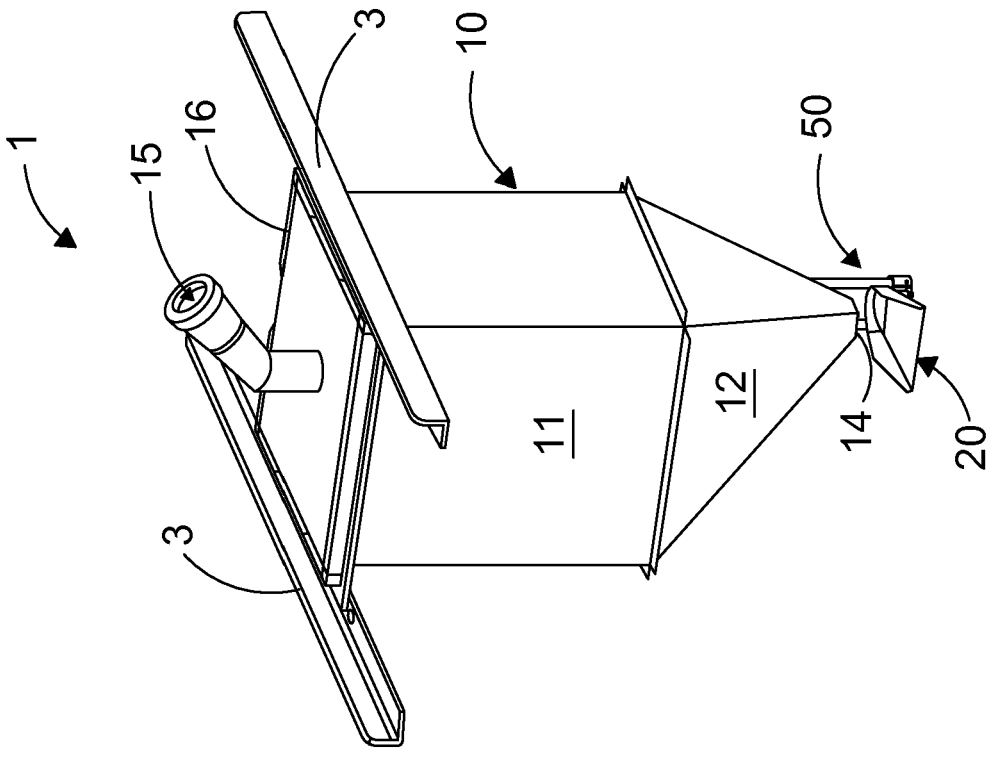


FIG. 1

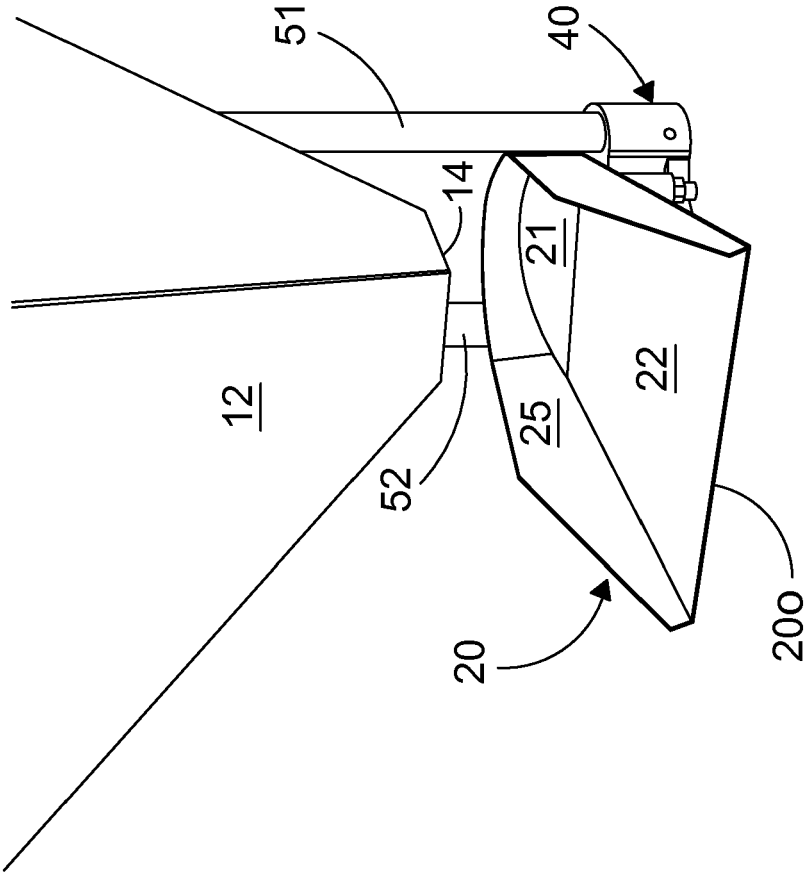


FIG. 2

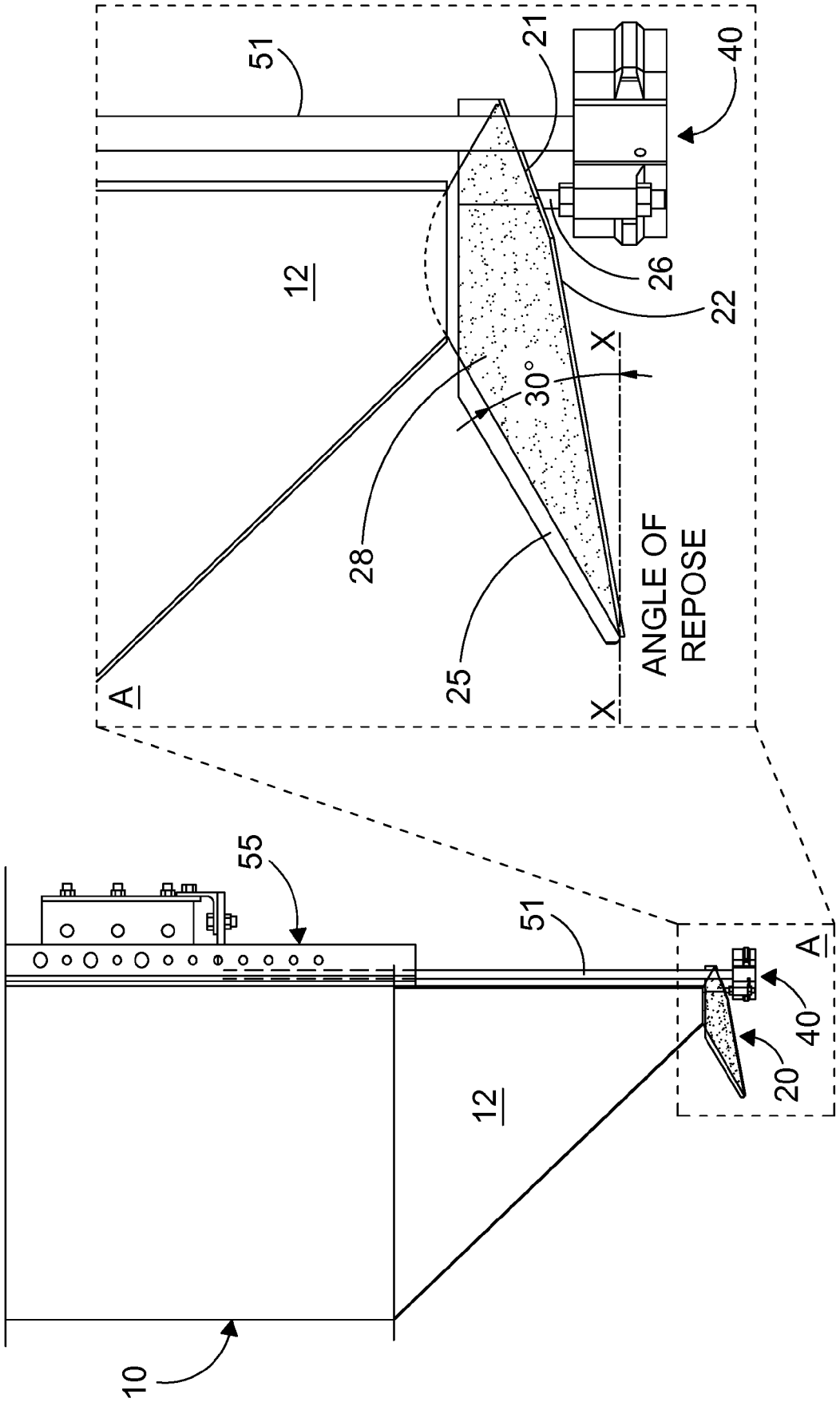


FIG. 4

FIG. 3

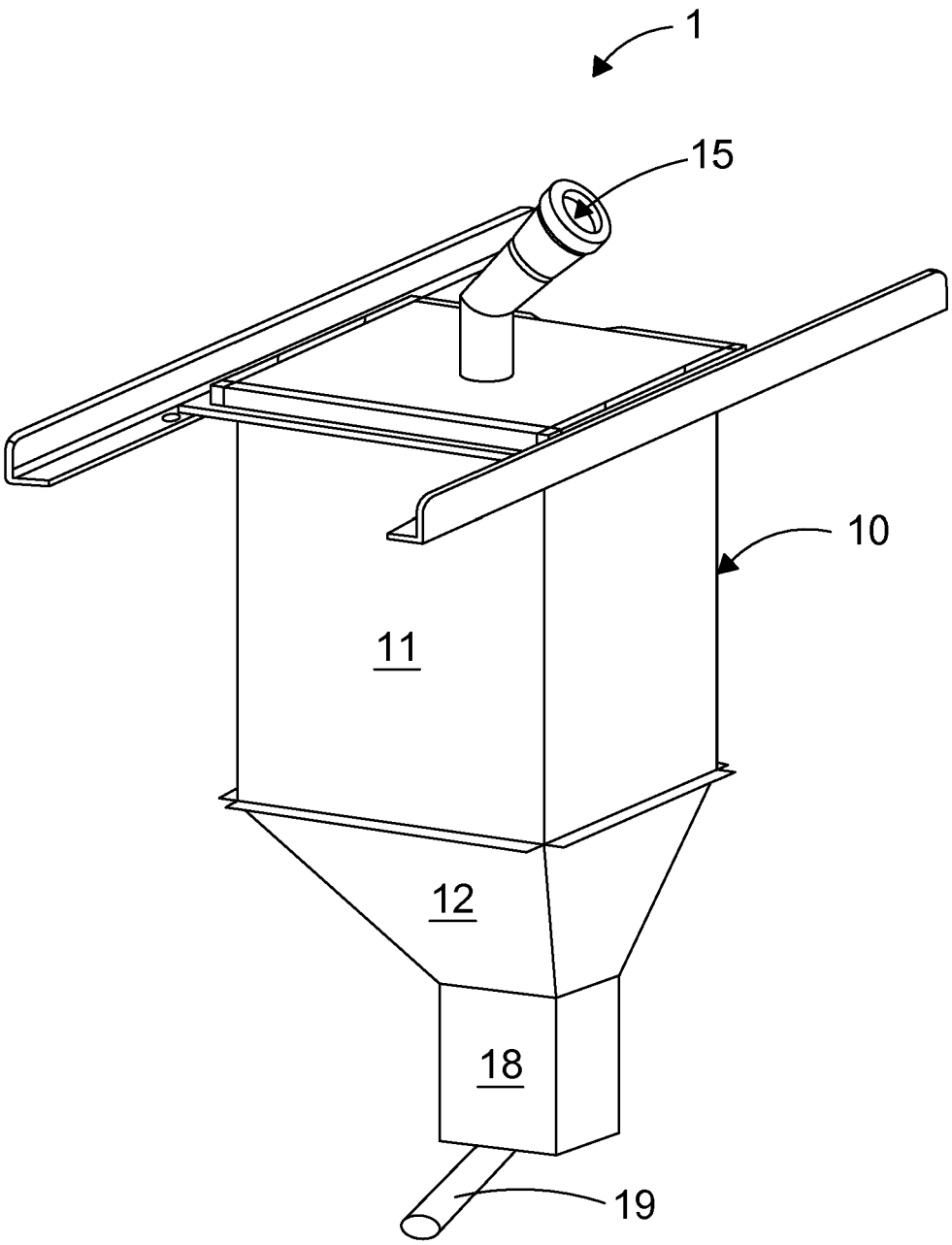


FIG. 5

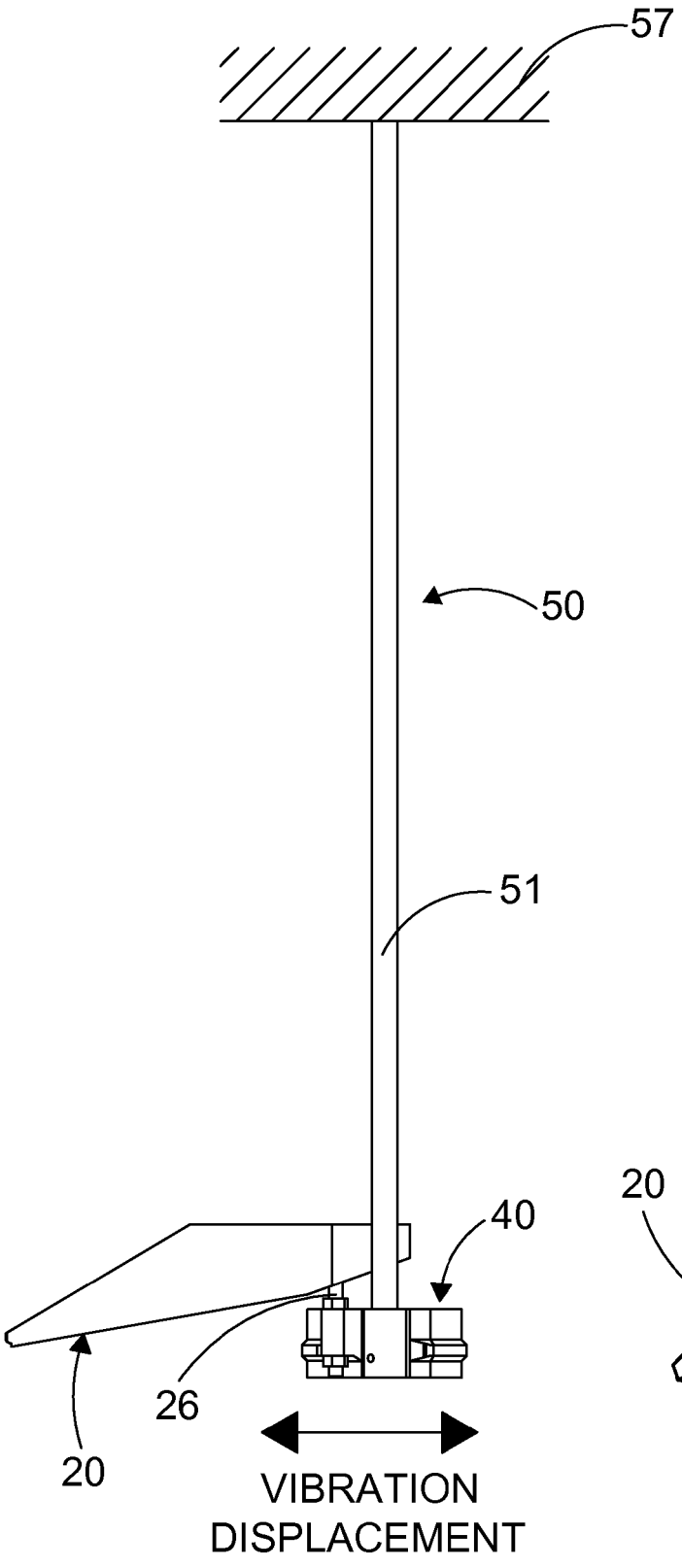


FIG. 6

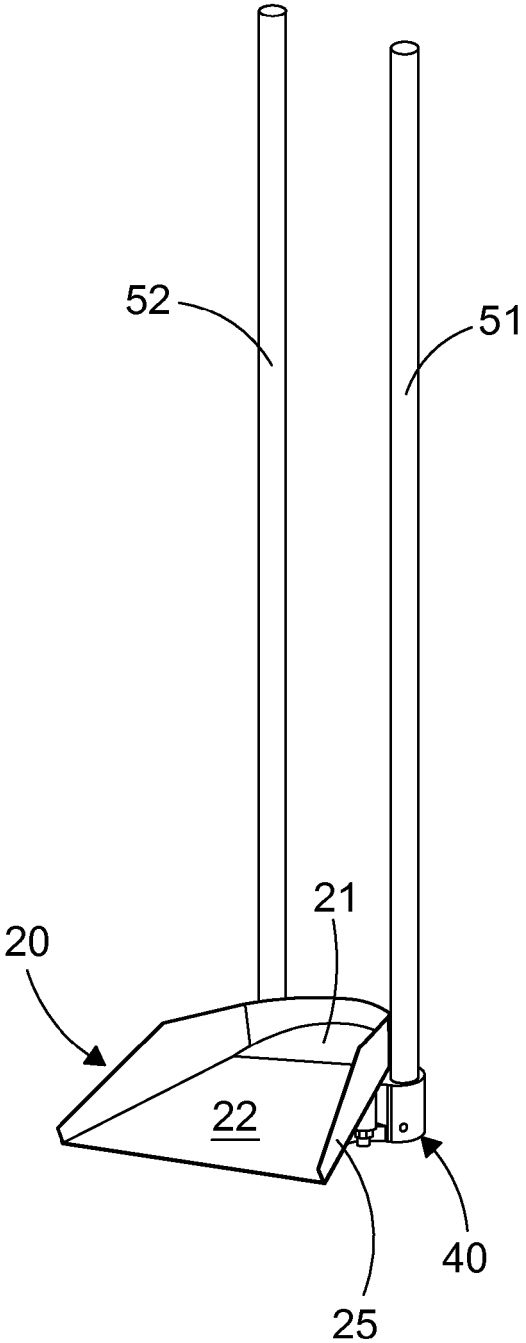


FIG. 7

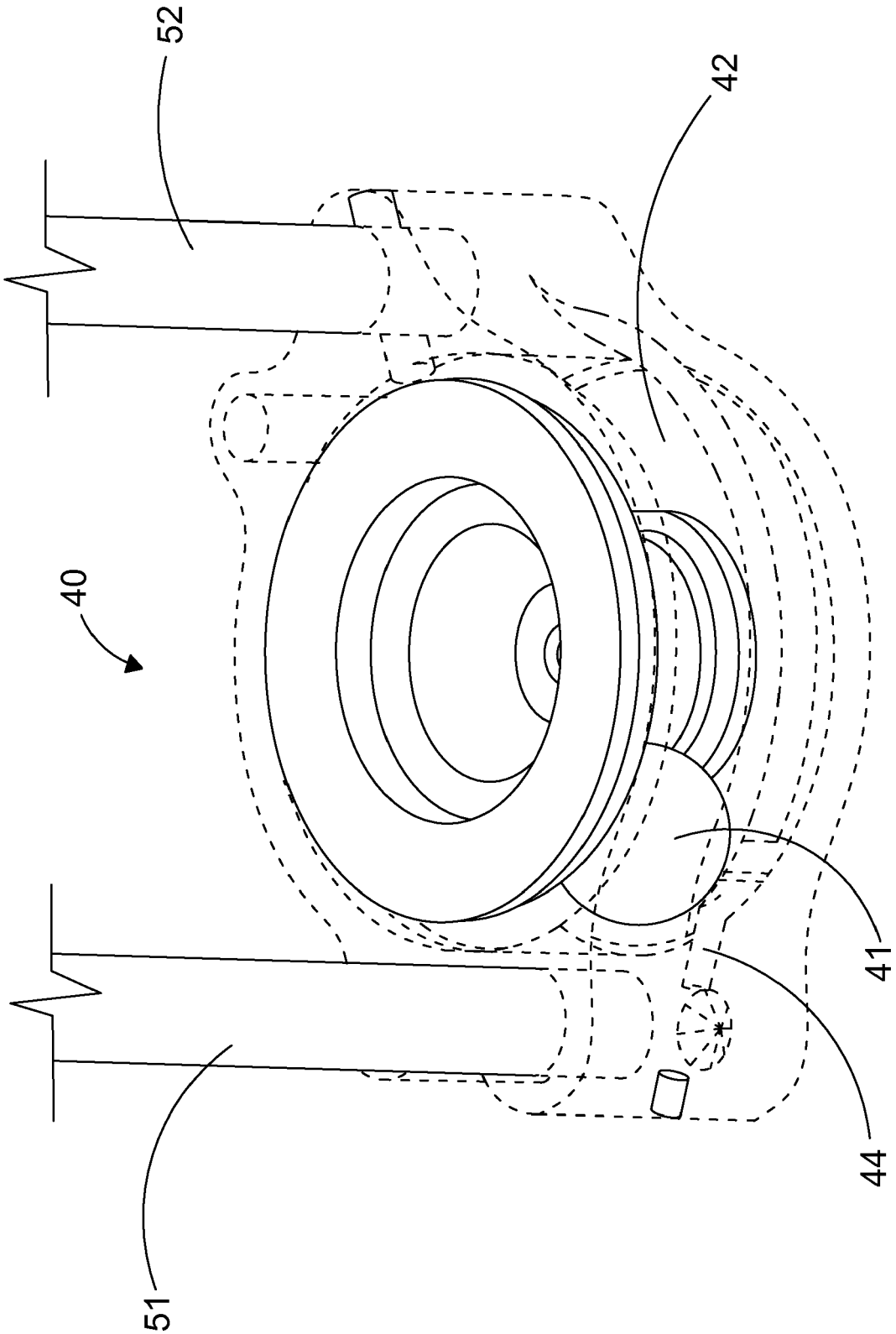


FIG. 8

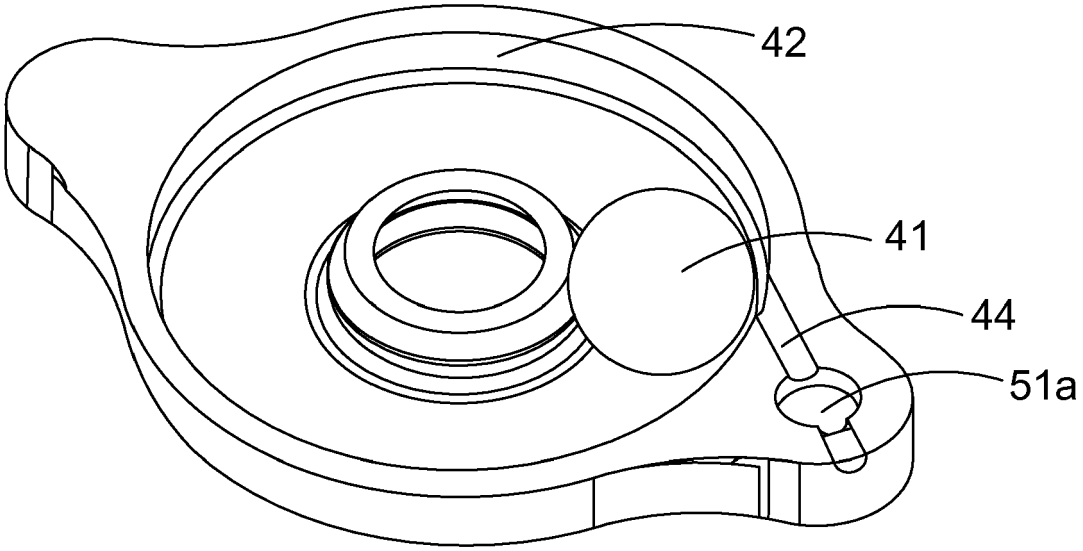


FIG. 9

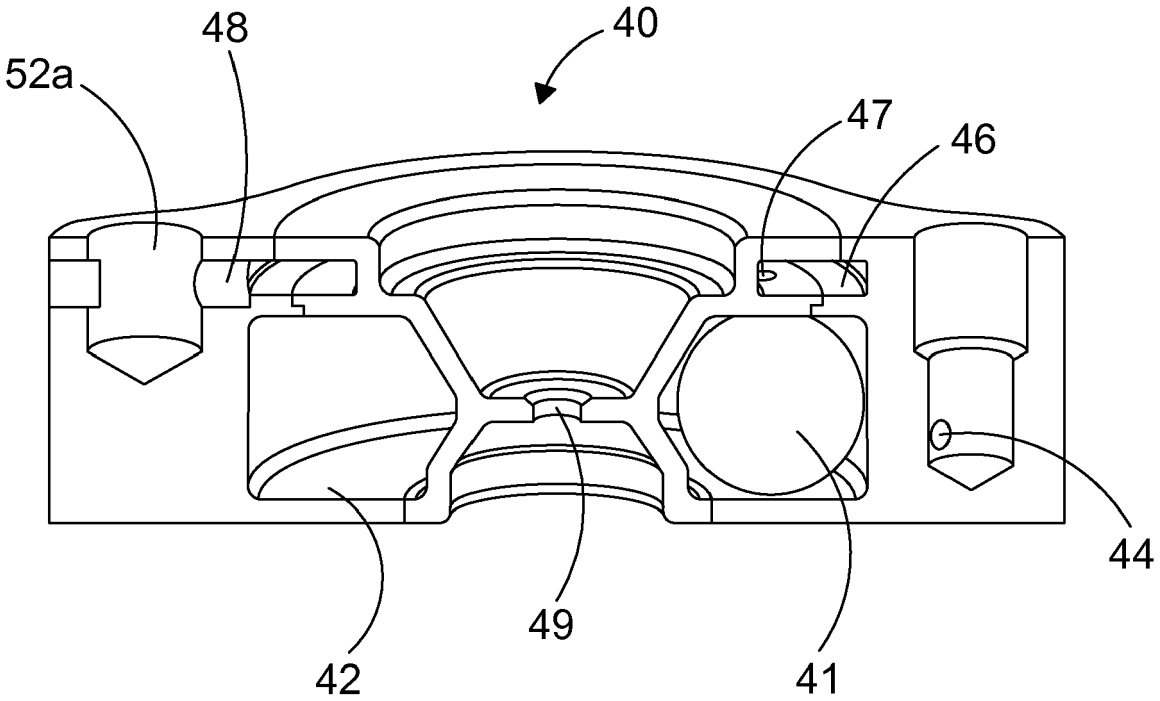


FIG. 10

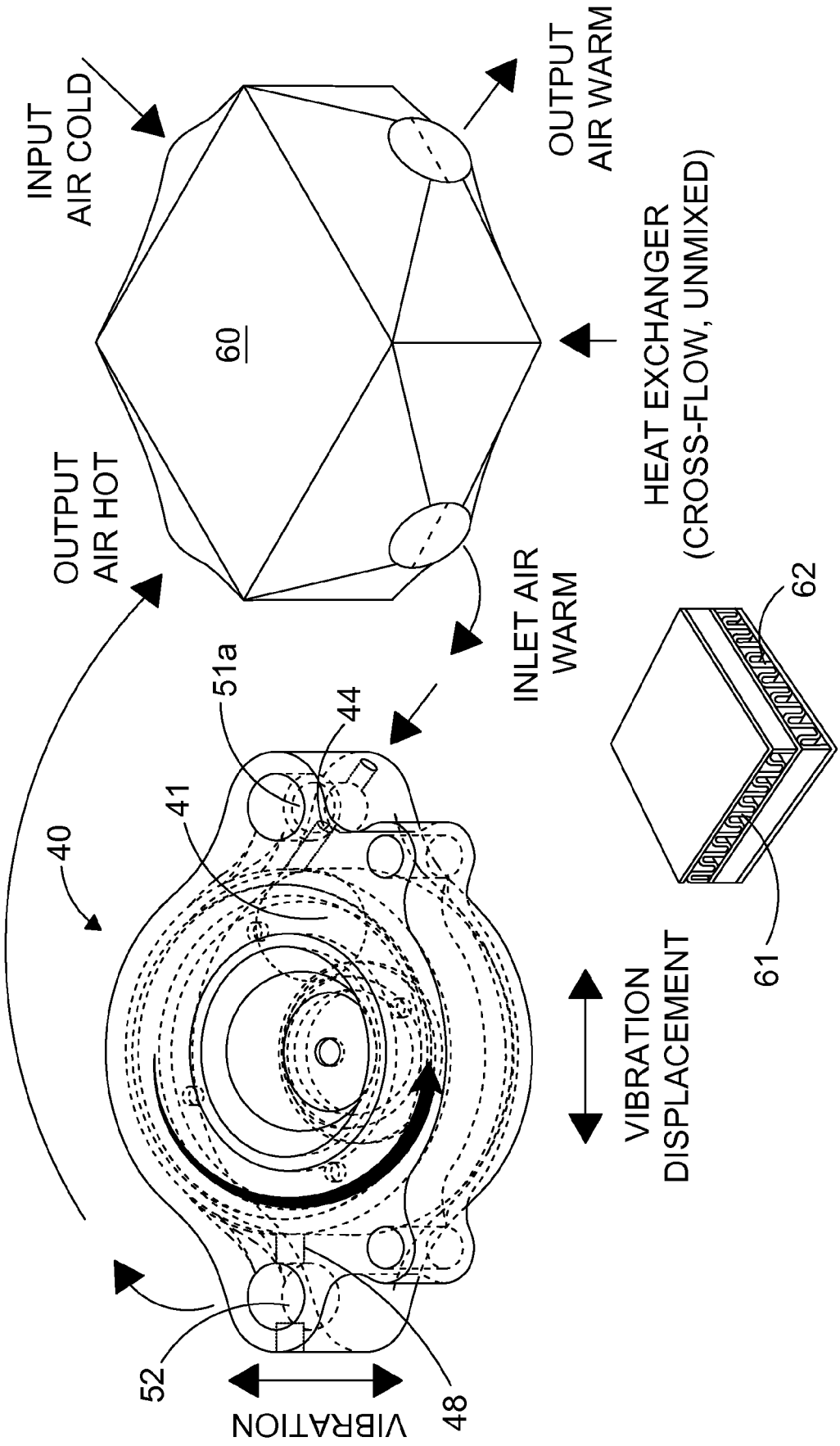

INPUT
AIR COLD
OUTPUT
AIR WARM
60
HEAT EXCHANGER
(CROSS-FLOW, UNMIXED)
OUTPUT
AIR HOT
INLET AIR
WARM
62
51a
44
41
40
61
VIBRATION
DISPLACEMENT
52
48
VIBRATION

FIG. 11

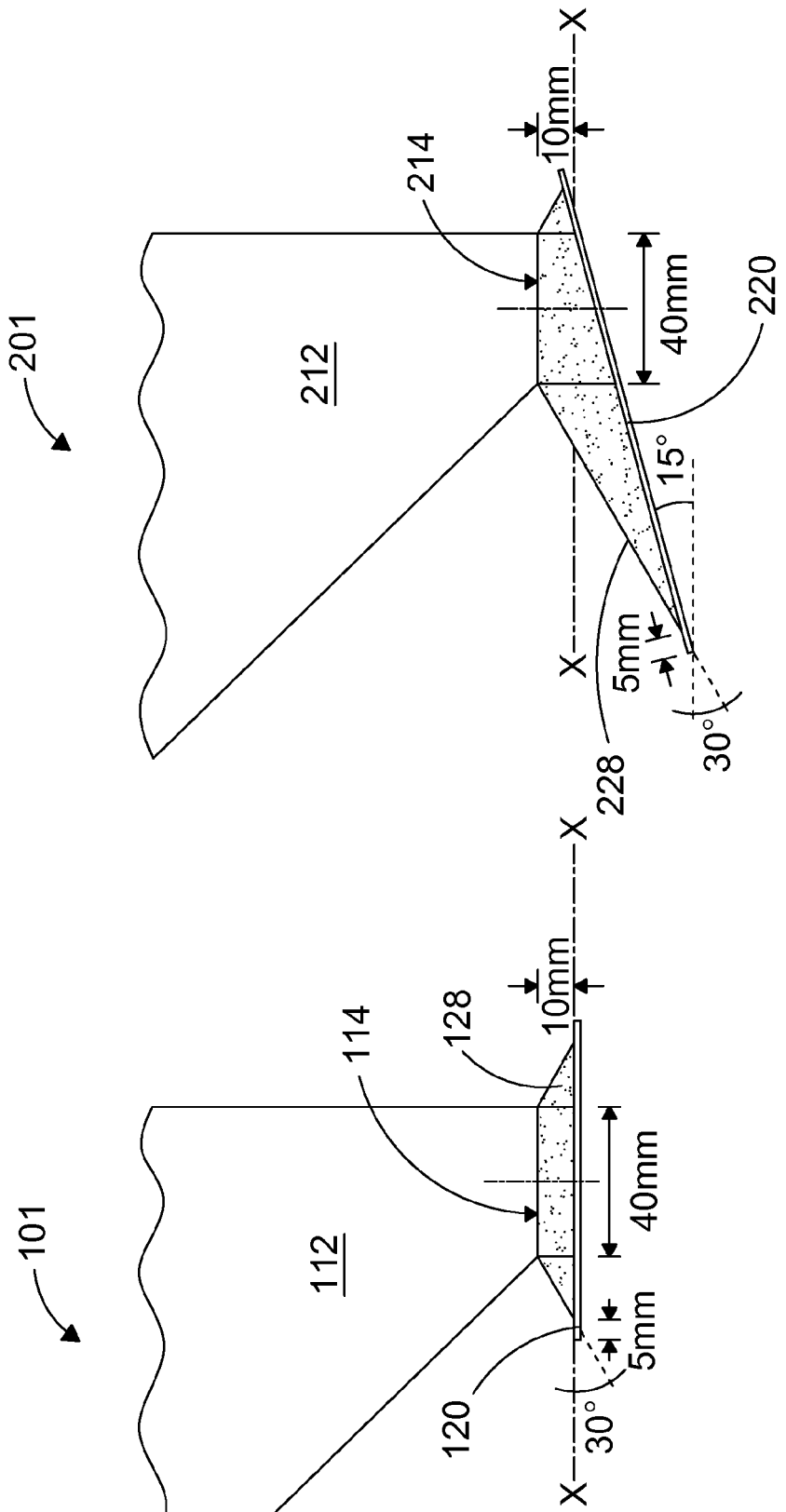

201
212
214
10mm
X
40mm
220
15°
5mm
30°
228
X
101
112
114
128
10mm
X
40mm
5mm
30°
120
X

FIG. 13

FIG. 12

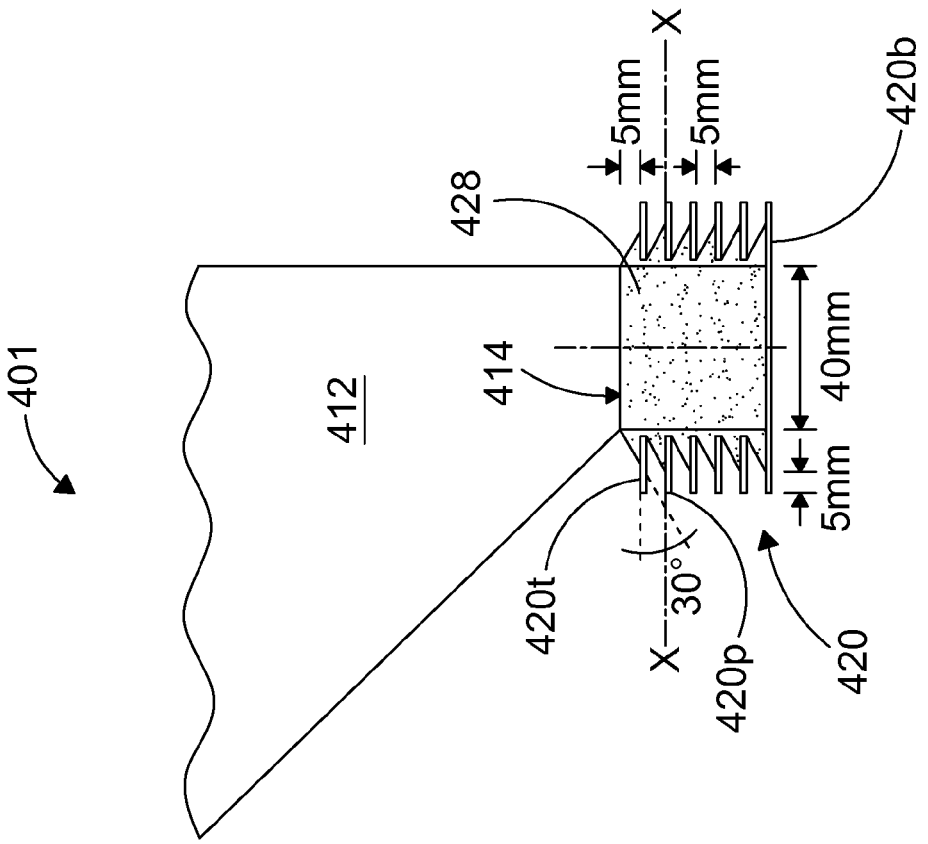

401
412
414
428
5mm
5mm
X
420b
40mm
5mm
420t
30°
X
420p
420

FIG. 15

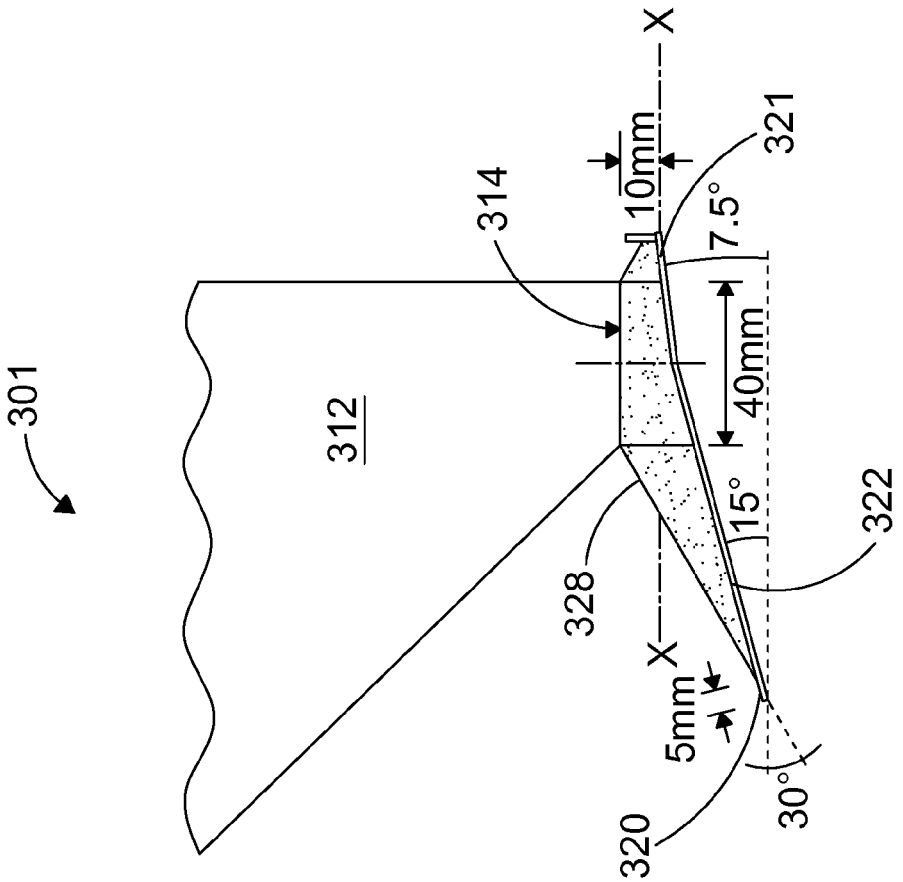

301
312
314
10mm
X
321
7.5°
40mm
15°
322
328
X
5mm
320
30°

FIG. 14

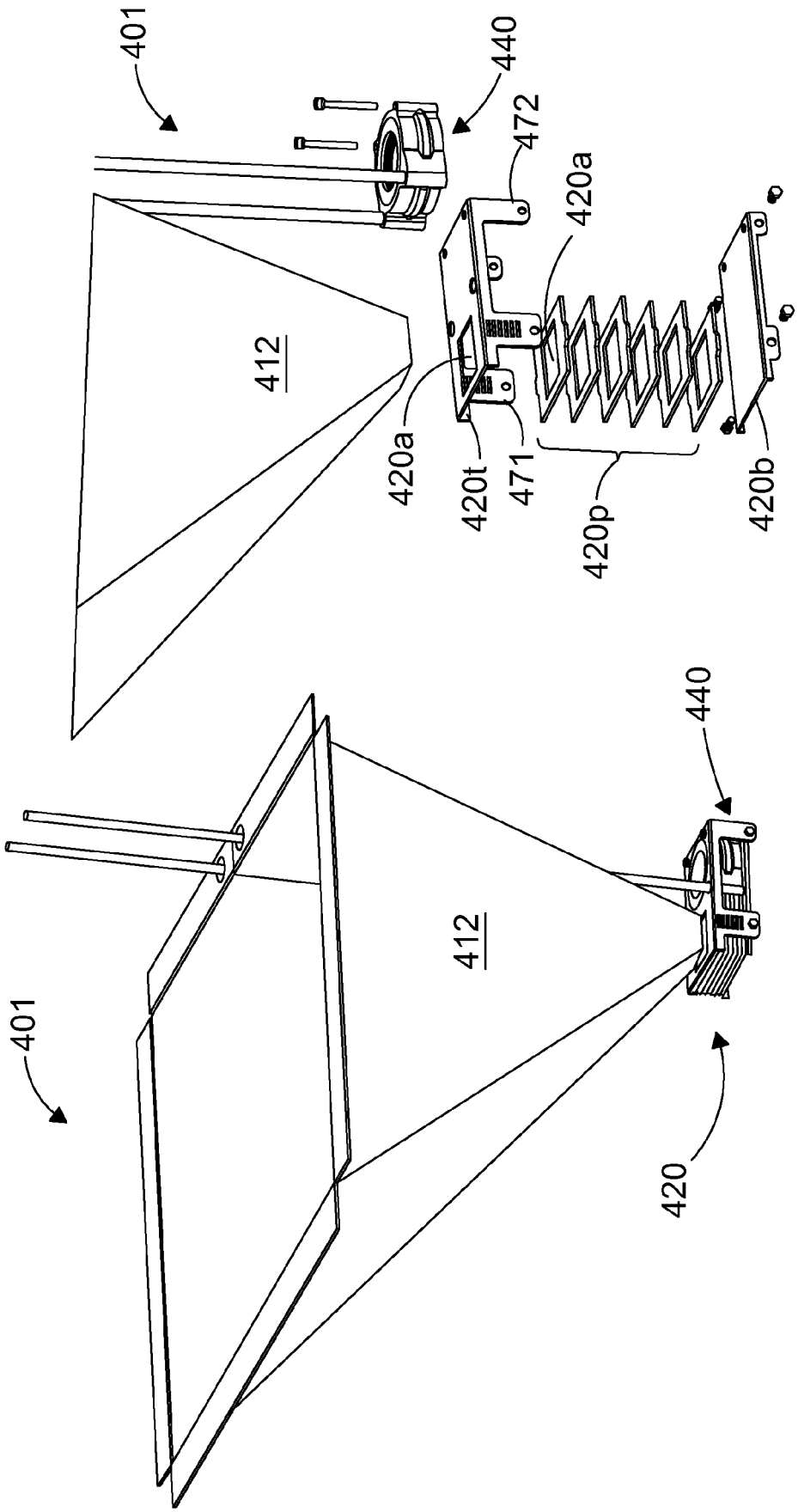


FIG. 17

FIG. 16

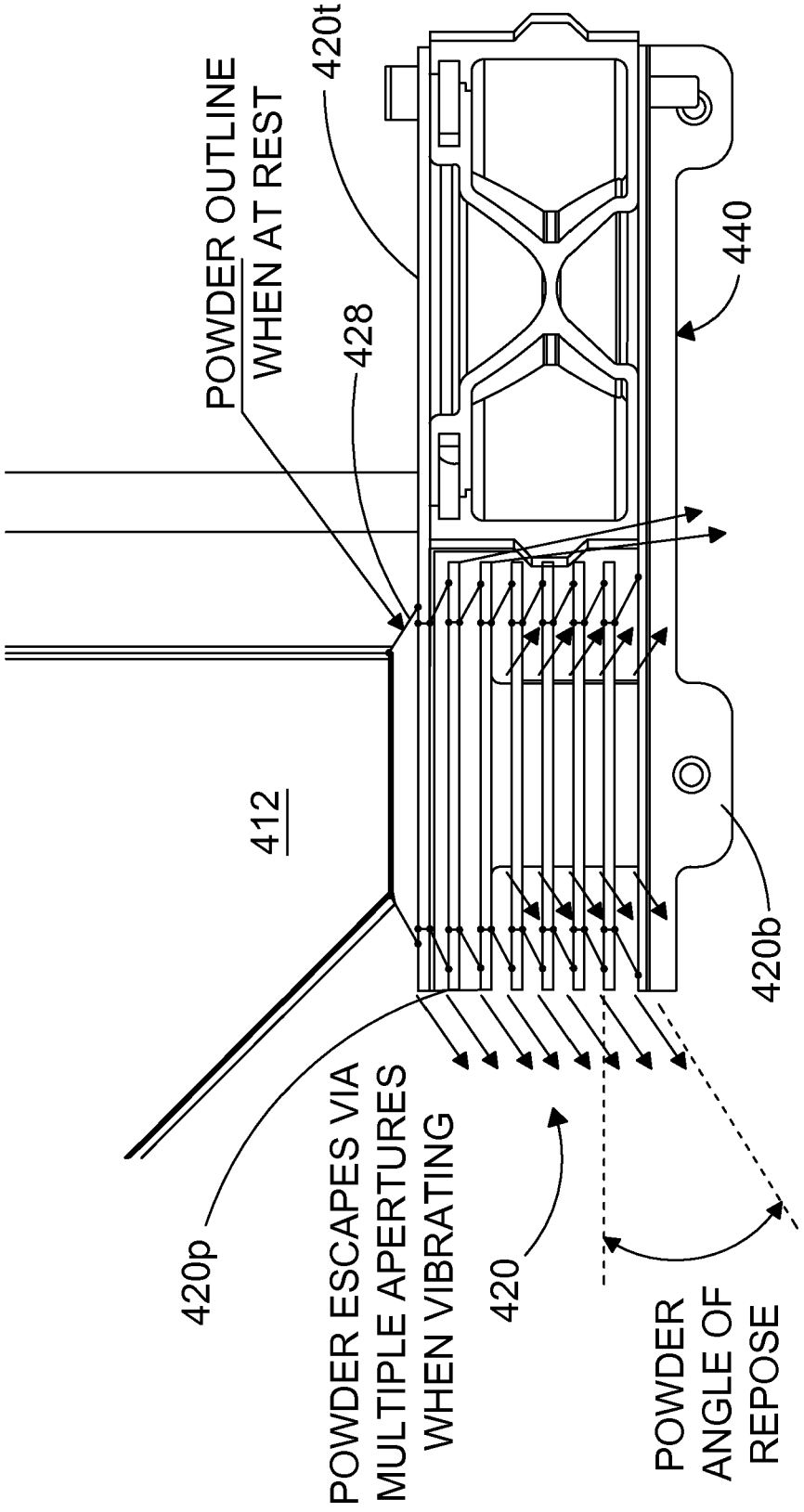

POWDER OUTLINE
WHEN AT REST
420t
428
440
412
420b
420p
POWDER ESCAPES VIA
MULTIPLE APERTURES
WHEN VIBRATING
420
POWDER
ANGLE OF
REPOSE

FIG. 18

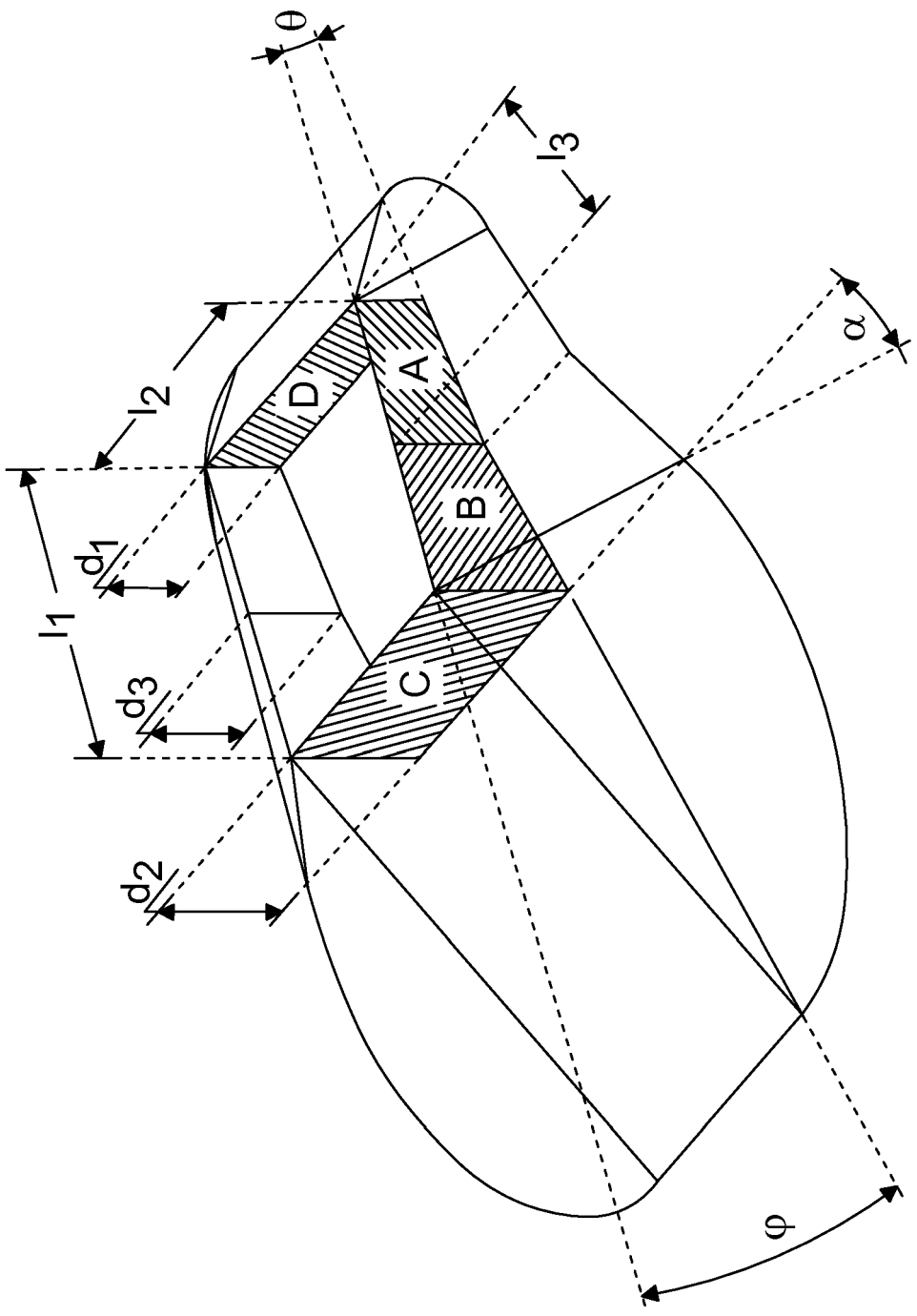


FIG. 19

Europäisches Patentamt
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EUROPEAN SEARCH REPORT

Application Number
EP 17 18 1604

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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			TECHNICAL FIELDS SEARCHED (IPC)
			B65D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	25 September 2017	Lämmel, Gunnar

CATEGORY OF CITED DOCUMENTS

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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