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— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

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**(54) Title**: VIBRATING CENTRIFUGE

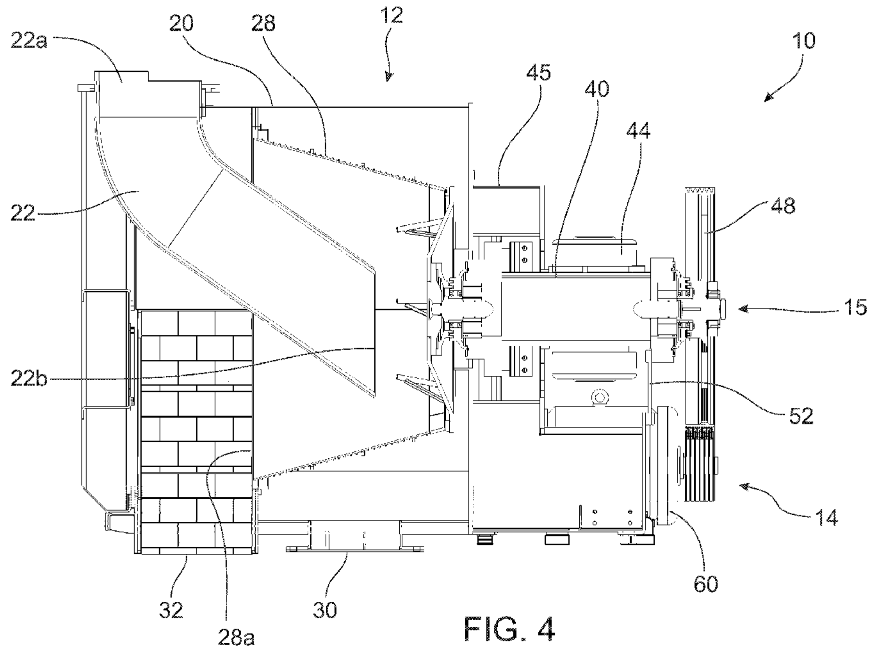


FIG. 4

**(57) Abstract**: A two degree of freedom vibrating centrifuge 10 used for separation of materials such as, for example, coal from slurry. The vibrating centrifuge 10 has horizontally aligned tuning leaf springs 50 and a vertically arranged support leaf spring 52. The tuning leaf springs 50 have a high stiffness that provides a damping effect to the system without the need for separate compression springs, or the like. The horizontal arrangement of the tuning leaf springs 50 reduces local bending loads.

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# VIBRATING CENTRIFUGE

## CROSS-REFERENCE TO RELATED APPLICATIONS

This international application claims the benefit of United States Provisional Patent Application No. 61/984,273 filed on 25 April 2014, the document of which is hereby incorporated by reference in its entirety for any and/or all purposes set forth herein.

## FIELD OF THE INVENTION

The invention relates to a vibrating centrifuge. In particular, although not exclusively, the invention relates to a vibrating centrifuge having a vibrator, such as an unbalanced motor, that provides axial vibration to a basket through a spring system.

## BACKGROUND TO THE INVENTION

Reference to background art herein is not to be construed as an admission that such art constitutes common general knowledge in Australia or elsewhere.

Examples of vibrating centrifuges may be appreciated from Patent Application Nos. WO2012/174588 and US2010/0120600 and U.S. Patent Nos. 5,616,425; 7,534,358; and 4,082,675. Centrifugal separators are often used for the separation of solids and liquids from slurry. For example, for separating coal solids from a coal slurry that includes water. Vibrating centrifuges typically have an axially vibrating rotational basket, which the slurry traverses, with the liquids being expelled outwards through the basket and the solids being carried down tapered sides of the basket to an outlet.

Some prior vibrating centrifuges include complicated eccentric weight mechanisms that are either belt driven or directly driven by a motor connected to an eccentric shaft. These arrangements result in high production costs, increased maintenance requirements, and difficulty in adapting the vibrating centrifuge to process changes.

Newer vibrating centrifuges are typically tuned to operate at particular frequencies to improve efficiency. However, tuning the vibrating centrifuge can be difficult and costly. This is at least partially because tuned vibrating centrifuges generally require certain parts, such as springs, to be within a very high tolerance. Such high tolerance parts not only significantly increase manufacturing costs, but are prone to error and can be difficult to source.

Elastomeric compression springs, and the like, can be used for tuning, but the vast amount of energy involved results in the compression springs increasing in temperature to a point which can lead to early failure. See Application No. WO2012/174588. Such failures not only decrease reliability, but also increase maintenance and servicing costs, as well as resulting in downtime of the separating equipment.

It will be clearly understood that any reference herein to background material or information, or to a prior publication, does not constitute an admission that any material, information or publication forms part of the common general knowledge in the art, or is otherwise admissible prior art, whether in Australia or in any other country.

## OBJECT OF THE INVENTION

It is an object of the invention to overcome or at least alleviate one or more of the above problems and/or provide the consumer with a useful or commercial choice.

Other preferred objects of the present invention will become apparent from the following description.

## DISCLOSURE OF THE INVENTION

In one form, although it need not be the only or indeed the broadest form, the invention resides in a vibrating centrifuge comprising:

a separation screen that is connected to a drive shaft, the drive shaft having an axial axis;

at least one vibrator that generates vibration in the separation screen; and

one or more leaf springs that substantially restrict vibration generated by the vibrator to a single degree of freedom that is parallel to the axial axis;

wherein at least one of the one or more leaf springs is a tuning leaf spring that has a stiffness that is predetermined to tune the vibration frequency of the vibrating centrifuge.

Preferably a plurality of tuning leaf springs are provided. Preferably the stiffness of the tuning leaf springs is selected as a function of the operating frequency and total sprung mass, wherein the total sprung mass preferably includes at least the separation screen, the drive shaft, a bearing housing assembly, and/or a drive pulley attached to the drive shaft. Preferably the stiffness of the tuning leaf springs is selected as a function of operating frequency squared times the total sprung mass.

Preferably the tuning leaf springs have a stiffness of greater than 5 kN/mm, more preferably greater than 10 kN/mm, even more preferably greater than 15 kN/mm, still more preferably greater than 20 kN/mm, and yet more preferably greater than 30 kN/mm.

Preferably the tuning leaf springs are arranged radially with respect to the drive shaft in pairs where one leaf spring in the pair is located substantially 180° opposite the other leaf spring in the pair. Preferably the tuning leaf springs are horizontally positioned in relation to a ground. Alternatively, an odd number of tuning leaf springs can be spaced equidistantly with respect to each other. Alternatively, the leaf springs are aligned at any orientation along an axis that is orthogonal to the axial axis. Alternatively, the leaf springs extend radially with respect to the drive shaft along separate axes, each axis being substantially orthogonal to the ground.

Preferably there are separate tuning leaf springs and one or more support leaf springs. Alternatively, all of the leaf springs are tuning leaf springs. Preferably the stiffness of the tuning leaf springs is substantially greater than the stiffness of the support leaf springs. Preferably the stiffness of the tuning leaf springs is at least one order of magnitude greater than the stiffness of the support leaf spring. Alternatively the tuning leaf springs may also function as the supporting leaf springs.

Preferably there are no additional biasing members, such as compression springs, located between the separation screen and a separation housing that contains the separation screen.

Preferably there is no tuning mass included in the total sprung mass. Alternatively, there is a tuning mass included in the total sprung mass.

Preferably at least the tuning leaf springs are fibre reinforced composite (FRP), preferably glass fibre reinforced composite. Preferably the tuning leaf spring stiffness is modified to tune the vibratory frequency of the centrifuge to suit an electric motor's operating speed with a (e.g. to suit a supply frequency of 50Hz or 60Hz) electrical supply frequency. Preferably the tuning leaf spring stiffness is predetermined and/or tuned by modifying the width, length, shape, thickness, material composition and/or preloading of the tuning leaf spring.

Preferably the vibration is transmitted to the total sprung mass via the leaf springs.

In another form, although it need not be the only or indeed the broadest form, the invention resides in a vibrating centrifuge comprising:

a separation screen that is connected to a drive shaft, the drive shaft having an axial axis;

at least one vibrator that generates vibration in the separation screen; and

one or more leaf springs that substantially restrict vibration generated by the vibrator to a single degree of freedom that is parallel to the axial axis;

wherein at least one of the leaf springs is mounted substantially horizontally.

Preferably two leaf springs are substantially horizontally aligned along an axis that is orthogonal to the axial axis. Preferably one of the two leaf springs is located on either side of the bearing housing substantially 180° apart. Alternatively, the two leaf springs are substantially vertically aligned along an axis that is orthogonal to the axial axis. Alternatively, the two leaf springs are aligned at any orientation along an axis that is orthogonal to the axial axis. Alternatively, the two leaf springs extend radially from a bottom of the bearing housing along separate axes, each axis being substantially orthogonal to the ground. Preferably the leaf springs are located between two vibrators. Preferably the leaf springs are tuning leaf springs. Preferably the vibration is transmitted to the total sprung mass via the leaf springs.

Preferably at least one support leaf spring is provided. Preferably the support leaf spring is mounted vertically. Preferably the support leaf spring is mounted vertically beneath the drive shaft. Alternatively the support leaf spring is a tuning leaf spring.

The drive shaft preferably passes from the separation screen inside the separation housing, through the bearing housing, to a drive portion. The drive portion preferably includes a drive pulley. Preferably the drive shaft is connected to the bearing housing by a set of bearings.

Preferably the vibrator is a vibratory motor, such as an unbalanced motor. Alternatively, the vibrator may be a dedicated vibrating unit or a vibrator with an integral mechanism, preferably one which generates only axial vibration. The dedicated vibrating unit may have two rotating forces, preferably counter-rotating, that cancel each other out in at least one axis to provide an axial force. Preferably there are two vibrators comprising two counter rotating unbalanced motors to provide a linear drive force.

Preferably the separation screen is a basket. Even more preferably the basket is a frustoconical basket that rotates axially in use. An inlet is preferably provided to convey material to be separated, such as slurry, to the inside of the basket. Preferably the inlet is a chute.

Preferably the vibrating centrifuge is configured as a two degree of freedom system. The tuned two degree of freedom system minimises the loads transferred from the machine to the surrounding plant or environment during operation. This reduces the cost of supporting structures, minimises unwanted structural vibrations and reduces the risk of fatigue damage to the surrounding structure.

Further features of the present invention will become apparent from the following detailed description.

## BRIEF DESCRIPTION OF THE DRAWINGS

By way of example only, preferred embodiments of the invention will be described more fully hereinafter with reference to the accompanying figures, wherein:

Figure 1 is a perspective view of a vibrating centrifuge according to an embodiment of the invention;

Figure 2 is a perspective view of a vibrating centrifuge according to figure 1 with portions of a belt drive system removed;

Figure 3 is a rear elevation view of figure 2;

Figure 4 is a side elevation cross-sectional view of figure 1; and

Figure 5 is a top plan cross-sectional view of figure 1.

## DETAILED DESCRIPTION OF THE DRAWINGS

Figures 1 to 5 illustrate a vibrating centrifuge 10 having a separation portion 12, a drive portion 14, and a sprung mass portion 15. The vibrating centrifuge 10 has ground engagement feet 24 which include isolation springs 26. The isolation springs 26 are typically elastomeric members that connect the ground engagement feet 24 to the vibrating centrifuge 10. The ground engagement feet 24 are affixed to the ground or other part of the structure of the plant.

The separation portion 12 has a separation housing 20 having an inlet in the form of a chute 22 which conveys material to be separated, such as slurry, inside the separation housing 20, as will be discussed herein. The drive portion 14 has vibrators in the form of a pair of unbalanced motors 44 which are mounted on a common support frame 45. The unbalanced motors 44 are configured such that in use they rotate in opposite directions (i.e. counter rotating).

The sprung mass portion 15 has a number of components which move together in use. These components include a bearing housing 40, a drive shaft 46, a driven pulley 48, a basket 28, and other components such as bearings and bearing covers. The drive shaft 46 is engaged with the bearing housing 40 via bearings. The drive shaft 46 is provided with a drive portion in the form of a driven pulley 48 on an end thereof. The drive shaft 46 is provided with a separation portion in the form of a basket 28 on an end thereof opposite the drive portion. The driven pulley 48 engages with a belt 64 that also engages with drive pulley 62 of motor 60 such that rotation of the drive pulley 62 rotates the driven pulley 48, which in turn rotates the shaft 46 and consequently the basket 28.

Leaf springs are provided that restrict movement of the sprung mass 15 to a single degree of freedom that is parallel to the axial axis of the drive shaft 46. Two of the leaf springs are tuning leaf springs 50 and one of the leaf springs is a support leaf spring 52 (seen most clearly in figures 2 and 3).

The tuning leaf springs 50 have a designed stiffness that avoids the need for separate dampers, such as elastomeric compression springs or torsion bars. The tuning leaf springs 50 in a preferred embodiment are made of glass fibre reinforced composite (FRP) having a stiffness of approximately 30 kN/mm to suit the operating speed of a 4 pole motor with a 50 Hz electrical supply frequency. This is in contrast to a typical leaf spring stiffness of less than 1 kN/mm in similar applications which have separate biasing members. The masses of the system coupled with the tuning leaf springs 50 and the isolation springs 26 provide a two degree of freedom vibrating system.

The tuning leaf springs 50 are arranged adjacent to the bearing housing 40. The tuning leaf springs 50 are substantially rectangular having two affixed sides and two free sides. The tuning leaf springs 50 are affixed at one end to the bearing housing assembly 40 180° from each other. An opposite end of the leaf springs 50 is attached to the common support frame 45. The affixed sides of the two tuning leaf springs 50 are substantially vertical and the free sides are substantially horizontal in relation to a ground.

The support leaf spring 52 is located below, and provides support to, the bearing housing 40. The support leaf spring 52 has nominal stiffness relative to the tuning leaf springs 50. The support leaf spring 52 is located adjacent the driven pulley 48 end of the drive shaft 46. The tuning leaf springs 50 are arranged substantially horizontal and in the support leaf spring being arranged substantially vertical in relation to the ground. The support leaf spring 52 is located beneath the drive shaft 46 centrally between the horizontally arranged tuning leaf springs 50.

The tuning leaf springs 50 generally define a tuning leaf spring plane. The support leaf spring 52 generally defines a support leaf spring plane that is parallel to the tuning leaf spring plane. The axial axis of the drive shaft 46 is substantially normal to tuning leaf spring plane and the support leaf spring plane.

The tuning leaf springs 50 and support leaf spring 52 are arranged to allow movement of the sprung mass portion 15 in an axis parallel to the axial axis of the drive shaft 46 but limits movement in other axes. Effectively, the leaf springs 50, 52 limit the movement of the sprung mass portion 15 to one degree of freedom and, as a result, vibration energy from the unbalanced motors 44 is translated into a single axis, namely the axial axis of the drive shaft 46.

The masses of the system coupled with the tuning leaf springs 50 and isolation springs 26 provide a two degree of freedom dynamic absorber system. In particular, the mass of the sprung mass portion 15 is effectively an absorber mass and the mass of the components rigidly connected to the ground engagement feet 24, including the separation housing 20, is effectively a secondary mass of a dynamic absorber system. The springs, most notably the tuning leaf springs 50, can have their stiffness altered by modifying the width, length, shape, thickness, material composition and/or preloading of the tuning leaf springs 50 to change the dynamic absorber characteristics as desired, preferably to maintain a tuned dynamic absorber system.

This two degree of freedom system of the vibrating centrifuge 10 provides an efficient transfer of energy by advantageously causing motion of the vibrating bearing housing assembly 40 to effectively absorb energy and minimise loads transferred to the separation housing 20 and associated components. This not only improves efficiency but also minimises the risk of fatigue damage and unwanted vibrations.

Turning specifically to figures 4 and 5, which illustrate the internal components, particularly of the separation housing 20, it can be seen that the separation portion 12 has a separation screen in the form of a basket 28. The basket 28 is engaged with, and rotates with, the drive shaft 46. The chute 22 has an inlet end 22a and an outlet end 22b which conveys the material to be separated from a source (not shown) to inside the basket 28. The separation housing 20 has a first outlet 30 which allows material separated by the centrifuge 10, namely material that passes through apertures in the basket 28, to be removed from the centrifuge 10. A second outlet 32 allows material that does not pass through the apertures in the basket 28 to also be removed from the centrifuge 10. In use, the driven pulley 48 is driven by drive pulley 62 of the motor 60 via belt 64. The unbalanced motors 44 rotate providing vibrations to the sprung mass portion 15 through the tuning leaf springs 50 along the axial axis of the drive shaft 46 causing the basket 28 to vibrate. The leaf springs 50, 52 constrain vibrations from the unbalanced motors 44 to one degree of freedom, normal to their at rest leaf spring plane. The stiffness of the tuning leaf springs 50 is predetermined such that maximum vibration energy is transferred from the unbalanced motors 44 to the basket 28 while minimizing vibration energy transfer to the separation housing 20.

A material to be separated, such as slurry being a combination of solids and liquids, is fed into the inlet end 22a of the chute 22 where it is conveyed to the outlet end 22b inside the basket 28. The material to be separated then hits the sides of the basket 28, which has apertures, and is rotated which applies centrifugal force to the material. The liquid component of the slurry passes through the basket while the solid component cannot.

The liquids, which are usually undesirable, are drained down first outlet 30 for further processing and/or disposal. The solid component which cannot pass through the basket 28 traverses the inclined walls of the basket 28 under centrifugal force. The axial vibration provided by the drive portion 14 assists in movement of the solids along basket 28 and prevents, or at least minimises, build up of solid material on the inner surface of the basket 28. When the material reaches the outermost edge 28a of the basket 28 it primarily comprises the solid component of the material as the liquid component has been removed. The solids may then be transferred for further processing, or the like, via the second outlet 32.

Advantageously, the present invention results in a vibrating centrifuge 10 that utilises tuning leaf springs 50 with a high stiffness to tune the system. Energy losses from the hysteresis of the leaf springs 50, which are normally converted to thermal energy, can be dissipated over the relatively large surface area of the tuning leaf springs 50. Furthermore, the construction of the tuning leaf springs 50 is designed to withstand the forces and energy output from the system without premature failure. By using high stiffness leaf springs 50 to provide the damping effect the number of parts, and associated cost and maintenance, is reduced by not requiring further components, such as compression springs for tuning.

The horizontal arrangement of the tuning leaf springs 50 advantageously reduces local bending loads. This not only reduces local loads introduced between the tuning leaf springs 50 and the separation housing 20, but also assists in reducing the cost of the tuning leaf springs 50 due to advantages in the stiffness and stress relationships that the horizontal arrangement provides.

In this specification, adjectives such as first and second, left and right, top and bottom, and the like may be used solely to distinguish one element or action from another element or action without necessarily requiring or implying any actual such relationship or order. Where the context permits, reference to an integer or a component or step (or the like) is not to be interpreted as being limited to only one of that integer, component, or step, but rather could be one or more of that integer, component, or step etc.

The above description of various embodiments of the present invention is provided for purposes of description to one of ordinary skill in the related art. It is not intended to be exhaustive or to limit the invention to a single disclosed embodiment. As mentioned above, numerous alternatives and variations to the present invention will be apparent to those skilled in the art of the above teaching. Accordingly, while some alternative embodiments have been discussed specifically, other embodiments will be apparent or relatively easily developed by those of ordinary skill in the art. The invention is intended to embrace all alternatives, modifications, and variations of the present invention that have been discussed herein, and other embodiments that fall within the spirit and scope of the above described invention.

In the present specification and claims (if any), the word "comprising" and its derivatives including "comprises" and "comprise" include each of the stated integers but does not exclude the inclusion of one or more further integers unless the context of use indicates otherwise.

**CLAIMS:**

1. A vibrating centrifuge comprising:

a separation housing;

a separation screen contained within the separation housing;

a drive shaft, having an axial axis, attached to the separation screen;

at least one vibrator that generates vibration in the separation screen; and

one or more leaf springs that substantially restricts vibration generated by the vibrator to a single degree of freedom that is parallel to the axial axis;

wherein at least one of the one or more leaf springs is a tuning leaf spring that has a stiffness that is predetermined to tune a vibration frequency of the vibrating centrifuge.

2. The vibrating centrifuge of claim 1 wherein the tuning leaf spring stiffness is predetermined by modifying the width, length, shape, thickness, material composition and/or preloading of the tuning leaf spring.

3. The vibrating centrifuge of claim 1 wherein the stiffness of the tuning leaf spring is selected relative to an operating frequency and a total sprung mass portion of the vibrating centrifuge.

4. The vibrating centrifuge of claim 3 wherein the total sprung mass portion comprises at least the drive shaft, the separation screen attached to

an end of the drive shaft, a bearing housing assembly positioned adjacent to the drive shaft, and a drive pulley attached to an end of the drive shaft opposite the separation screen.

5. The vibrating centrifuge of claim 1, wherein the tuning leaf spring has a stiffness of greater than 5 kN/mm.

6. The vibrating centrifuge of claim 1, wherein there are two tuning leaf springs and at least one support leaf spring.

7. The vibrating centrifuge of claim 6 further comprising a bearing housing assembly attached to the drive shaft by at least one bearing wherein the tuning leaf springs are attached to the bearing housing assembly 180° from each other on an axis substantially orthogonal to the axial axis.

8. The vibrating centrifuge of claim 1 wherein the vibrator further comprises an unbalanced electric motor having an electric motor operating frequency;

the tuning leaf spring stiffness is modified to tune the vibratory frequency of the vibrating centrifuge to suit the electric motor operating frequency.

9. The vibrating centrifuge of claim 1 further comprising:

a plurality of isolation springs positioned between a plurality of ground engagement feet and the separation housing, the ground engagement feet being attached to a ground;

wherein the tuning leaf springs and the isolation springs are configured such that the vibrating centrifuge is a two degree of freedom dynamic absorber system.

10. A method of imparting vibration to a vibrating centrifuge comprising the steps of:

(a) providing a separation screen for receiving and separating solids from liquids inside a separation housing;

(b) rotating the separation screen with a motor;

(c) providing a drive shaft between the motor and the separation screen;

(d) mounting a bearing housing assembly adjacent the drive shaft;

(e) mounting at least one tuning leaf spring between the bearing housing assembly and the separation housing;

(f) generating a vibration in the separation screen by powering at least one vibrator connected to the separation housing.

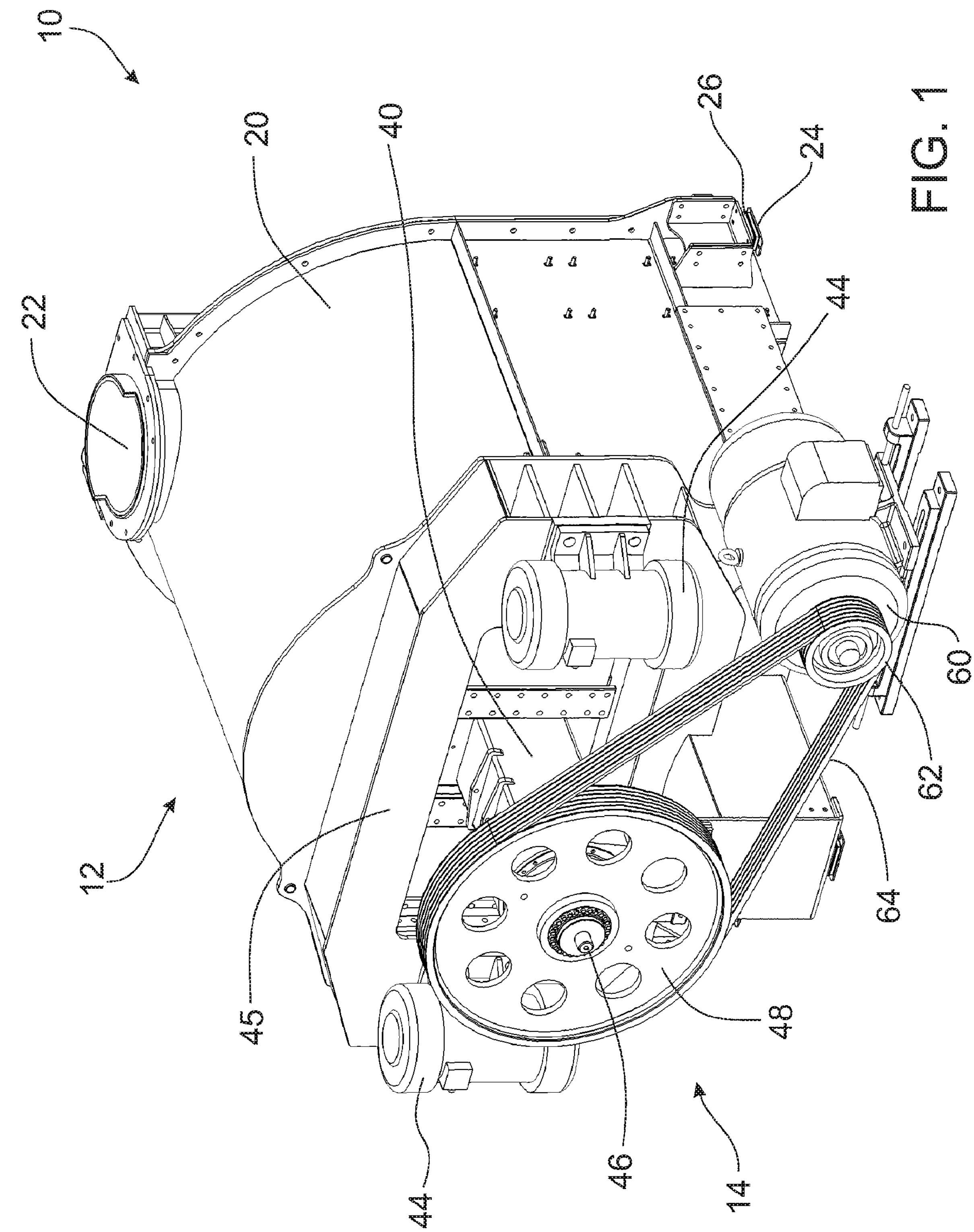


FIG. 1

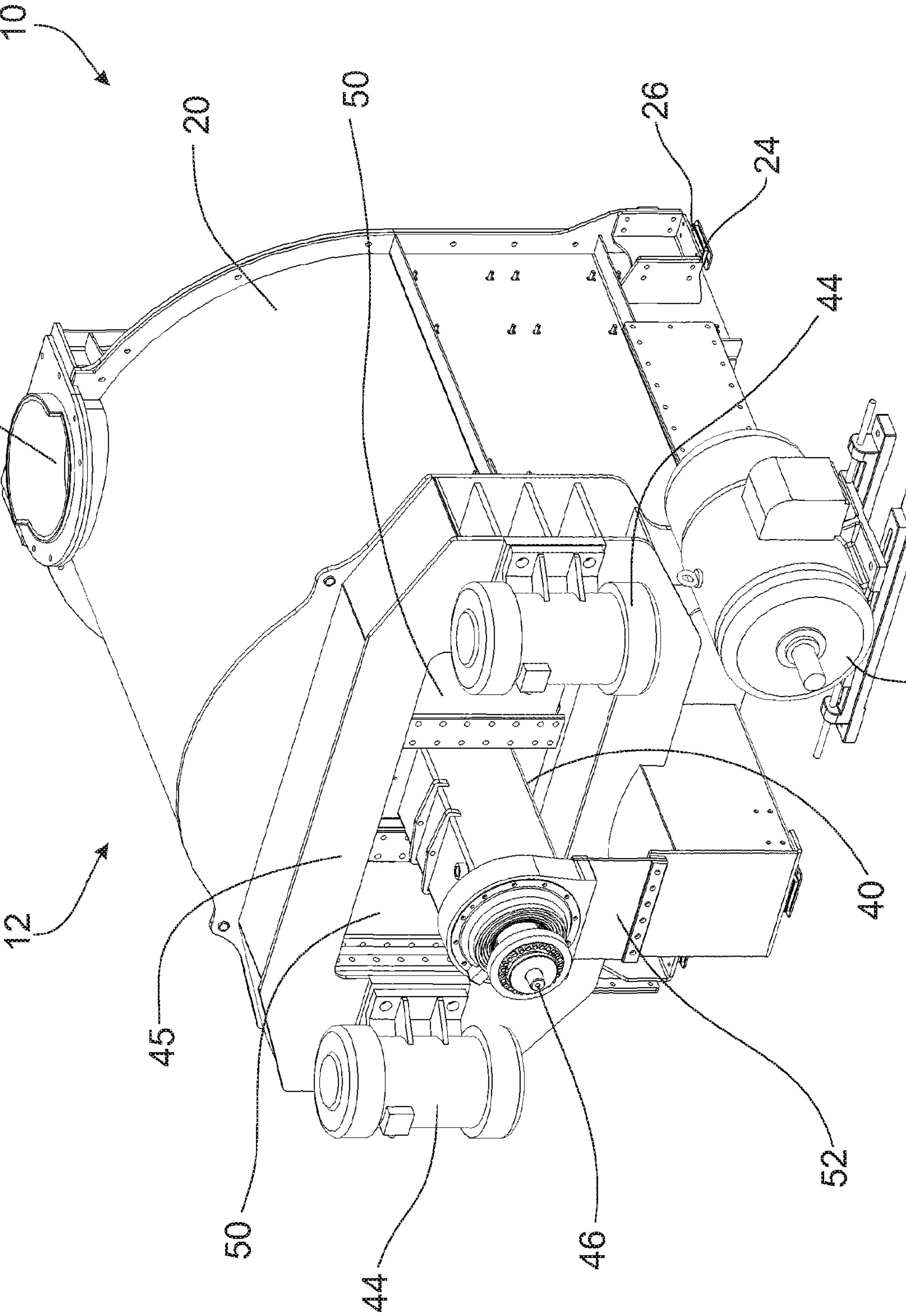


FIG. 2

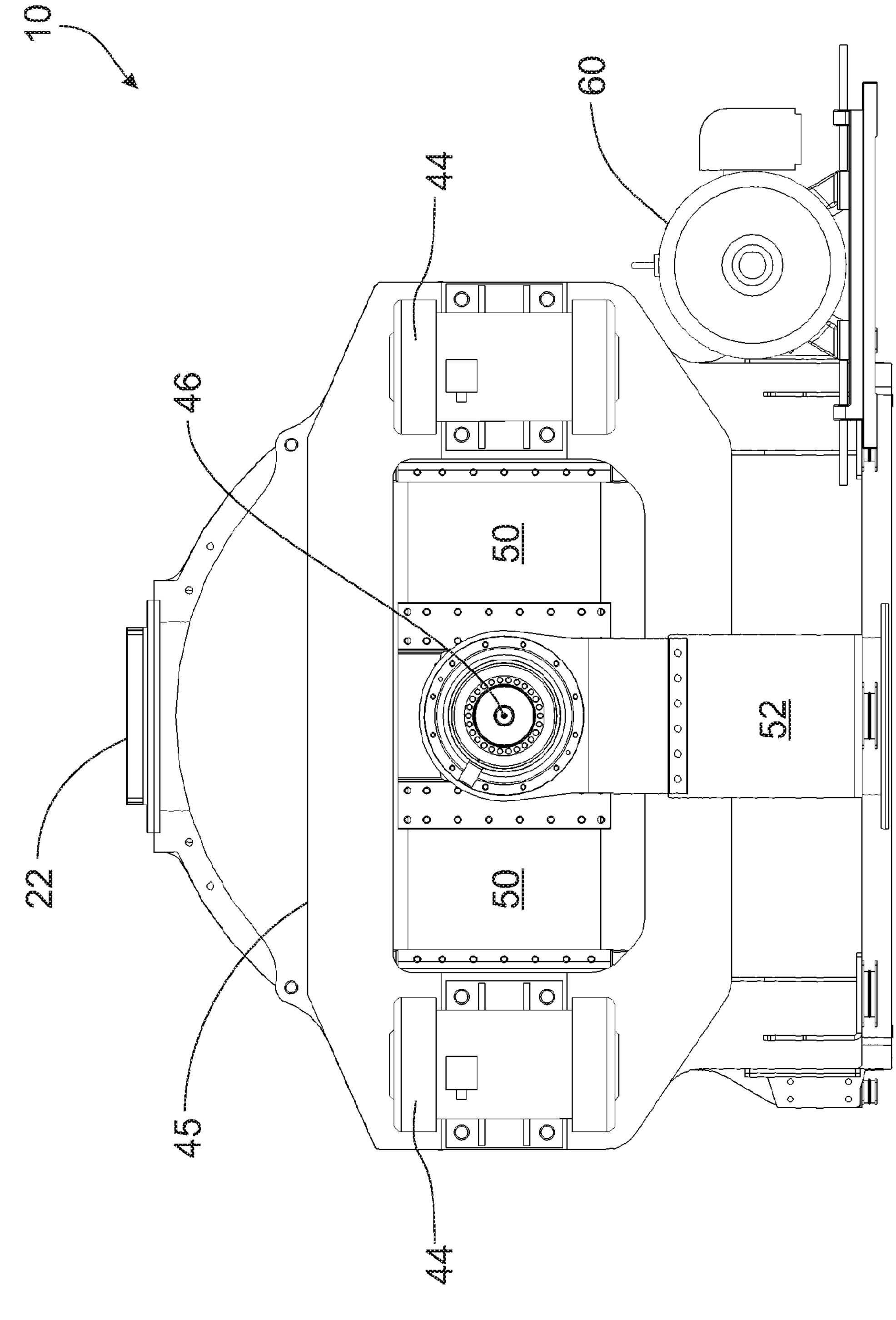


FIG. 3

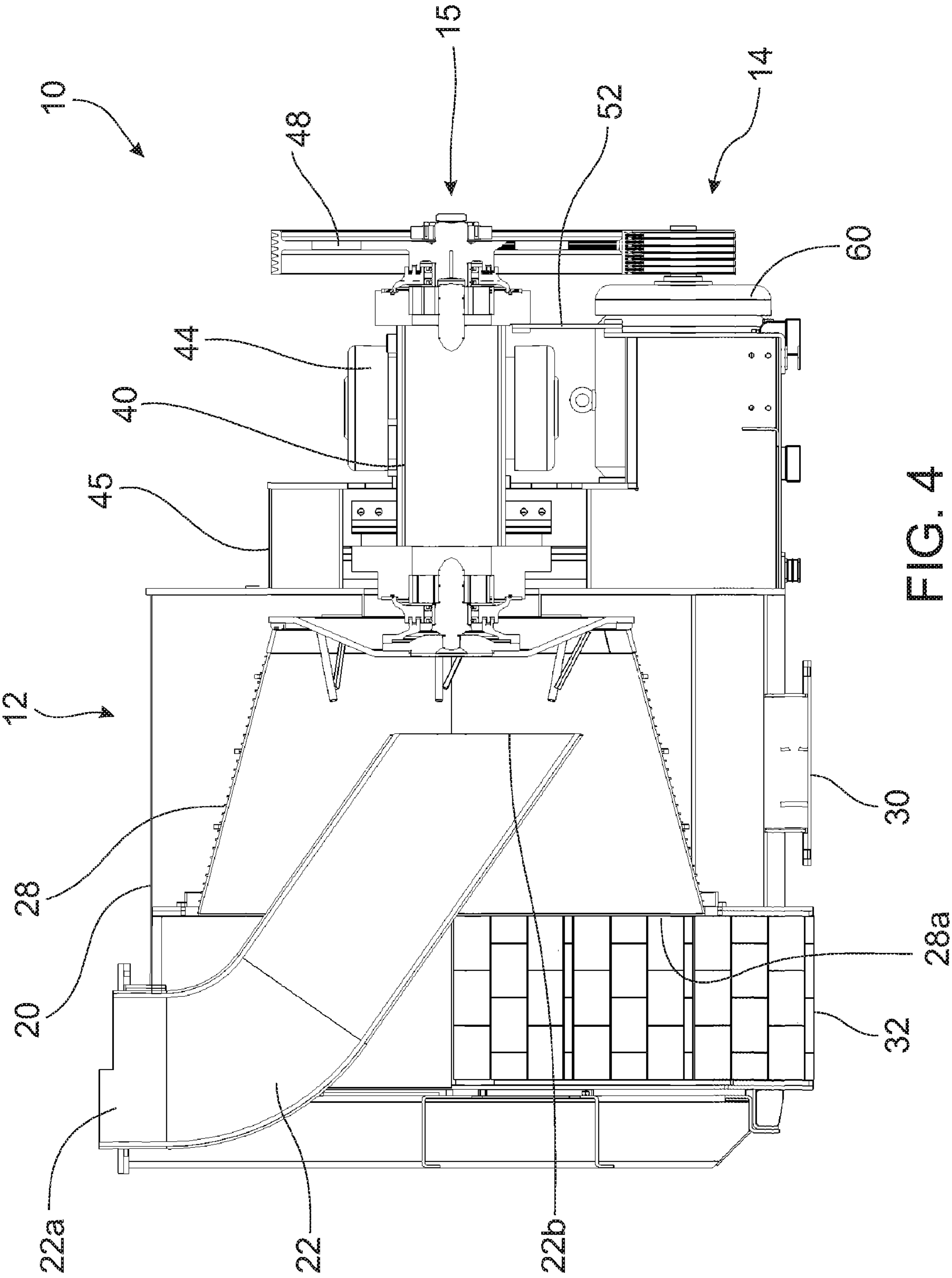


FIG. 4

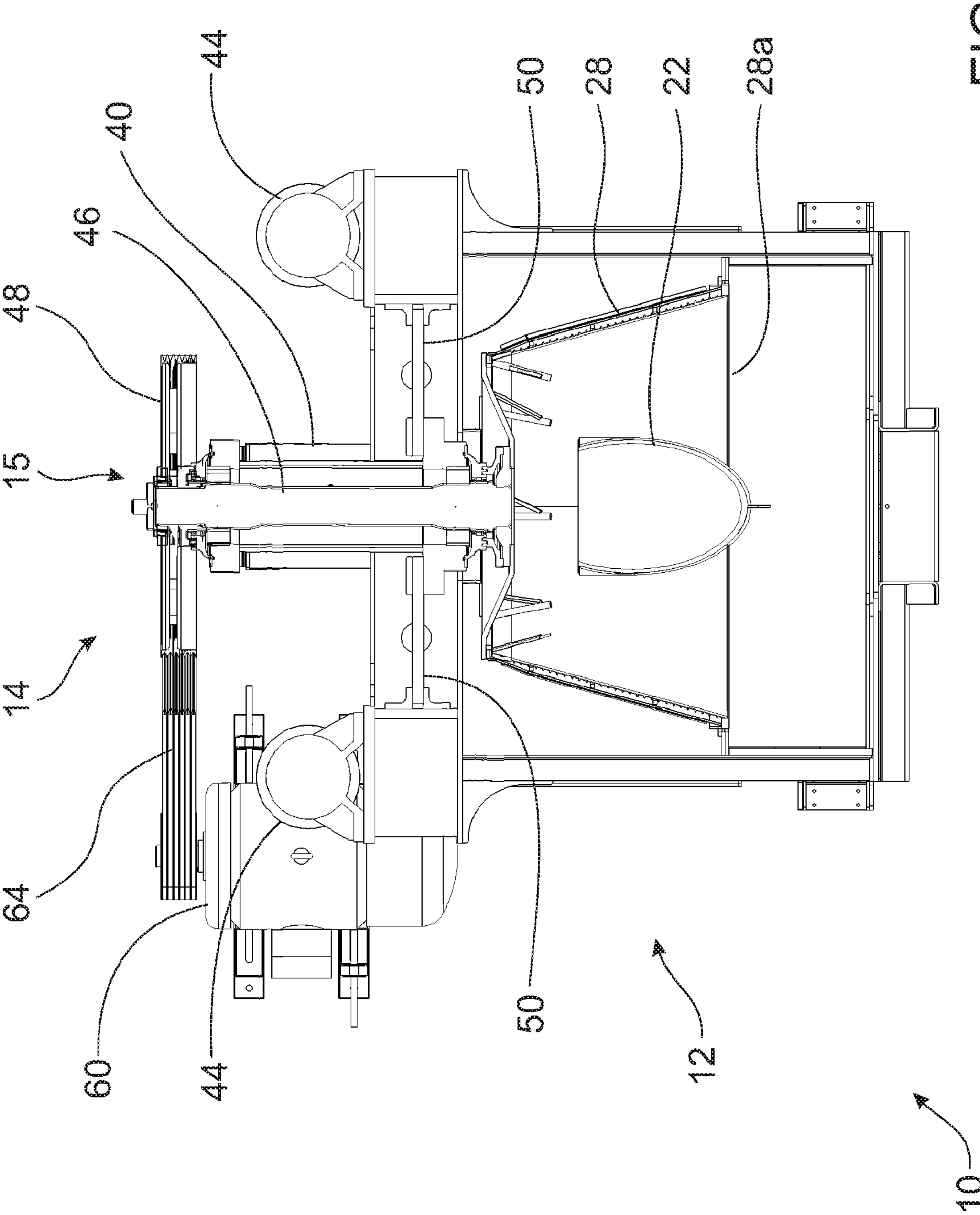


FIG. 5

| INTERNATIONAL SEARCH REPORT | International application No. **PCT/IB2015/052981** |
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A. CLASSIFICATION OF SUBJECT MATTER

***B04B 15/00 (2006.01) B04B 3/06 (2006.01)***

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC, WPIAP: IPC/CC Marks- B04B/LOW and Key Words- VIBRAT+, SHAK+, OSCILLA+, DAMP+, ATTENUAT+, SPRING+, SPRUNG, LEAF, SPRING?, TUN+, VIBRAT+, FREQUENC+

INTESS: Applicant name search

ESPACE: Applicant/Inventor name search with IPC mark B04B

GOOGLE PATENTS: Vibrating, Centrifuge, Spring/Leaf, Tuning/Frequency

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| | Documents are listed in the continuation of Box C | |

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 22 June 2015 | 22 June 2015 |
| **Name and mailing address of the ISA/AU** | **Authorised officer** |
| AUSTRALIAN PATENT OFFICE<br>PO BOX 200, WODEN ACT 2606, AUSTRALIA<br>Email address: pct@ipaustralia.gov.au | Pathma Fernando<br>AUSTRALIAN PATENT OFFICE<br>(ISO 9001 Quality Certified Service)<br>Telephone No. 0262837948 |

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y | WO 2012/174588 A1 (LUDOWICI AUSTRALIA PTY LTD) 27 December 2012<br>page 1, lines 5-13; page 3, lines 12-17; fig 2 | 1-10 |
| Y | US 4069966 A (CROSBY et al.) 24 January 1978<br>see column 7, lines 50-61; figs 1, 2, 2a | 1-10 |
| A | US 2007/0215560 A1 (WHISLER et al.) 20 September 2007<br>see abstract; figs 1, 2, 5 | |
| A | CN 102652930 A (CHINA ACAD ENG PHYSICS GEN ENG RES INST) 05 September 2012<br>see English language translation of the abstract retrieved from the EPODOC database | |

| INTERNATIONAL SEARCH REPORT<br>Information on patent family members | International application No.<br>**PCT/IB2015/052981** |
|---|---|

This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

| **Patent Document/s Cited in Search Report** | | **Patent Family Member/s** | |
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**End of Annex**

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.