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Davidson et al.

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[54] **AGITATOR FOR ORBITAL AGITATION**

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[51] **Int. Cl.**[6] **B01F 11/00**

[52] **U.S. Cl.** **366/208**

[58] **Field of Search** 366/110–112, 114, 366/208–213, 215–217, 219

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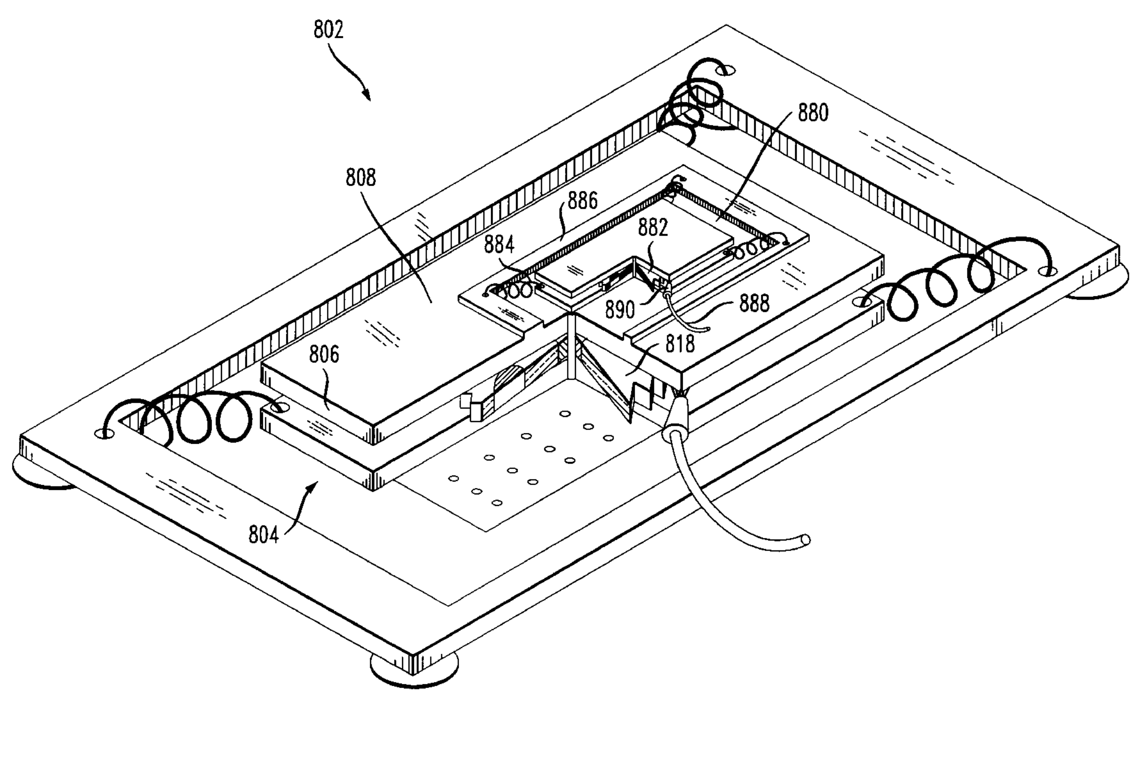
[57] **ABSTRACT**

An agitator capable of generating complex mixing motions is described. In some embodiments, an agitator in accordance with the present teachings includes a movable assembly that is suspended, via several resilient supports, from a frame. The movable assembly receives a vessel containing a material(s) to be agitated. The movable assembly advantageously includes spaced upper and lower plates having a rotatably-supported member disposed therebetween. The mass of the rotatably-supported member is asymmetrically distributed about its rotational axis. A drive force, such as a directed air flow, which may be used in conjunction with a belt drive mechanism, causes the rotatably-supported member to rotate. Due to the asymmetric mass distribution of the rotatably-supported member, force is non-uniformly applied to resilient supports such that, at any given time, some of such resilient supports are subjected to a compressive force while other resilient supports are placed under tension. The particular resilient supports that are subjected to the compressive force change as a function of the rotation of the rotatably-supported member, thereby placing the movable assembly in orbital motion and agitating the material(s) within the vessel disposed thereon.

20 Claims, 5 Drawing Sheets



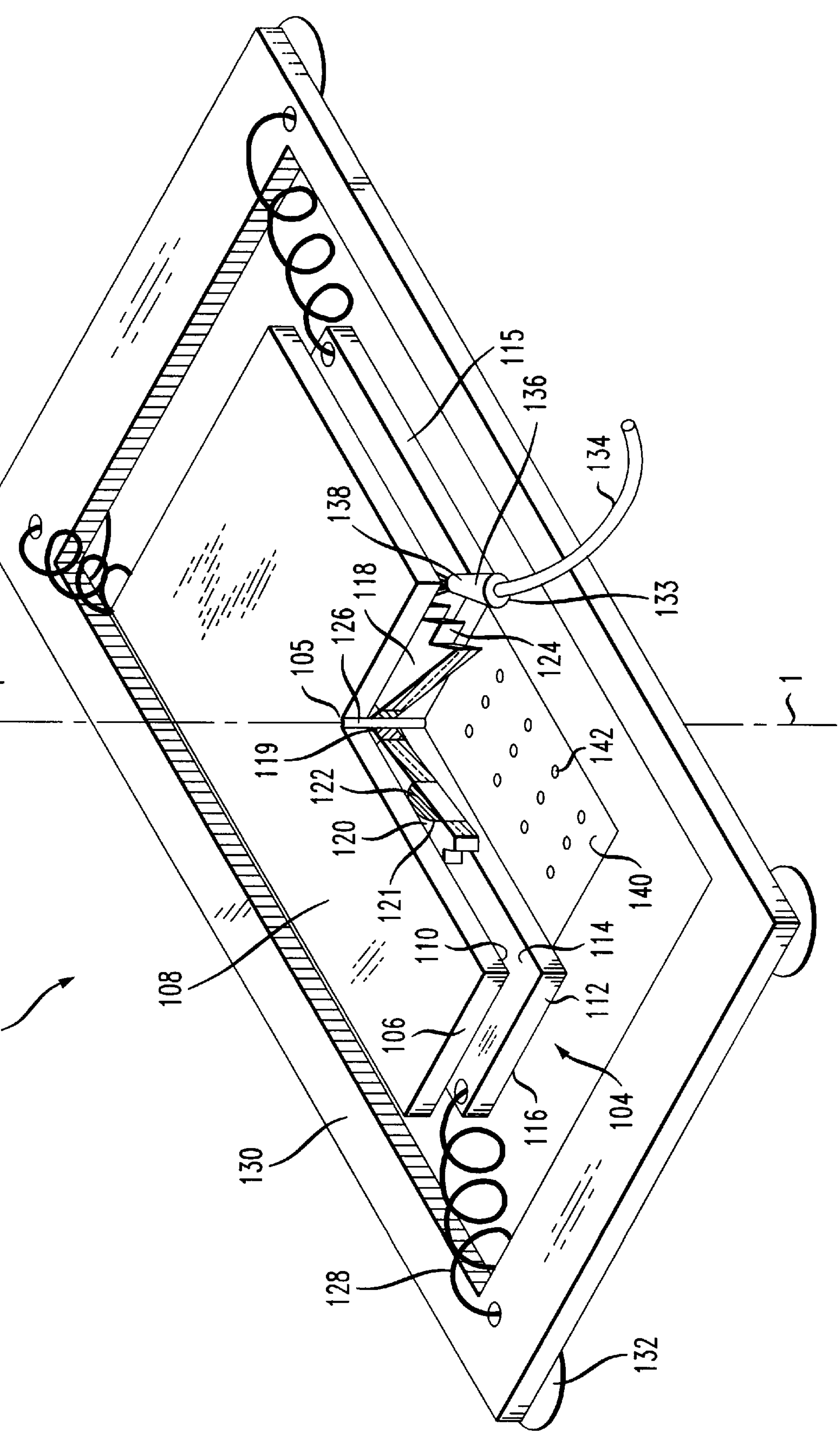

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FIG. 1

FIG. 2

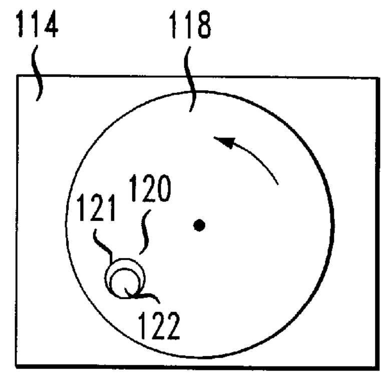
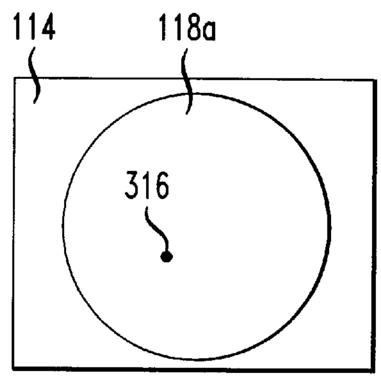


FIG. 3



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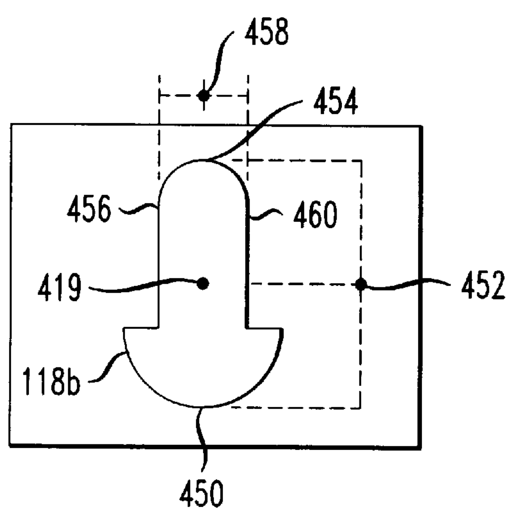


FIG. 5

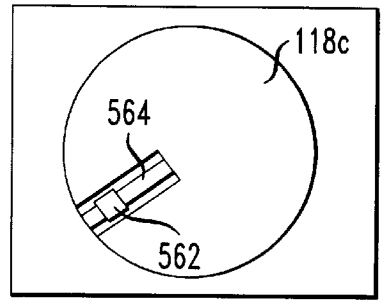


FIG. 6

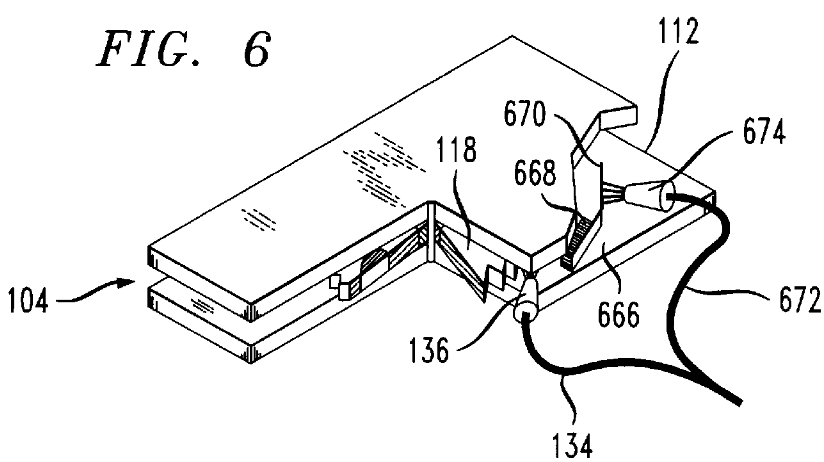
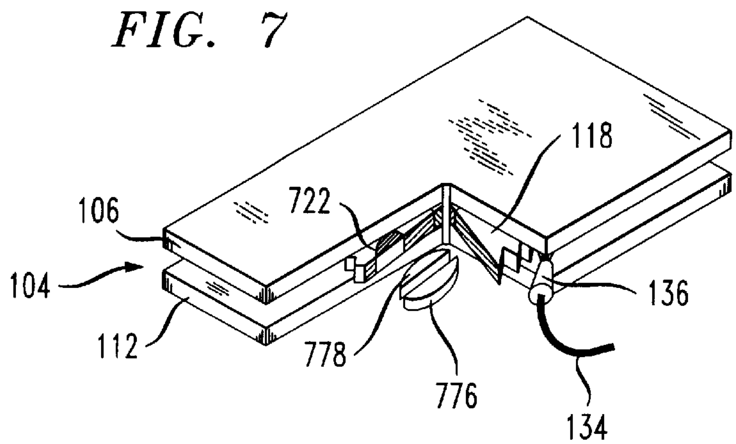


FIG. 7



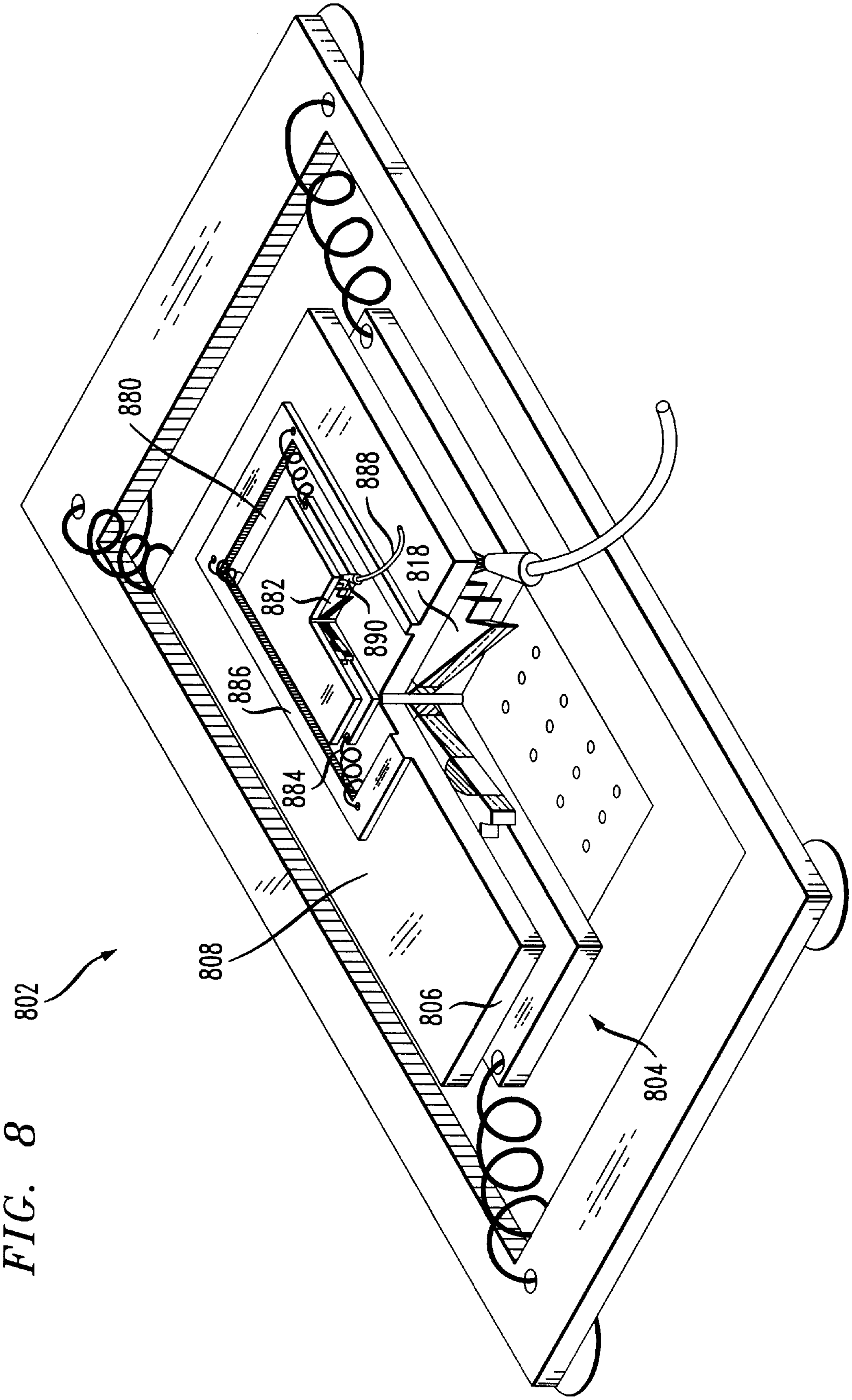


FIG. 8

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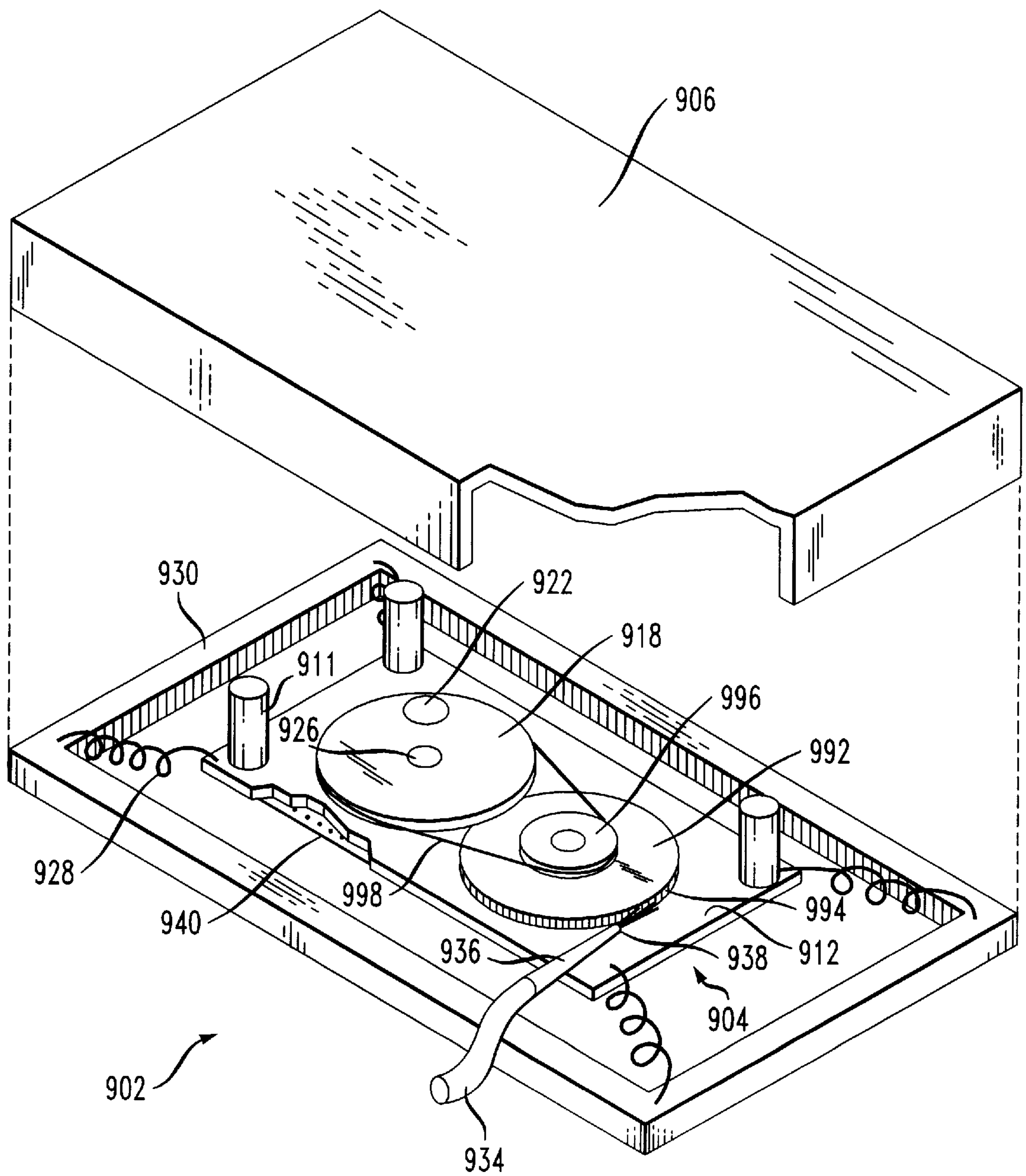
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AGITATOR FOR ORBITAL AGITATION

FIELD OF THE INVENTION

The present invention relates generally to devices useful for agitating or stirring substances contained within a vessel. More particularly, the present invention relates to a device capable of generating a vortex or other efficient mixing motion within a substance contained in a vessel.

BACKGROUND OF THE INVENTION

It is often desirable to agitate/stir substances that are contained within a vessel. Such agitation is useful, for example, for increasing mass and heat transfer coefficients to promote chemical reaction, among other purposes.

Many different types of agitators are known. One type of widely-used agitator is an orbital shaker/agitator. Orbital shakers are used, primarily, for generating a vortex of material within a vessel. Such shakers typically comprise a platform moving in orbital fashion. Large-sized orbital shakers (e.g., platform size greater than about 20 centimeters) characteristically suffer from control and reliability problems. In particular, such shakers have a limited ability to withstand significant mechanical stresses that they receive due to the intense agitation of the relatively large platforms supporting massive loads. On the other hand, small-sized orbital shakers, which are used for agitating small vessels and microtiter plates, are difficult to implement as such shakers must generate very rapid movements with a small, controllable amplitude. Due to the aforementioned difficulties or limitations, orbital shakers tend to be rather expensive and unreliable.

Both large- and small-sized orbital shakers are often integrated into automated fluid handling systems. Such integration typically requires that the orbital shaker must include appropriate means for stopping the platform such that it comes to rest in a predefined position. Existing "robotic-friendly" shakers typically include a "home-position" sensor and related control circuitry to accomplish such a task. The sensor and circuitry increase the complexity of orbital shakers, thereby increasing the expense of and reliability problems with such devices.

In view of the foregoing, the art would benefit from an inexpensive and reliable agitation device capable of generating a vortex or other efficient mixing motions within a captive fluid in both large and small containers. It would be particularly desirable for such a device to be capable of returning to a home position when agitation stops.

SUMMARY OF THE INVENTION

An agitator capable of generating complex mixing motions is described. Such complex mixing motions include, for example, forming a vortex in a captive substance. In some embodiments, an agitator in accordance with the present teachings includes a movable assembly that is suspended, via several resilient supports, from a frame.

The movable assembly advantageously comprises spaced upper and lower plates having a rotatably-supported member disposed therebetween. The mass of the rotatably-supported member is asymmetrically distributed about its rotational axis. A drive means causes the rotatably-supported member to rotate. Due to the asymmetric mass distribution of the rotatably-supported member, force is non-uniformly applied to resilient supports such that, at any given time, some of such resilient supports are subjected to a compressive force while other resilient supports are placed under tension. The particular resilient supports that are subjected to the compressive force change as a function of the rotation of the rotatably-supported member, thereby placing the movable assembly in orbital motion. Such orbital motion generates complex mixing motions, such as a vortex, in material retained within a container located on a receiving surface of the movable assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** depicts an agitator in accordance with an illustrative embodiment of the present invention.

FIG. **2** depicts a first embodiment of a rotatably-supported member having an asymmetric weight distribution.

FIG. **3** depicts a first alternate embodiment of a rotatably-supported member having an asymmetric weight distribution.

FIG. **4** depicts a second alternate embodiment of a rotatably-supported member having an asymmetric weight distribution.

FIG. **5** depicts a third alternate embodiment of a rotatably-supported member having an asymmetric weight distribution.

FIG. **6** depicts a first illustrative embodiment of a braking mechanism for slowing the motion of the movable assembly.

FIG. **7** depicts a second illustrative embodiment of a braking mechanism for slowing the motion of the movable assembly.

FIG. **8** depicts an agitator having dual movable assemblies in accordance with the present teachings.

FIG. **9** depicts an agitator having a belt-drive system in accordance with the present teachings.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** depicts agitator **102** in accordance with an illustrative embodiment of the present invention. Illustrative agitator **102** comprises movable assembly **104** which has a receiving surface **108**. In use, a container (not shown) such as, for example, a microtiter plate, a flask, a test-tube rack containing test-tubes, or the like is placed on receiving surface **108**. As movable assembly **104** moves, such movement agitates material retained in the container. In some embodiments, receiving surface **108** includes guides or other structures (not shown) for preventing a container from sliding off of the receiving surface **108** when assembly **104** is in motion.

In the embodiment depicted in FIG. **1**, movable assembly **104** is suspended within frame **130** via resilient supports **128** that attach to lower plate **112** of the movable assembly. Frame **130** is advantageously rigid so that energy developed in movable assembly **104** is not dissipated within said frame. Frame **130** may be suitably formed, for example, from plastic. Moreover, frame **130** is advantageously attachable to a supporting surface (e.g., bench top), or otherwise capable of being immobilized, so that energy developed in the movable assembly does not cause agitator **102** to move or "walk" across the supporting surface. In the embodiment depicted in FIG. **1**, attachment devices **132**, realized in the illustrated embodiment as suction cups depending from frame **130**, temporarily secure said frame to a supporting surface.

In the illustrated embodiment, resilient supports **128** are springs. It should be understood, however, that other devices or arrangements possessing the characteristic resilience of a spring and its ability to store energy under compression and tension, may suitably be used as resilient supports **128**. In addition to supporting movable assembly **104** above a bench top or other surface so that it is free to move in orbital motion, the resilient supports "guide" movable assembly **104** into orbital motion and serve as a centering means, as described later in this specification.

In the illustrative embodiment depicted in FIG. **1**, movable assembly **104** comprises spaced upper and lower plates **106** and **112**, respectively. Posts or the like (not shown), are used for spacing the upper and lower plates. Rotatably-supported member **118**, shown in partial section for clarity of illustration, is disposed in the space between the upper and lower plates. In the illustrated embodiment, rotatably-supported member **118** is rotatable about pin **126** that passes through said rotatably-supported member **118** and defines the rotational axis **1—1** thereof. In the embodiment depicted in FIG. **1**, rotational axis **1—1** is advantageously located at the geometric center **105** of movable assembly **104** and at the center **119** of rotatably-supported member **118**. Pin **126** is received by a retaining member (not shown) located on inner opposed surfaces **110** and **114** of each of respective upper and lower plates **106** and **112**. In one embodiment, the retaining member is simply a hole in each plate that receives pin **126**.

The mass of rotatably-supported member **118** is asymmetrically distributed about rotational axis **1—1** (hereinafter referred to as an "asymmetrical mass distribution"). Such a rotationally asymmetrical mass distribution may be accomplished in a variety of ways, as described below. In the embodiment depicted in FIG. **1**, an asymmetric mass distribution is achieved by increasing the mass of the rotatably-supported member **118** at a selected eccentric location (i.e., not situated at the geometric center **119** and rotational axis **1—1** of rotatably supported member **118**), such as location **120**. In the illustrated embodiment, such an increase in mass is implemented by disposing load element **122** in bore **121** at location **120**. The aforementioned arrangement wherein an additional mass is located off the rotational axis is illustrated by plan view in FIG. **2**.

It will be recognized that numerous and varied other arrangements that provide an asymmetric mass loading may suitably be used in conjunction with the present invention. A few of such other arrangements are described below.

In a first alternate embodiment depicted in FIG. **3**, an asymmetric mass loading is achieved by locating the rotational axis of rotatably-supported member **118*a*** at an off-center location **316**. In a second alternate embodiment depicted in FIG. **4**, an asymmetric mass loading is achieved by providing an asymmetrically-shaped rotatably-supported member **118*b***. Thus, even though the rotational axis is located at a point **419** that is at the midpoint **452** between edge **450** and **454**, and at a midpoint **458** between edge **456** and edge **460**, the mass of rotatably-supported member **118*b*** can be seen to be asymmetrically distributed about rotational axis **1—1**.

In a third alternate embodiment depicted in FIG. **5**, weight **562** is engaged to rod **564** such that the weight is movable along the rod in a radial direction. Such an arrangement provides a variable asymmetric mass loading to rotatably-supported member **118*c***. By way of example, rod **564** may be implemented as a screw, and weight **562** may be implemented as a nut, with the nut and screw joined in threaded engagement.

Drive **133**, described in more detail later in this specification, causes rotatably-supported member **118** to rotate. Due to the asymmetric mass distribution of rotatably-supported member **118**, force is non-uniformly applied to resilient supports **128** such that, at any given time, two of such resilient supports are subjected to a compressive force while the other two resilient supports are placed under tension. The two resilient supports that are subjected to the compressive force change as a function of the rotation of rotatably-supported member **118** (i.e., the angular position of load element **122**), thereby guiding movable assembly **104** in orbital motion.

By virtue of its structure, illustrative agitator **102** of FIG. **1** advantageously returns movable assembly **104** to a "zero" or "home" position when agitation motion ceases. In agitator **102**, such a homing function is provided by resilient supports **128**. The four identical resilient supports **128** of agitator **102** advantageously return movable assembly **104** to the center of stationary frame **130**.

In some embodiments, an agitator in accordance with the present teachings includes a secondary support device for keeping movable assembly **104** suspended above the supporting surface (e.g., bench top). In the embodiment depicted in FIG. **1**, such a secondary support device is realized as distribution plate **140**. Distribution plate **140** includes a plurality of holes **142** and a feed line (not shown). Compressed air or other conveniently available gas/vapor (hereinafter "lift gas") is directed through the feed line and into distribution plate **140**. The lift gas flows through holes **142** impacting lower surface **116** of lower plate **112** of movable assembly **104**. The force of the lift gas against lower surface **116** "floats" movable assembly **104** ensuring that, in use, the movable assembly does not contact the support surface, which contact would hinder motion.

In the illustrated embodiment, rotatably-supported member **118** is driven by compressed air, or another conveniently available gas/vapor (hereinafter "drive gas"). The drive gas is advantageously delivered to rotatably-supported member **118** via nozzle **136** that depends from an end of drive gas feed conduit **134**. Nozzle end **138** directs drive gas between upper and lower plates **106** and **112** of movable member **104** towards rotatably-supported member **118**. More particularly, nozzle end **138** delivers the drive gas to the perimeter of rotatably-supported member **118** along a path that is substantially tangential to said perimeter. Drive gas impacting the perimeter of rotatably-supported member **118** causes the rotatably-supported member to rotate.

It will be appreciated that the rate of rotation of movable member **118** is primarily dependent upon the rate of flow of the drive gas from nozzle end **138** and the efficiency of energy transfer from the drive gas to movable member **118**. To improve the efficiency of energy transfer to rotatably-supported member **118**, the perimeter of the rotatably-supported member is physically adapted, in some embodiments, to capture the tangentially-directed drive gas. In the embodiment depicted in FIG. **1**, such an adaptation takes the form of uniform serrations **124**, akin to the circumferentially-disposed "teeth" of a gear. In another embodiment, the physical adaptation can be circumferentially-disposed "vanes," as used in turbines. In still other embodiments, the rotatably-supported member **118** can be optimized for energy capture, wherein, for example, the serrations may be non-uniform in size and/or spacing.

When the flow of drive gas is stopped, movable platform **104** will come to rest at its home position. To accelerate that process, an agitator in accordance with the present invention includes, in some embodiments, a braking mechanism. In a first embodiment depicted in FIG. **6**, such a braking mechanism consists of spring-loaded braking brush **666** actuated by auxiliary gas nozzle **674** fed by conduit **672**. During operation of the agitator, a slip-stream of drive gas is diverted, via conduit **672**, to receiving surface **670** of braking brush **666**. The force of the gas against receiving surface **670** overcomes the tendency of a biasing member (not shown) to bias braking surface **668** against rotatably-supported member **118**. When the flow of drive gas is stopped, the biasing member biases braking surface **668** against rotatably-supported member **118**, thereby providing braking action. FIG. **7** depicts a second embodiment of a braking mechanism that is particularly well suited for use with agitators that utilize a load element (see FIGS. **2** and **5**) for providing the required asymmetric mass distribution. The braking mechanism comprises an electrically-activated magnet, depicted as poles **776** and **778**, that is disposed within the lower plate **112** or upper plate **106** of the movable assembly **104**. In such embodiments, the load element advantageously comprises a magnetic material. Thus, to stop the agitator, drive gas is cut off and the magnet is energized. The ensuing magnetic interaction between magnet **776**/**778** and magnetic load element **722** rapidly stops rotatably-supported member **118**.

The characteristics of the orbital motion of movable platform **104** are primarily dependent upon (1) geometric parameters; (2) the "spring" constant of the resilient supports; (3) the specifics of the asymmetric weight distribution; and (4) the rate of rotation of the rotatably-supported member **118**. The effect of each of such parameters on the orbital motion of movable platform **104** is described below.

Geometric parameters determine the precise shape of the orbital motion. More particularly, with regard to illustrative agitator **102**, one resilient support **128** depends from each corner of rectangularly-shaped lower plate **112** of movable assembly **104**. For such an arrangement, the "orbit" is oval or ellipsoidal in shape. In another embodiment, a circular orbit is obtained by moving the attachment points of resilient supports **128** inwardly along long edges **115** of lower plate **112** such that the attachment points define a square. A circular orbital motion can also be obtained by attaching the resilient supports **128** to the corners of a square-shaped lower plate.

The amplitude of motion of movable assembly **104** is determined, in part, by the "spring" constant of resilient supports **128**. The spring constant and the amplitude of motion have an inverse relationship. For example, a relatively larger spring constant results in a relatively smaller amplitude of motion, and vice versa. Additionally, the amplitude of motion is influenced by the asymmetric mass distribution of rotatably-supported member **118**. More particularly, with respect to the illustrative embodiment depicted in FIG. **1**, the radial position and weight of load element **122** influences amplitude. The closer that load element **122** is to the perimeter of rotatably-supported member **118**, or the greater the weight of load element **122**, the larger the amplitude of motion. The frequency of the orbital motion of movable assembly **104** is determined by rate at which rotatably-supported member **118** is driven.

While mathematical expressions that quantitatively describe the aforementioned relationships can be developed, such expressions do not describe the behavior of a captive fluid being agitated by the present agitator. Rather, given an agitator comprised of selected components (e.g., resilient supports having a specific spring constant, a rotatably-supported member having a specific asymmetric mass distribution, a movable platform having a particular shape, etc.), the behavior of substances retained with a container of interest (e.g., 96 well microtiter plate, 1536 well microtiter plate, etc.) are visually monitored to determine when a desired agitation behavior (e.g., vortexing) is established. Such desired agitation behavior can then be associated with a specific revolutions-per-minute (rpm) of rotatably-supported member **118** in a variety of ways known in the art. For example, rpm can be electrically determined using a magnetic pick-up coil and a frequency meter or oscilloscope, or optically determined via a stroboscope. In embodiments in which rotatably-supported member **118** is driven by drive gas, the desired agitation behavior can be associated with a specific drive gas flow rate by placing a flow meter in-line and noting the flow rate at the onset of the desired agitation behavior.

Illustrative agitator **102** provides a simple, reliable device for generating a vortex within a substance contained in a vessel. FIG. **8** depicts a second illustrative embodiment of an agitator **802** in accordance with the present teachings.

Agitator **802** is adapted to provide random and very efficient mixing action. In illustrative agitator **802**, upper movable assembly **880** is suspended within frame **886** by resilient supports **884**. Frame **886** is disposed on upper surface **808** of top plate **806** of lower movable assembly **804**. Frame **886** can be formed integrally with upper plate **806**, (e.g., molded as part of upper plate **806**) or, alternatively, can be suitably attached to upper plate **806** in any convenient manner (e.g., epoxy, etc.). Sufficient spacing should be provided between upper movable assembly **880** and upper surface **808** so that when a container is placed on the upper movable assembly, it does not "bottom out," touching upper surface **808**. Such spacing is dependent upon the height of the frame **886** above upper surface **808** and the spring constant of resilient supports **884**.

In an alternative embodiment (not shown), a portion of upper plate **806** can be removed such that upper movable assembly **880** is suspended by resilient supports **884** within such a cut-out region. In such an embodiment, frame **886** may not be necessary. Rather, resilient supports **884** can be attached directly to upper plate **806**. Care must be taken to ensure that when a container is placed on upper movable platform **880**, the weight of such a container does not force the upper movable assembly to contact first rotatably-supported member **818**.

Upper and lower movable assemblies **804** and **880** are arranged in the manner of movable assembly **104** of FIG. **1**. Upper movable assembly **880** includes second rotatably-supported member **882** having an asymmetric weight distribution, drive gas feed conduit **888**, nozzle **890**, and the like. Agitator **802** allows for the generation of random and very efficient mixing motion via the superimposition of different rotation patterns generated by the two movable plates.

EXAMPLE 1

Agitators similar to agitator **102**, as depicted in FIG. **1**, and in accordance with the present teachings, were fabricated. The agitators were able to generate a vortex in the wells of 96-, 384- and 1536-well microtiter plates. The upper and lower plates (e.g., plates **106** and **112** of agitator **102**), which were made from plexiglass, had a standard outer dimension of 5 inches by 3 inches. Conventional "expansion-type" springs were used as the resilient supports (e.g., supports 128 of agitator **102**). The springs used in the agitators had spring constants in the range of from about 0.8 to 65 lb/inch. The spring constant was selected based on several performance considerations. Such considerations included, for example, avoiding system resonance over the expected operating frequencies and obtaining a suitable amplitude of deflection, among other considerations.

All rotationally-supported members were made from plastic, including Delrin™, which is an acetal-based plastic made by DuPont, Nylon and Fiberglass. High speed ball bearings, as well as self-lubricating composite bearings, were used in conjunction with the rotatably-supported member.

The rotational speed for developing a vortex within wells of the microtiter plates varied as a function of well size. In particular, for a 96-well plate having a well diameter of about 5 mm, vortexing began at about 1300 RPM of the rotatably-supported member. For a 1536-well plate having a well diameter of about 1 mm, vortexing was observed in the range of about 10,000 RPM.

The above-described illustrative embodiments of the present agitator use a "direct"- drive system. In the illustrated direct-drive system, the action of the drive gas against the rotatably-supported member drives said rotatably-supported member. While such a direct-drive system is particularly well suited for generating relatively higher agitation rates, other arrangements are advantageously used when lower agitation rates are desired. Lower agitation rates may be desired, for example, when attempting to develop a vortex within a fluid contained in a vessel having a very large diameter (there is an inverse relationship between the agitation speed required for vortexing and container diameter).

FIG. **9** depicts an exploded view of an illustrative embodiment of an agitator **902** particularly well suited for generating lower agitation rates. Agitator **902** advantageously incorporates a belt-drive system for driving the rotatably-supported member. The overall layout of agitator **902** is similar to the previously-described illustrative agitators. In particular, agitator **902** comprises movable assembly **904** which has a receiving surface **908**. Movable assembly **904** is suspended within frame **930** via resilient supports **928** that attach to lower plate **912** of the movable assembly.

Movable assembly **904** comprises spaced upper and lower plates **906** and **912**, respectively. In FIG. **9**, movable assembly **904** is depicted with upper plate **906** removed so that rotatably-supported member **918** and the drive system, which in illustrative agitator **902** are disposed on lower plate **912**, are visible. Separators **911** are used for spacing the upper and lower plates **906** and **912**.

In the illustrated embodiment, rotatably-supported member **918** is rotatable about pin **926** that passes through it and defines the rotational axis thereof. Like agitator **102**, the mass of rotatably-supported member **918** is asymmetrically distributed about its rotational axis. In the illustrated embodiment, such an asymmetrical mass distribution is achieved utilizing an eccentrically located (i.e., not aligned with the rotational axis) loading element **922**. As the rotatably-supported member **918** rotates, force is non-uniformly applied to resilient supports **928** due to the asymmetric mass distribution of the rotatably-supported member. As a result, movable assembly **904** is guided into orbital motion as previously described.

Like agitators **102** and **802**, illustrative agitator **902** is advantageously structured to return movable assembly **904** to a home position when agitating motion ceases. Since agitator **902** will typically be agitating relatively massive loads, it advantageously includes a secondary support device for providing additional support for movable assembly **904**.

In the illustrated embodiment, the secondary support device is realized as distribution plate **940**, configured in the manner of distribution plate **140**, previously described. (See FIG. **1** and accompanying description). Moreover, agitator **902** advantageously includes a braking mechanism (not shown), such as previously described.

Illustrative agitator **902** utilizes a belt-drive system for driving the rotatably-supported member, as opposed to the direct-drive system of agitators **102** and **802**. The belt-drive system includes a rotatable drive member **992**, pulley **996**, belt **998**, nozzle **936** and drive gas feed conduit **934**.

In operation, drive gas (e.g., compressed air or other suitable fluid) is delivered to drive member **992** via nozzle **936** that depends from an end of drive gas feed conduit **934**. Nozzle end **938** directs drive gas towards the perimeter **994** of drive member **992** along a path that is substantially tangential to said perimeter. Drive gas impacting the perimeter of drive member **992** causes the drive member to rotate. Like rotatably-supported member **118**, the perimeter of drive member **992** is advantageously physically adapted to capture the tangentially-directed drive gas using uniform serrations, vanes, teeth and the like.

An arrangement for transferring the rotation of drive member **992** to rotatably-supported member **918** is provided. In the illustrated embodiment, the arrangement consists of pulley **996** that is rigidly attached to drive member **992**, and belt **998** that mechanically links pulley **996** to rotatably-supported member **918**.

In embodiments in which agitator **902** is intended to agitate materials contained in very large vessels, the agitator provides a low agitation rate. Consequently, rotatably-supported member **918** should be driven at a low rate of speed. Turning down the flow of compressed air to slow the rate of rotation of rotatably-supported member **918** may become problematic once a certain minimum flow rate is reached. As an alternative, a low drive speed may be obtained by providing pulley **996** having a smaller circumference than that of drive member **992**. It will be appreciated that, when the drive system is so configured, the velocity of pulley **996** at its perimeter is lower than the velocity of drive member **992** at its perimeter. As such, rotatably-supported member **918**, driven by pulley **996**, rotates at a lower rpm than drive member **992**. In this manner, the rate of rotation of rotatably-supported member **918** may be reduced to very low speeds while drive gas flow is maintained at a suitably high rate.

EXAMPLE 2

An agitator incorporating a belt-drive system for driving the rotatably-supported member was fabricated. All parts were made out of plastic. The rotatably-supported member is a glass-filled nylon, and the weights used to provide the mass loading were either steel inserts or lead that was poured into a pre-drilled cavity in the rotatably-supported member. The pulley was made of Delrin™ (DuPont), and bearings for the rotatable members were ball bearings or non metallic bearings such as Rulon™ J available from Dixon Industries. A "friction-type" belt (e.g., an O-ring) or Polycord™, available from SMI Small Parts Inc. of Miami Lakes, Fla., was used for connecting the pulley to the rotatably-supported member.

The upper and lower plates were substantially larger than those used for the agitators described in EXAMPLE 1, and were able to support a vessel having a diameter as large as about 10 inches. The agitator developed a maximum agitation speed of about 1000 rpm.

It is to be understood that the embodiments described herein are merely illustrative of the many possible specific arrangements that can be devised in application of the principles of the invention. Other arrangements can be devised in accordance with these principles by those of ordinary skill in the art without departing from the scope and spirit of the invention. It is therefore intended that such other arrangements be included within the scope of the following claims and their equivalents.

We claim:

1. An article comprising:

a movable assembly supported by resilient supports;

a rotatably-supported member in mechanical communication with said movable assembly, the rotatably-supported member having a rotationally asymmetric weight distribution;

a secondary support device for supporting said movable assembly, said secondary support device comprising an element operable to distribute lift gas across a surface of the movable assembly such that said lift gas at least partially supports said movable assembly; and

a drive for causing the rotatably-supported member to rotate, wherein,

upon rotation of the rotatably-supported member, the movable assembly is placed in orbital motion due to the rotationally asymmetric weight distribution of said rotatably-supported member.

2. The article of claim **1** further comprising:

a frame, wherein the resilient supports are attached to said frame.

3. An article comprising:

a movable assembly supported by resilient supports;

a rotatably-supported member supported by said movable assembly, the rotatably-supported member having a rotationally asymmetric weight distribution; and

a drive for causing the rotatably-supported member to rotate, said drive using a flow of drive gas to cause rotation of said rotatably-supported member.

4. The article of claim **3** further comprising a frame wherein said resilient supports are attached to said frame.

5. The article of claim **4**, and further comprising:

a secondary support device for supporting the movable assembly.

6. The article of claim **5**, wherein the secondary support device comprises a distribution plate operable to distribute lift gas across a surface of the movable assembly such that the lift gas at least partially supports the movable assembly.

7. The article of claim **3**, wherein the movable assembly comprises first and second spaced, superposed plates.

8. The article of claim **7**, wherein the rotatably-supported member is disposed in the space between the first and second plates of the movable assembly.

9. The article of claim **8**, wherein the rotatably-supported member comprises a load member disposed at a location that is offset from a rotational axis of the rotatably-supported member, thereby providing the rotationally asymmetric weight distribution.

10. The article of claim **9**, wherein the load member is movable in a radial direction, thereby providing a variable rotationally asymmetric weight distribution.

11. The article of claim **3**, wherein the drive comprises a nozzle operable to deliver said drive gas to a perimeter of the rotatably-supported member, wherein impact of said drive gas at the perimeter of the rotatably-supported member causes the rotatably-supported member to rotate.

12. The article of claim **11**, wherein the perimeter of the rotatably-supported member is physically adapted to receive said drive gas.

13. The article of claim **12**, wherein the physical adaption is a plurality of serrations.

14. The article of claim **3**, wherein the drive comprises:

a rotatable drive member;

a nozzle operable to deliver said drive gas to a perimeter of the rotatable drive member, wherein impact of said drive gas at the perimeter of the rotatable drive member causes the rotatable drive member to rotate;

a pulley attached to the rotatable drive member; and

a belt for mechanically linking the pulley to the rotatably-supported member, wherein,

as the pulley rotates due to the rotation of the rotatable drive member, the belt moves causing the rotatably-supported member to rotate.

15. The article of claim **14**, and further wherein the pulley has a perimeter that is smaller than the perimeter of the rotatable drive member, so that the rotatably-supported member is rotated at a speed slower than a speed at which the rotatable drive member rotates.

16. The article of claim **3**, wherein the resilient supports are springs.

17. The article of claim **3**, wherein attachment points at which the resilient supports are attached to the movable assembly are symmetrically distributed over a surface of the movable assembly.

18. The article of claim **17**, wherein the attachment points collectively define a square.

19. An article comprising:

a movable assembly supported by resilient supports;

a rotatably-supported member supported by said movable assembly, the rotatably-supported member having a rotationally asymmetric weight distribution;

a drive for causing the rotatably-supported member to rotate; and

a second movable assembly that is supported, via a second set of resilient supports, from the movable assembly.

20. The article of claim **19**, and further comprising:

a second rotatably-supported member in mechanical communication with the second movable assembly, the second rotatably-supported member having a rotationally asymmetric weight distribution; and

a second drive for causing the second rotatably-supported member to rotate.

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