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[54] CENTRIFUGE ROTOR

[75] Inventors: **William L. Schmidt**, Boulder, Colo.; **Herschel E. Wright**, Santa Clara, Calif.

[73] Assignee: **Beckman Instruments, Inc.**, Fullerton, Calif.

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[52] **U.S. Cl.** **233/27**, 233/32

[51] **Int. Cl.** **B04b 7/06**

[58] **Field of Search** .... 233/1 R, 26, 32, 33, 44, 233/27, 28, 46, 1 B, 1 A

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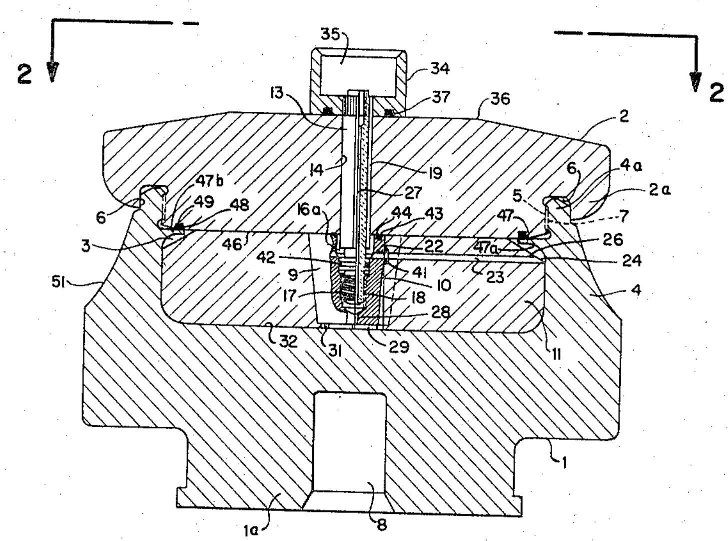
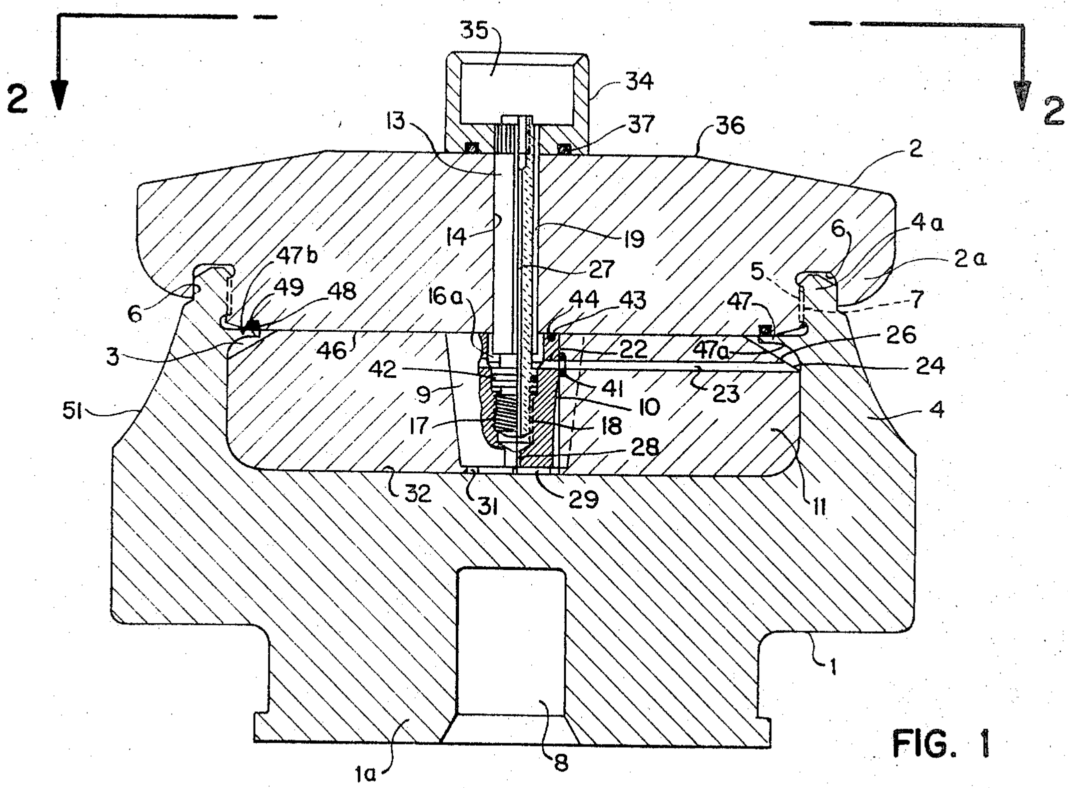
Primary Examiner—George H. Krizmanich
Attorney, Agent, or Firm—R. J. Steinmeyer; F. L. Mehlhoff

[57] **ABSTRACT**

A rotor for a centrifuge apparatus having a substantially cylindrical sidewall forming a bowl-like chamber open on one side thereof, and including a cover secured to the cylindrical sidewall and closing the opening to the chamber. The rotor also includes a resilient sealing lip attached to the sidewall and overhanging the chamber, the lip having an upper surface engaging a lower surface of the cover and having sufficient resiliency to follow movement of the cover under hydrostatic pressures produced in the rotor during centrifugation of liquid products within the chamber.

5 Claims, 2 Drawing Figures

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2
35
34
13
37
36
2
14
19
4a
6
2a
47b
49
48
27
5
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16a
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43
47
7
26
3
46
22
47a
24
42
41
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9
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51
17
18
28
32
31
29
11
1
1a
8

FIG. 1

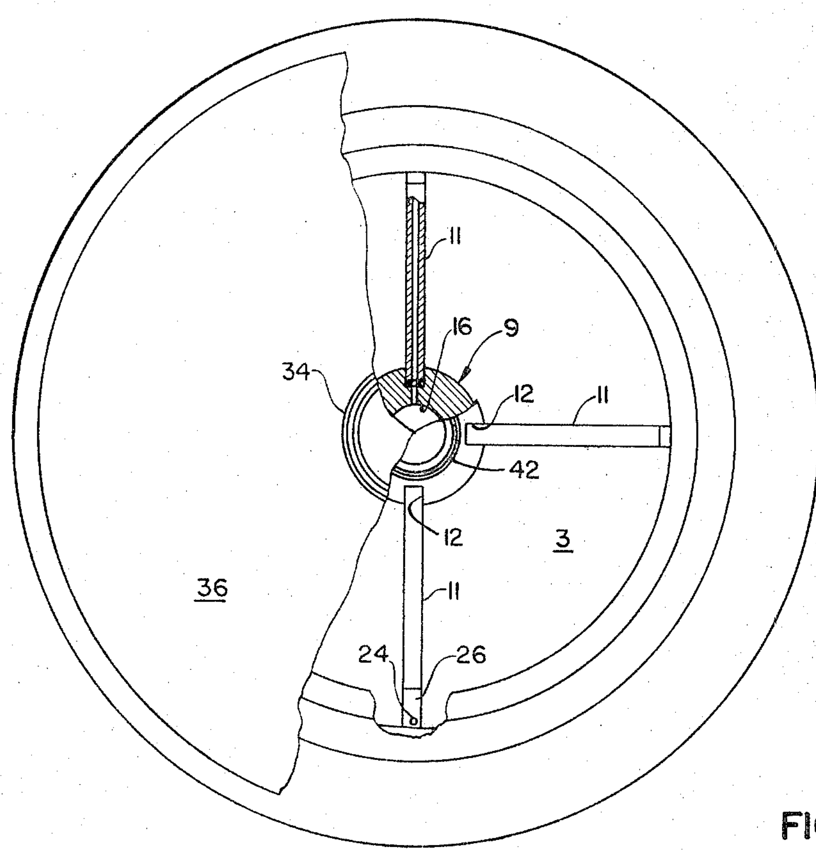
11
16
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FIG. 2

CENTRIFUGE ROTOR

BACKGROUND OF THE INVENTION

The invention described herein relates generally to rotors for centrifuge apparatus and more particularly to an improved bowl-type rotor of the type employed for zonal centrifugation.

The apparatus is utilized to provide quantitative separations of minute particulate matter, such as tissue cells or cell particles, or the like, in density gradients for the purpose of collecting discrete fractions thereof for subsequent analysis in research and clinical studies. Typically, in a bowl-type rotor, a sample solution is pumped into the central region of a rotor chamber which is filled with an appropriate density gradient solution. During centrifugation, the particles of interest in the sample disperse in a radial direction throughout the density gradient solution and at equilibrium are suspended in concentric layers in the density gradient solution at a location wherein their respective buoyant densities correspond to that of the solution.

During centrifugation of bowl-type rotors tremendous hydrostatic pressures are developed within the rotor at the extremities or outer walls of the bowl. The hydrostatic pressures tend to force the wall of the rotor outwardly and also create an upward thrust on the cover in the region adjacent the joint between the bowl rotor and its cover. The outward pressure on the rotor walls also creates a moment of force around the rotor bowl which, in turn, creates an upward thrust at the central portion of the bowl. The hydrostatic forces are so great that they sometimes cause separation between the cover of the bowl and the wall of the rotor where connected and result in a leakage of the liquid solution from the rotor. In an attempt to overcome this, a resilient seal, such as a resilient O-ring, is sometimes employed between the rotor wall and the cover which will prevent leakage of the solution from the rotor chamber. However, the seal member around the cover or the sidewall of the rotor is placed under extreme stress during the high speed centrifugation and, when the rotor and lid separate, the force of the solution on the seal very often causes the seal member to extrude from its seat thereby releasing the solution from the chamber.

SUMMARY OF THE INVENTION

In accordance with the invention, there is provided an improved bowl-type zonal centrifuge rotor including a base having a substantially cylindrical sidewall forming a bowl-shaped chamber over which is mounted a cover member and which is attached to the cylindrical sidewall. A resilient flexible sealing lip protrudes inwardly from the sidewall over the rotor chamber, the lip having a smooth surface adapted to abut against the cover in the region of a resilient sealing member or O-ring seated in an annular slot formed in the cover. The flexible lip maintains a sealing pressure against the cover and its O-ring and, under hydrostatic pressure created during centrifugation, the flexible lip moves with any slight movement of the cover to maintain a constant sealing pressure against the O-ring. A central core positioned within the rotor between the cover and the bottom of the chamber provides a vertical thrust against the bottom wall of the rotor chamber which thrust is opposite from the moment of force created by the centrifugal forces on the sidewall of the rotor. This reduces the upward displacement of the bottom wall of the rotor and reduces the movement of the sidewall in a direction radial to the axis of rotation.

It is an object of the present invention to provide a new and improved bowl-type rotor with an attached cover in which the hydrostatic forces, created by the liquid within the rotor during centrifugation, are reduced in the region of the seal between the cover and the sidewall to which it is attached.

It is another object of this invention to reduce the deflection between the cover and the sidewalls of the bowl by reducing the hydraulic axial loading on the cover.

It is another object of the present invention to provide a bowl-type rotor having a central core designed to oppose the upward thrust normally occurring in the bottom central portion of the bowl-shaped rotor during high speed centrifugation.

Further objects and advantages of the invention will become apparent as the following description proceeds, and the features of novelty which characterize the invention will be pointed out with particularity in the claims annexed to and forming a part of the specification.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a vertical sectional view of a rotor bowl assembly made in accordance with the present invention;

FIG. 2 is a plan view taken generally along the line 2—2 with portions of the rotor bowl assembly broken away to illustrate the location of the central core and the core wings with respect to the chamber in the rotor.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawing, and, more particularly, to FIG. 1, there is shown a rotor bowl 1 having a substantially cylindrical sidewall 4 enclosing a bowl-shaped chamber 3 over which there is positioned a lid or cover member 2. In order to retain the cover 2 in place, the sidewall 4 of the rotor is provided with threads 5 adjacent the open end thereof and the outer edge portion *4a* of the rotor sidewall is adapted to fit snugly within an annular cavity 6 formed in the cover 2. Threads 7 on the cavity wall are adapted to mate with the thread 5 on the rotor sidewall so that the cover may be threaded down tightly onto the sidewall of the motor. The overhanging edge *2a* of the cover helps retain the sidewall 4 in place against the centrifugal forces produced during high speed rotation of the apparatus. In the base portion *1a* of the rotor, there is provided a well 8 which is adapted to receive a drive spindle (not shown) extending from the driving mechanism of a centrifuge apparatus.

Within the chamber 3, there is provided a rotor core or centerpiece 9 which is a relatively solid member, formed of a suitable metal, and which is tapered slightly in an outward direction from bottom to top. The core is provided with a plurality of slots 12 (see FIG. 2) formed in the outer surface thereof in a direction parallel to the vertical axis of the core 9. A plurality of projecting vanes or wings 11 (three of which are shown in FIG. 2) each have one end positioned in one of the slots 12 and extend radially outward thereby dividing the rotor chamber into equal sector compartments for minimizing turbulence during operation of the apparatus. Because the core or centerpiece **9** is subjected to high axial loading and because the core wings **11** must extend to the cavity wall under the lip **47**, it is necessary to construct the core **9** and vanes **11** as separate parts and assemble them in the rotor chamber **3**.

In assembling the rotor core **9** within the chamber **3**, the vanes **11** are first inserted into the camber **3** and positioned generally into their relative positions therein. The core **9** is then inserted into the chamber so that the ends of the vanes extend into slots **12** formed in the rotor core. In order to facilitate insertion of the core or centerpiece **9** and permit orientation of the vanes **11** within the slots **12**, each of the slots **12** is indented in the lower end adjacent the bottom of the core and tapered or beveled to form a ramp **10** so that there is a slight tolerance, permitting the ends of the vanes to fit initially into the slots **12**. As the core centerpiece **9** is moved downwardly into the chamber, the ramp **10** forces the vanes **11** outwardly against the inner surface of the sidewall of the motor chamber. The outer ends of the vanes **11** conform to the bowl shape of the chamber and fit snugly against the sidewall beneath the lip **47**. The rotor core abuts the bottom **32** of the cavity and legs or abutments **31** support the core thereon.

Inserted centrally within the rotor core is a feed or transfer tube assembly **13** which extends downwardly through an aperture **14** formed in the cover **2** into a cavity **16** formed in the rotor core **9**. The lower end of the transfer tube **13** is provided with screw threads **17** which mate with internally formed threads **18** formed within the cavity **16** of the rotor core. The transfer tube **13** includes an outer conduit **19** (or plurality of conduits **19**) formed as slots in the outer surface of the shaft **13**. Slots **19** communicate with an enlarged opening **16*a*** in the upper portion of the rotor core. This opening **16*a*** in turn communicates with radial passages **22** in the wall of the core each of which communicate with passages **23** extending through each of the vanes or wings **11** and opening into the chamber **3** at the end of each wing. An opening **24**, formed in a beveled or cutaway portion **26** of each vane, communicates with the upper portion of the chamber. The core member acts as a manifold to deliver fluids into each of the vanes **11**.

The feed or transfer tube **13** is also provided with a central tubular conduit **27** which extends completely through the axial length of the transfer tube and communicates with a passage **28** formed in the lower end of the core. Passages **29** formed in the lower end of the rotor core **9** by means of abutments or shoulders **31** communicate with the passage **28** in the core. At least one of the passages **29** leads into each of the segments between the vanes **11** within the chamber. Attached to the upper end of the transfer tube is a cup **34** having an opening **35** therein which communicates with the passages **19** and **27** in the transfer tube. In operation, a liquid delivery means (not shown) is inserted into the opening of the cup **34** for introducing liquid gradient and sample materials through the passages **19** and **27** and thence into the rotor chamber. Cup **34** is firmly attached to the end of the transfer tube **13** and is tightly pulled downwardly against the upper surface **36** of the lid **2** so that an O-ring **37** formed within an annular slot in the lower surface of the cup abuts in sealing fashion against the upper surface **36** of the lid.

In order to provide a seal between the passages **23** formed in the vanes **11** and the passages **22** formed in the rotor centerpiece, a small O-ring or resilient seal ring **41** is provided within an enlarged opening surrounding the pasage **23**. O-ring **41** seals around the surface of the pasage **23** and the surface of the core leading into the opening **22**. Another resilient seal member **42** is fitted within a slot formed on the surface of the transfer tube **13** and abuts against the inner surface of the cavity **21** in the upper end **16*a*** of the core centerpiece. This seal **42** prevents the flow of liquid beyond the upper end **16*a*** of the cavity **21** and forces liquid from the cavity into the passages **22** and thence into the passages **23** formed in vanes **11**. In order to prevent leakage around the upper surface of the core centerpiece **9**, there is also provided an annular sealing means in the form of a resilient O-ring **43** positioned within an annular slot **44** in the upper surface of the core. The O-ring **43** abuts against the lower surface **46** of the cover **2** when the cover is tightened down onto the rotor. In addition the cover actually has its lower surface **46** abutting tightly against the upper flat surfaces of the core.

In a typical operation of the above-described rotor, a rotatable liquid delivery means (not shown) is inserted into the cup **34** through which a liquid may be pumped into the rotor. The rotor bowl is first loaded with a liquid gradient which is pumped into the bowl through the conduits **19, 21, 22** and **23**. During the loading operation, the rotor bowl is rotated at a low speed (500–3,000 r.p.m.) causing the gradient liquid to form concentric annular "zones" of constant density liquid. The vanes **11** extend radially through the "zones," segmenting them and reducing mixing between adjacent zones of different densities. After the rotor bowl is filled with a liquid of graded density, a sample to be centrifuged is pumped through the conduit or transfer tube passage **27** where it flows through the passage **28** and the passages **29** beneath the rotor core into the center portion of the rotor chamber. The sample is normally followed by an overlay of low density liquid to move the sample clear of the core **9** and to assure complete removal of the sample from beneath the rotor core. The means for inserting the liquid materials into the rotor is then removed and the cap **34** is closed with a suitable sealing cap (not shown) to close the passages **19** and **27**. The rotor is then accelerated for the actual centrifuging operation.

When centifugation has been completed, the rotor bowl is decelerated to unloading speed (500–3,000 r.p.m.) and the rotor contents emptied through the liquid delivery means by pumping high density fluid to the outer wall of the rotor cavity through the passages **19, 21 22** and passages **23**. The high density fluid forces the gradient and the sample, dispersed in the annular gradient rings, toward the rotor core **9** and the taper on the exteral surface of the rotor core forces each of the gradient rings to flow downwardly through the passages **29** and up the central passage **27** of the transfer tube and thence out through the delivery means attached to the upper end of the transfer tube.

As the rotor is subjected to the high angular velocity by a drive hub at **8**, the resulting hydraulic forces within the chamber cause the cover **2** and the bowl **1** to tend to move relative to one another. These members are restrained only by the threads and the overhanging lip **2*a*** of the cover at **2*a***. This hydraulic force is proportional to the fourth power of the maximum radius at which it can act. In order to effectively reduce the radius at which these forces may act on the cover, the rotor is provided with a lip 47 extending from an upper portion of the sidewall 4, which intrudes radially into the clearance volume adjacent the lid 2 of the rotor. The lip 47 has a lower curved surface 47*a* and an upper flat surface 47*b*. At its base or connection with sidewall 4, the lip is relatively thick but it gradually tapers toward the end intruding into the chamber.

The thinner portion of the lip 47 are somewhat resilient and flex under the influence of axial hydraulic force such that as the lid 2 moves upwardly under the hydraulic pressure, the lip 47 moves just enough to follow the cover's motion and maintains contact with a resilient O-ring seal 48 positioned in an annular slot 49 within the lower surface of the cover. The upper surface 47*b* of the lip 47 is flat and maintains continuous contact with the O-ring 48 as the cover and sidewalls of the motor move relative to each other. At the base of the lip 47, it is much thicker and much less resilient so that any load exerted by the hydraulic forces is prevented from being transmitted to the cover in this region. The hydraulic forces may be transmitted in an upward direction toward the cover only at the inner edge of the resilient lip 47. Since this is at a radius much less than the outer extremity of the rotor wall, the hydraulic pressure exerted against the inner surface of the cover 2 is less than would normally be present if there were no resilient lip or seal abutting the lower surface of the cover.

Under the influence of centrifugal force, the wall of the rotor at 51 tends to move radially outward. Since this wall is attached to the base and restrained by the base, this tendency to move outward results in a moment about the center of the base causing the center to move upwardly relative to the threads of the cylindrical wall at 7. This upward movement of the central portion of the base is restrained by virtue of the force exerted by the cover 2 downwardly against the heavy metallic core member 9 which tends to exert a force axially against the base. By restraining the center of the base from bulging upward by the use of the rigid central core 9, the radial excursion of the sidewall 4 of the rotor is reduced with a corresponding reduction in stresses in the sidewall 4 under high speed centrifugation.

While in accordance with the patent statutes there has been described what at present is considered to be the preferred embodiment of the invention, it will be understood by those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, the aim of the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A rotor for a centrifuge apparatus comprising

a rotatable bowl having a base and a substantially cylindrical sidewall forming a chamber having an open side substantially coextensive with said cylindrical sidewall;

a cover for closing said open side of said chamber;

means for securing said cover to said sidewall of said rotatable bowl; and

a resilient lip attached to said sidewall and overhanging said chamber, said lip having an upper surface engaging the lower surface of said cover, said lip having sufficient resiliency to permit it to move and follow movement of said cover thereby maintaining sealing contact with said cover during centrifugation of liquid products within said chamber.

2. A rotor for a centrifuge apparatus comprising

a rotatable bowl having a base and a substantially cylindrical sidewall forming a chamber having an open side substantially coextensive with said cylindrical sidewall;

a cover for closing said open side of said chamber, including means engaging said sidewall for supporting said cover over said chamber, said cover having a substantially flat lower surface;

means for delivering liquid gradient and sample products through said cover into said chamber; and

a resilient lip attached to said sidewall and overhanging said chamber, said lip having an upper surface engaging said substantially flat surface of said cover, said lip having sufficient resiliency to permit it to move and follow movement of said cover thereby maintaining sealing contact with said cover during centrifugation of liquid products within said chamber.

3. The rotor defined in claim 2 in which said cover includes an annular groove formed in the lower surface thereof in which is mounted a resilient O-ring and said resilient lip extending from said sidewall is so constructed and arranged as to engage said O-ring and follow movement thereof to maintain sealing contact with said O-ring during centrifugation of liquid products within said chamber.

4. The rotor defined in claim 1 in which said resilient lip is relatively thick at its attachment to said sidewall and gradually reduces in thickness to form a resilient portion which moves in response to hydrostatic pressure in said chamber created during centrifugation thereby forcing said resilient lip to maintain contact with said cover.

5. The rotor defined in claim 4 in which said cover is provided with an annular groove in the lower surface facing said chamber, and an O-ring is disposed in said groove and said resilient lip is so positioned and disposed as to engage said O-ring thereby maintaining sealing contact with said O-ring and said cover during centrifugation of liquid products within said chamber.

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