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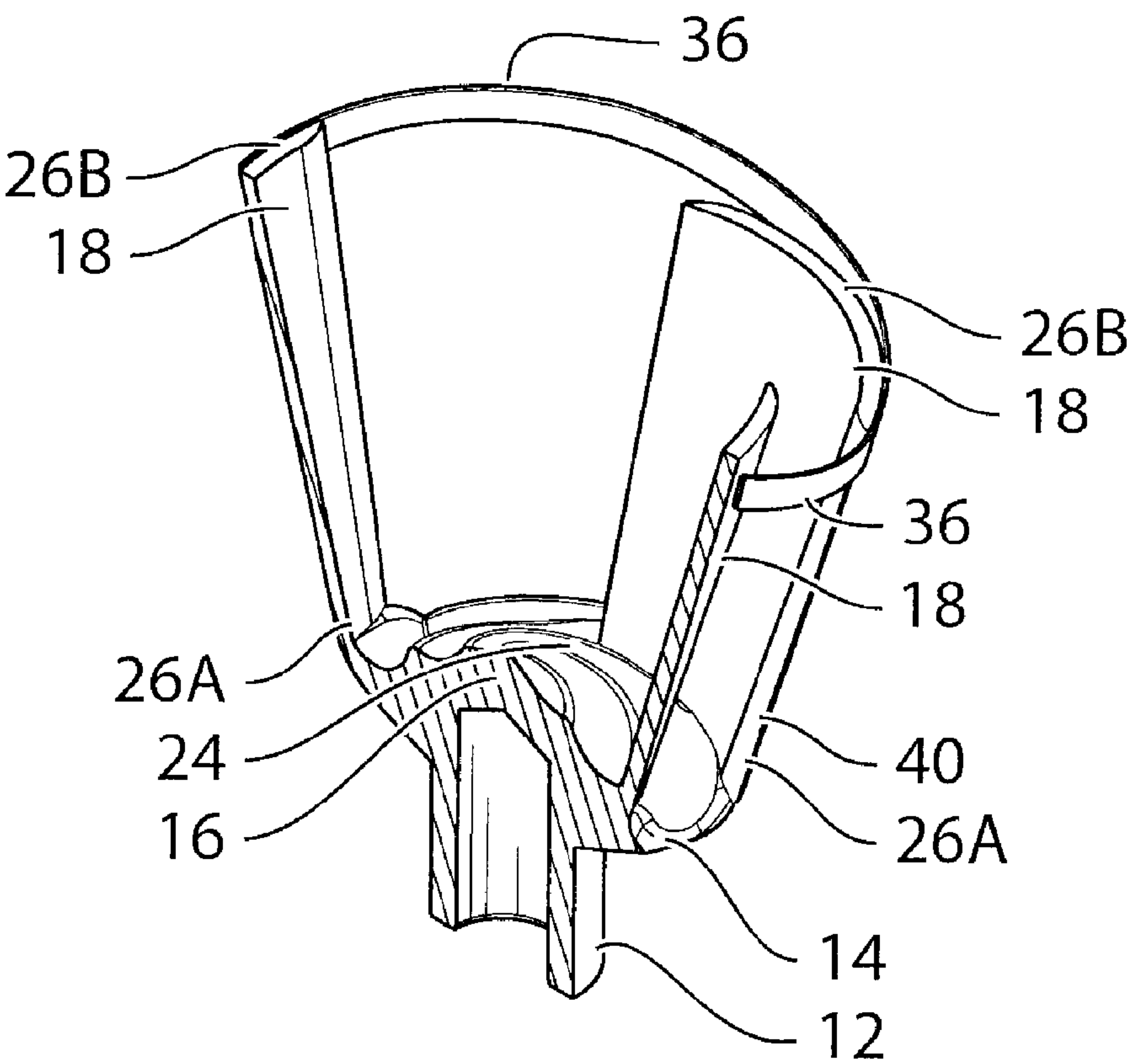
(54) **Titre : ROUE A AILETTES AYANT UNE FAIBLE VITESSE DIFFERENTIELLE ET UN FAIBLE CISAILLEMENT OFFRANT UN VOLUME DE MOYEU A PROFIL PROGRESSIF PERIODIQUE FORME SUR UNE SURFACE DE FOND**

(54) **Title: LOW SHEAR, LOW VELOCITY DIFFERENTIAL, IMPELLER HAVING A PROGRESSIVELY TAPERED HUB VOLUME WITH PERIODS FORMED INTO A BOTTOM SURFACE**



(57) **Abrégé/Abstract:**
Disclosed herein is an impeller for mixing a fluid wherein the impeller is fashioned so as to substantially reduce areas of fluid acceleration and deceleration around a hub region of the impeller during fluid mixing. The impeller has a generally circularly shaped

(57) **Abrégé(suite)/Abstract(continued):**
hub having a downwardly directed progressively tapered volume which has plurality of periods formed therein corresponding to the number of increasingly arced blades. Each of the increasingly arced blades flare outwards to a distal end region of the impeller and have an increasing radius to said arc towards a peripheral edge region of said hub. The flare to the increasingly arced blades defines a larger circumference than that of said hub, thereby imparting a generally frusto-concial shape to the impeller. A method mixing a fluid using the impeller disclosed herein is also disclosed.

ABSTRACT

Disclosed herein is an impeller for mixing a fluid wherein the impeller is fashioned so as to substantially reduce areas of fluid acceleration and deceleration around a hub region of the impeller during fluid mixing. The impeller has a generally circularly shaped hub having a downwardly directed progressively tapered volume which has plurality of periods formed therein corresponding to the number of increasingly arced blades. Each of the increasingly arced blades flare outwards to a distal end region of the impeller and have an increasing radius to said arc towards a peripheral edge region of said hub. The flare to the increasingly arced blades defines a larger circumference than that of said hub, thereby imparting a generally frusto-concial shape to the impeller. A method mixing a fluid using the impeller disclosed herein is also disclosed.

LOW SHEAR, LOW VELOCITY DIFFERENTIAL, IMPELLER HAVING A PROGRESSIVELY TAPERED HUB VOLUME WITH PERIODS FORMED INTO A BOTTOM SURFACE

TECHNICAL FIELD

[0001] The present disclosure relates to an impeller for mixing fluids. In particular, the present disclosure relates to an impeller for mixing fluids in a bioreactor vessel which requires a low-shear environment substantially free from zones of turbulent flow velocity differentials, maintaining laminar flow) within for cell propagation.

BACKGROUND

[0002] Stem cell bioreactors and vaccine bioreactors are used to propagate and grow cells. Suspension culturing is a technique that is known to grow and propagate large numbers of cells, such as stem cells, as well as cells which are not easily cultured in petri dishes. Certain suspension cell culturing techniques may involve the use of microcarriers to increase available surface area for the cells to attach thereto during culturing; similar to that of culturing cells in a substrate-attached petri dish-cell culturing. In other suspension culturing techniques, the cells are cultured in a free-floating environment without the aid of micro carriers to which cells may attach.

[0003] In bioreactors which use microcarriers during suspension culturing, one of the first steps to successful propagation is cell attachment. Some cell varieties rely on a slight charge or cellular stickiness to attach to the microcarriers and/or to each other, and in a bioreactor, the fluid environment may be continuously mixed for purposes of even cell distribution, even gas gradients, even temperature and pH distributions. To maintain heterogeneity of the culture medium and that of the cell distribution, the fluid medium carrying the cells must be substantially constantly mixed. However, in many culture environments it is desirable, and often required that the medium flow be laminar and free from turbulent regions as well as velocity gradients within the dynamically moving culture medium. Providing a medium flow which is laminar and free from turbulent regions as well as velocity gradients promotes cell attachment and aids to prevent damage to the cells during culturing.

[0004] It is known that in the fluid flow and cellular suspension culturing fields that, that the fluid dynamics should adhere to strict parameters regarding velocity changes and stagnant zones so as to replicate an *in vivo* environment during *in vitro* culturing of cells as closely possible. Since suspension culturing inherently involves having the cells in motion during culturing, avoiding, or at least substantially reducing turbulence and zones of acceleration and deceleration within the bioreactor aids to simulate a substantially static *in vivo* growth environment.

[0005] Conical impellers, such as those disclosed in U.S. Patent serial number 5,314,310, entitled "SPIDER MOUNTED CENTRIFUGAL MIXING IMPELLER", issued May 24, 1994 (Bachellier, Carl R.), U.S. Patent serial number 5,938,332, entitled "MIXING DEVICE", issued August 17, 1999 (Bachellier, Carl R.) and International Patent Application serial number PCT/CA2012/050873, entitled "IMPROVED IMPELLER APPARATUS AND DISPERSION METHOD FIELD OF THE INVENTION", filed December 5, 2012 (Bachellier, Carl R.) disclose various impellers for mixing fluids which comprise a top hub having a flat interior surface; that is, the inside bottom surface of the hub is perpendicular to the axis of rotation. For example, the bottom surface of the hub, when the impeller is oriented in a vertical plane, is oriented horizontally. During use, when such impellers rotate, an upward spiral helical intake vortex to the fluid is created. This vortex collides with the flat surface, causing the vortex to compress and collapse on itself thereby creating an area of fluid deceleration and a turbulent region. In the upper part of these impellers, typically the top third, the fluid is discharged from the impeller at approximately a 90-degree angle to the axis of rotation, which disrupts the otherwise upward flow of fluid from the lower two thirds of the impeller. This can result in inadequate discharge to the exterior of the impeller of the fluid in approximately the upper third of the interior of the impeller, which then provides resistance to the fluid entering the bottom of the impeller (i.e. a backwash or stall effect), thereby impeding it from moving up to the hub. Thus, the fluid does not flow around and from the impeller in a smooth, substantially non-turbulent manner. In addition, particulates or other second phase materials, such as cells in a suspension culture collide, with the flat interior surface and may adhere to that surface in addition to colliding with one another in a detrimental fashion. This effect is exacerbated by the sharp interior angle where the upper edge of the blade attaches to the bottom surface of the hub.

[0006] International Patent Application serial number PCT/US2015/02580, entitled "CONICAL IMPELLER AND APPLICATIONS THEREOF", filed April 14, 2015 (Bachellier, Carl R.) discloses a generally conically-shaped impeller for mixing fluids. The application, having the same inventor as the instant application, discloses a low shear impeller which has a hub with a conical surface extending into the interior of the impeller and a plurality spiral, or in other words, increasingly arced blades towards the outer peripheral are of the impeller. At the intersection of the conical surface and the spiral blades, during rotation in a fluid, this arrangement causes the fluid to form an upwardly swirling vortex in which entrained particles or gases are brought into the interior of the impeller and subsequently ejected from the impeller at a trailing edge of the spiral blades and along the trailing edge of the spiral blades. However, during testing and Computational Fluid Dynamics (CFD) modeling, it was discovered that at the conical surface of the hub, the fluid flow is turbulent, that being having zones of fluid acceleration and deceleration where the fluid becomes trapped in a recirculating flow pattern. It was discovered that the conical surface acts as a deceleration mechanism and in conjunction with the spiral blades creates a turbulent discharge.

[0007] Therefore, in certain applications the impeller of International Patent Application serial number PCT/US2015/025820 has drawbacks for certain applications of suspension cell culturing techniques. For example, the abovementioned impeller, during testing showed a significant deceleration of fluid at the apex of the interior conical surface by a factor of 190 times and a reacceleration of the fluid upon discharge. The impeller of International Patent Application serial number PCT/US2015/02580 also displayed a recirculatory eddy formation around the drive shaft assembly attachment point which may trap cells undergoing culturing into a zone which prevents even distribution to the rest of the colony growing in the bioreactor. Accordingly, although functional in many other applications, the fluid dynamic characteristics of the impeller disclosed in International Patent Application serial number PCT/US2015/02580 does not satisfactorily meet several of the needs for suspension cell propagation in bioreactors due to the inherent ultra low stress requirements' of certain cell types, in particular, stem cells.

[0008] This background information is provided to reveal information believed by the applicant to be of possible relevance. No admission is necessarily intended, nor should it be construed, that any of the preceding information constitutes prior art.

SUMMARY

[0009] The following presents a simplified summary of the general inventive concepts described herein to provide a basic understanding of some aspects of the invention. This summary is not an extensive overview of the invention. It is not intended to restrict key or critical elements of the invention or to delineate the scope of the invention beyond that which is explicitly or implicitly described by the following description and claims.

[00010] In light of the above background discussion it would desirable to develop an impeller for mixing fluid mediums and in particular fluid mediums for growing live cells or viruses in suspension culturing bioreactors for vaccine and stem cell production. Such an impeller may also aid in bioreactor devices for large-scale cell propagation purposes. In particular, it would be desirable to develop an impeller for mixing fluids which require a low-shear environment substantially free from zones of velocity differentials such as regions of acceleration and deceleration of the fluid medium as well as maintaining laminar flow around various areas of the impeller within a bioreactor vessel. The use of such an impeller which is substantially free from turbulent flow could allow scalable and healthy cell propagation in certain applications of suspension cell culturing.

[00011] It has been surprisingly discovered that by providing a hub to the impeller which has a downwardly directed progressively tapered volume interior to a proximal end region where an outer edge of the blades are coupled to the hub and the blades being further coupled to the downwardly directed progressively tapered volume in a decreasing arc, or in other words following a spiral helical pattern, inward to a predetermined point aids to produce a prewhirl to a fluid below the impeller as it is rotated.

[00012] The internal surface structure of the hub, the downwardly directed progressively tapered volume having the blades following along a corresponding period formed therein, acts to create as a prewhirl device which substantially matches the prewhirl generated by the circumferentially attached inwardly decreasingly arced blades. Swirling channels, the periods in some embodiments, intermittent the inwardly decreasingly arced blades allows the vortex created by the blades and motion of the hub to meet and be divided upwardly and outwardly with minimal velocity change to the various regions of the fluid about the hub. The swirling internal channels of the downwardly directed progressively tapered volume of the hub extend into discharge channels on the upper anterior side of the hub which provide a substantially smooth velocity transition of the fluid in various zones and reduce or substantially eliminate known zones of recirculation and turbulence associated with the above-discussed prior art. Additionally, the impeller described herein, unlike those of the abovementioned previously disclosed impellers, is substantially devoid of horizontal surfaces perpendicularly extending from the top of the hub near the rotatable drive attachment region which interrupts laminar flow of the fluid in and around various regions of the impeller.

[00013] In one aspect there is provided an impeller couplable to a rotatable drive by way of a rotatable drive attachment region coupled to a generally circularly shaped hub. The generally circularly shaped hub includes a downwardly directed progressively tapered volume having coupled thereto a proximal end region of one or more arced blades arranged along a periodic pattern formed into the downwardly directed progressively tapered volume wherein the number of periods corresponds to the number of blades. Each of the one or more arced blades has an increasing radius to the arc towards a peripheral edge region of the hub. The proximal end region of the one or more increasing radius arced blades extends from the peripheral edge region of the hub along the downwardly directed progressively tapered volume to a predetermined point inward of said peripheral edge region. Furthermore, each of the one or more arced blades is flared as it extends from the progressively tapered volume such that a distal end region of each of the one or more increasing radius arced blades, in combination, defines a larger circumference than that of the hub, thereby imparting a generally frusto-conical shape to the impeller.

[00014] In some embodiments, the impeller comprises at least two increasing radius arced blades.

[00015] In some embodiments, the periods formed into the downwardly directed progressively tapered volume comprise a plurality of spiral helices which corresponds to the number of increasing radius arced blades.

[00016] In some embodiments, the one or more increasing radius arced blades extending from the peripheral edge region of the hub along the downwardly directed progressively tapered volume extend from ridges of the spiral helices.

[00017] In some embodiments, the downwardly directed progressively tapered volume has channels formed intermittent said ridges following the spiral helices so as to form a path continuous with a sequence of distinct conical spiral segments between the one or more increasing radius arced blades. In some embodiments, the channels have a substantially semicircular profile.

[00018] In some embodiments, the hub has a curved peripheral surface forming a discharge channel located at a peripheral terminus of the spiral helices adjacent to each of the one or more arced blade proximal end regions extending from the channels.

[00019] In some embodiments, the spiral helices of the downwardly directed progressively tapered volume are a logarithmic spiral.

[00020] In some embodiments of the impeller, the one or more increasing radius arced blades are integrally formed with said hub.

[00021] In some embodiments, the impeller further comprises a ring coupled near the distal end regions of the one or more increasing radius arced blades for connecting the one or more increasing radius arced blades. And, in further embodiments, the ring is integrally formed with the one or more increasing radius arced blades.

[00022] In some embodiments, the progressively tapered volume has a compound logarithmic taper.

[00023] In another aspect, there is provided an impeller couplable to a rotatable drive which comprises a generally circularly shaped hub including a downwardly directed progressively tapered volume having coupled thereto, toward a peripheral end region thereof, one or more flaring arced blades arranged along a periodic pattern formed into said downwardly directed progressively tapered volume to project generally downwards from said peripheral edge region and so as to define a periodically flaring impeller radius along their length which allows for tangential fluid flow between adjacent blade ends.

[00024] In some embodiments, the impeller comprises at least two flaring arced blades.

[00025] In some embodiments, the periods formed into the downwardly directed progressively tapered volume comprise a plurality of spiraling grooves each flowing toward a corresponding one of the arced blades.

[00026] In some embodiments, the spiraling grooves are defined by respective outer ridges and wherein each of the arced blades extends from a corresponding one of the outer ridges. Furthermore, in some embodiments, the spiraling grooves define helical channels that flow toward the adjacent blade ends. In some further embodiments, the spiraling grooves have a substantially semicircular profile.

[00027] In some embodiments, the spiraling grooves discharge between the adjacent blade ends.

[00028] In some embodiments, the spiraling grooves are logarithmically spiraling grooves.

[00029] In some embodiments, the one or more flaring arced blades are integrally formed with said hub.

[00030] In some embodiments, the impeller further comprises a ring coupled near the distal end region of the one or more flaring arced blades for connecting said one or more flaring arced blade ends. Furthermore, in some embodiments, the ring is integrally formed with said one or more flaring arced blades.

[00031] In some embodiments of the instant aspect, the progressively tapered volume has a compound logarithmic taper.

[00032] In yet another aspect, there is provided a method for mixing a fluid. The method comprising:

introducing into a fluid an impeller coupled to a rotatable drive shaft;

the impeller comprising a generally circularly shaped hub, including a downwardly directed progressively tapered volume having coupled thereto a proximal end region of one or more arced blades arranged along a periodic pattern formed into the downwardly directed progressively tapered volume wherein the number of periods corresponds to the number of blades;

each of the one or more arced blades having an increasing radius to the arc towards a peripheral edge region of said hub;

the proximal end region of the at one or more increasing radius arced blades extending from the peripheral edge region of the hub along the downwardly directed progressively tapered volume to a predetermined point inward of the peripheral edge region;

the one or more arced blades further being flared as extending from the progressively tapered volume such that a distal end region of each of the one or more increasing radius arced blades, in combination, defines a larger circumference than that of the hub, thereby imparting a generally frusto-conical shape to the impeller;

causing the impeller to rotate in the direction of the predetermined point inward of the peripheral edge region;

by rotating of the impeller, creating a fluid vortex channeled upwards to a centre point of the progressively tapered volume so as to create a prewhirl to the fluid about a region near the hub, the velocity of which substantially matching the velocity of the fluid moving near the increasingly arced blades; and

tangentially discharging the fluid between adjacent ends of the one or more increasingly arced blades so as mix the fluid.

[00033] In still yet another aspect, there is provided a method for mixing a fluid. The method comprising:

introducing into a fluid an impeller coupled to a rotatable drive shaft;

the impeller comprising a generally circularly shaped hub including a downwardly directed progressively tapered volume having coupled thereto toward a peripheral end region thereof one or more flaring arced blades arranged along a periodic pattern formed into the downwardly directed progressively tapered volume to project generally downwards from the peripheral edge region and to define a periodically flaring impeller radius along their length which allows for tangential fluid flow between adjacent blade ends;

rotating of the impeller so as to create a fluid vortex channeled upwards to a centre point of the progressively tapered volume so as to create a prewhirl to the fluid about a region near the hub, the velocity of which substantially matching the velocity of the fluid moving near the one or more flaring arced blades; and tangentially discharging the fluid between adjacent ends of said one or more flaring arced blades so as mix the fluid.

[00034] In some embodiments of the above methods, the impeller includes at least two arced blades.

[00035] In some embodiments of the above methods, the periods formed into the downwardly directed progressively tapered volume comprise a plurality of spiral helices.

[00036] In some embodiments of the above methods, the arced blades extend from ridges of the spiral helices.

[00037] In some embodiments of the above methods, the spiral helices are logarithmic spirals. And in further embodiments of the above methods the ridges define helical channels that flow toward the adjacent blade ends and provide a fluid travel path.

[00038] In some embodiments of the above methods, the progressively tapered volume has a compound logarithmic taper.

[00039] Other aims, objects, advantages and features of the invention will become more apparent upon reading of the following non-restrictive description of specific embodiments thereof, given by way of example only with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

[00040] In order that the invention may be better understood, exemplary embodiments will now be described by way of example only, with references to the accompanying drawings, wherein:

[00041] Figure 1 is a cut-away perspective view along line A' of Figure 5 of an embodiment of the impeller of the instant disclosure;

[00042] Figure 2 is a top plan view of the impeller or Figure 1;

[00043] Figure 3 is a side view of the impeller of Figure 1;

[00044] Figure 4 is a top perspective view of the impeller of Figure 1;

[00045] Figure 5 is a bottom plan view of the impeller of Figure 1;

[00046] Figure 6a is a side view of the rotatable drive attachment region, the generally circularly shaped hub and the downwardly directed progressively tapered volume with the blades removed of the impeller of Figure 1;

[00047] Figure 6b is a side view of the rotatable drive attachment region, the generally circularly shaped hub and the downwardly directed progressively tapered volume with the blades removed of an embodiment of the impeller in accordance with the disclosure wherein the downwardly directed progressively tapered volume has logarithmic taper;

[00048] Figure 7 is a side perspective view of the embodiment of Figure 1 showing the rotatable drive attachment region, the generally circularly shaped hub and the downwardly directed progressively tapered volume with the blades removed;

[00049] Figure 8 is a top perspective view of the embodiment of Figure 1 showing the rotatable drive attachment region and the generally circularly shaped hub with the blades removed;

[00050] Figure 9 is a side view of the rotatable drive attachment region, the generally circularly shaped hub and the downwardly directed progressively tapered volume with the blades removed of the impeller of Figure 1;

[00051] Figure 10 is a bottom plan view of the impeller of Figure 1;

[00052] Figure 11 is a cutaway side view along line A' of Figure 5 of the rotatable drive attachment region, the generally circularly shaped hub and the downwardly directed progressively tapered volume with the blades removed of the impeller of Figure 1;

[00053] Figure 12 is a cutaway perspective view along line A' of Figure 5 of the rotatable drive attachment region, the generally circularly shaped hub and the downwardly directed progressively tapered volume with the blades removed of the impeller of Figure 1;

[00054] Figure 13 is a graphical representation of a spiral having the general profile of a blade of the impeller of an embodiment of the instant application laid there-over; and

[00055] Figure 14 is schematic side view of an impeller of the instant disclosure mixing a fluid showing the center vortex being drawn upwards into the downwardly directed progressively tapered volume.

DETAILED DESCRIPTION

[00056] With reference to the disclosure herein and the appended figures, an impeller 10 in accordance with various embodiments of the invention is described below.

[00057] With reference to Figure 1, there is shown an embodiment of the impeller 10 of the instant disclosure. The impeller 10 has a rotatable drive attachment region 12 coupled to a generally circular shaped hub 14, as shown, for example, in Figures 1, 2 and 3, where the rotatable drive attachment region 12 is adapted for coupling to a rotatable drive member (not shown). With the impeller 10 coupled to a rotatable drive member via the rotatable drive attachment region 12, for example the drive shaft of a motor, the impeller 10 is rotated as the drive shaft is turned. When immersed in a fluid, the rotation of the impeller 10 results in the fluid being moved in a circular pattern so as to result in mixing of the fluid, as shown in Figure 14, for example.

[00058] The impeller 10, with reference to the figures, has a generally circularly shaped hub 14 with the rotatable drive attachment region 12 coupled to a top side thereof and depending from a bottom side thereof, a downwardly directed progressively tapered volume 16. There is at least one, and in most embodiments, a plurality of increasingly arced blades 18 arranged along a periodic pattern formed into the downwardly directed progressively tapered volume 16. The number of periods corresponds to the number of increasingly arced blades 18, for example, as shown in Figure 10, five increasingly arced blades 18. As noted above, in some embodiments, not shown in the figures, the impeller 10 may be provided with only one blade 18, which, in such a case may follow a single helical period formed into the downwardly directed progressively tapered volume 16 such that the single blade 18 extends helically substantially around the hub 14 thus providing the required balance as the impeller 10 is rotated during use. In other embodiments, the single blade may be offset by counterbalance weight.

[00059] The increasingly arced blades 18 are coupled to the generally circularly shaped hub 14 at a proximal region 26a. The proximal region 26a of the blades extend from a peripheral edge region 20 of the hub 14 along the downwardly directed progressively tapered volume 16 to a predetermined point inward 24 of said peripheral edge region 20.

[00060] Turning now to Figure 3, it is shown that the increasingly arced blades 18 are flared as they extend from the progressively tapered volume 16 to a distal end region 26b of the blades 18. In doing so the circumference of the impeller 10, as defined by the distal end regions 26b of the blades 18 is larger than the circumference of the hub 14 thereby imparting a generally frusto-conical, or flaring, shape to the impeller 10. As more clearly seen in the top plan view of Figure 4, there is shown that the distal end regions 26b of the blades define a larger circumference to the impeller 10 in this distal area than near the hub 14. Thus, in other words, it can be said that the blades 18 are flared outwardly as they go from the peripheral end region 26a, coupled to the hub 14, to the distal end region 26b.

[00061] Arrow "A" of Figures 5 and 10 shows the direction of rotation of the impeller 10 in use to mix a fluid 50. During rotation of the impeller 10, a leading edge region 38 of the blades 18 is moved though the fluid 50 and the fluid is ejected or discharged, in part, from the impeller 10 at the trailing edge region 40 of the blades 18 thereby aiding to circulate the fluid 50 in a vessel (not shown), in a manner as shown in Figure 14, for example.

[00062] Turing now to the bottom plan view of the impeller 10 shown in Figure 5, the periods of the downwardly directed progressively tapered volume 16 may take the form of, in some embodiments, a plurality of spiral helices 34 formed into the downwardly directed progressively tapered volume 16. For example, the each spiral helix 34 is formed by a single period. The number of spiral helices 34 corresponds to the number of periods of the hub and thus also the number of increasing radius arced blades 18. The periods or spiral helices 34 begin at the centre of the progressively tapered, at point referred to herein as the progressively tapered volume centre 42. Furthermore, the periods or spiral helices 34, extending from the progressively tapered volume centre 42, have a ridge component, the spiral ridges 28a and channel component, the spiral channels or spiraling grooves, 28b, thus forming a corresponding period. It should be noted that in some embodiments, (not shown) that the periods may be a raised formation, as opposed to, for example, the channel. Figures 11 and 12, are side cross-sectional views of the downwardly directed progressively tapered volume 16 and the rotatable drive attachment region 12 along line A' of Figure 5. In these views, the spiral helices 34 and corresponding spiral ridges 28a and the spiral channels 28b can be seen. In some embodiments, the spiral channels 28b have a semi-circular profiles, as can be seen in the embodiment shown in figures.

[00063] With respect to the progressively tapered volume 16, in some embodiments it is provided as having a generally conical shape having the spiral ridges 26a and spiral 26b formed in its surface. In such an embodiment, the slope to the conical volume may have angle θ as shown for example in Figure 6a. However, in other embodiments, the progressively tapered volume 16 may have a profile such that a cross-sectional profile of progressively tapered volume 16 is not seen as a straight line from the progressively tapered volume centre 42 to the outer peripheral region near the hub 14. That being, in some embodiments, the progressively tapered volume 16 may have a curved profile and furthermore, an exponentially increasing curve, or in other words a compound logarithmic taper to the volume 16, as shown for example, in Figure 6b.

[00064] In some embodiments, the spiral component, formed by the spiral ridges 28a is provided as a logarithmic spiral. The logarithmic spiral pattern as formed on the surface of the progressively tapered volume 16 aids to create the above-noted prewhirl effect along a downward path extending from the progressively tapered volume centre 42 which matches a prewhirl generated by the circumferentially attached increasingly arced blades.

The spiral channels 28b, or in other words, the swirling channels intermittent the increasingly arced blades allows the vortex created by the blades and motion of the hub to meet and be divided upwardly and outwardly with minimal velocity change to the various regions of the fluid about the hub 14. The swirling internal channels 28b of the downwardly directed progressively tapered volume of the hub extended into discharge channels 32a on the upper anterior side of the hub which provide a substantially smooth velocity transition of the fluid in various zones and reduce or substantially eliminate known zones of recirculation as the fluid tangentially flows between adjacent blade ends.

[00065] Furthermore, with respect to a height and a depth of the spiral ridges 26a and the spiral channels 26b, these may be variable. For example, one of skill in the art may wish to increase the depth of the spiral channels 26b in certain applications and decrease it in others. Additionally, in some embodiments, the depth of the spiral channels 26b may be increased or decreased along a spiral path from the progressively tapered volume centre 42 to the discharge channels 32b near the peripheral region of the hub 14.

[00066] Turning now to Figure 13, with reference to the terminology of the increasing arced blade, a logarithmic spiral is shown. The spiral ridges 28a are formed along, for example, with reference to Figure 13, line "B". As one looks toward the peripheral region 44 of the spiral 46, it can be noted that the spiral expands. Therefore, as the blades follow this profile, the arc or radius to the blades 18 increases towards the peripheral region 20 of the hub 14; hence arc to the blades can be defined as an increasing radius. For the purposes of reference, line "C" is provided so as to show schematic reference to the peripheral edge region 20 of the generally circularly shaped hub 14. Therefore, the logarithmic spiral path of the spiral ridges 28a is shown by line B over-layed and reference to the peripheral edge path of the generally circularly shaped hub 14 by line C.

[00067] During rotation of the impeller 10 in a fluid, the fluid 46 in a vessel is drawn upward into the impeller 10 as a center vortex 48, as shown in Figure 14 towards the progressively tapered volume centre 42. The spiral ridges 28a and the spiral channels 28b create a prewhirl effect to the fluid. The fluid is drawn into the downwardly directed progressively tapered volume centre 42 and then travels along spiral channels 28b and then forwarded to the peripheral edge region 20 where is it ejected or discharged from the hub region via discharge channels 32. At the peripheral edge regions, the discharge channels 32a have a curved peripheral surface 32b.

[00068] Although is contemplated by the inventor that the impeller 10 of the instant disclosure can be formed through joining several independent parts, for example attaching the blades 18 and the rotatable drive attachment region 12 to the hub 14, in preferred embodiments, the blades 18 and/or the rotatable drive attachment region 12 are integrally formed with the hub 14. In more preferred embodiments, the impeller 10 and the various components are formed of a monolithic structure. Furthermore, in some embodiments, a connecting ring 36 is provided for joining each blade or blade ends to the next near the distal end region 26b, as shown in the figures.

[00069] It is to be understood that the above description it is intended to be illustrative, and not restrictive. Many other embodiments will be apparent to those skilled in the art, upon reviewing the above description. The scope of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

[00070] Although the present invention has been described with reference to specific exemplary embodiments, it will be evident that various modifications and changes may be made to these embodiments without departing from the broader spirit and scope of the disclosed subject matter as defined by the appended claims.

CLAIMS

What is claimed is:

1) An impeller couplable to a rotatable drive by way of a rotatable drive attachment region coupled to a generally circularly shaped hub, said generally circularly shaped hub including a downwardly directed progressively tapered volume having coupled thereto a proximal end region of one or more arced blades arranged along a periodic pattern formed into said downwardly directed progressively tapered volume wherein the number of periods corresponds to the number of blades;

each of said one or more arced blades having an arc with an increasing radius to said arc towards a peripheral edge region of said hub;

said proximal end region of said one or more increasing radius arced blades extending from said peripheral edge region of said hub along said downwardly directed progressively tapered volume to a predetermined point inward of said peripheral edge region;

said one or more arced blades further being flared as extending from said progressively tapered volume such that a distal end region of each of said one or more increasing radius arced blades, in combination, defines a larger circumference than that of said hub, thereby imparting a generally frusto-conical shape to the impeller.

2) The impeller as defined in claim 1, comprising at least two increasing radius arced blades.

3) The impeller as defined in either one of claim 1 or claim 2, wherein said periods formed into said downwardly directed progressively tapered volume comprises a

plurality of spiral helices which corresponds the number of increasing radius arced blades.

4) The impeller as defined in claim 3, wherein said one or more increasing radius arced blades extending from said peripheral edge region of said hub along said downwardly directed progressively tapered volume extend from ridges of said spiral helices.

5) The impeller as defined in claim 4, having channels formed intermittent said ridges following said spiral helices so as to form a path continuous with a sequence of distinct conical spiral segments between said one or more increasing radius arced blades.

6) The impeller as defined in claim 5, wherein said channels have a substantially semicircular profile.

7) The impeller as defined in either one of claim 5 or claim 6, said hub having a curved peripheral surface forming a discharge channel located at a peripheral terminus of said spiral helices adjacent each of the one or more arced blade proximal end region extending from said channels.

8) The impeller as defined in any one of claims 3 to 7, wherein said spiral helices of the downwardly directed progressively tapered volume is a logarithmic spiral.

9) The impeller as defined any one of claims 1 to 8, wherein said one or more increasing radius arced blades are integrally formed with said hub.

10) The impeller as defined in any one of claims 2 to 9, further comprising a ring coupled near the distal end regions of said one or more increasing radius arced

blades for connecting said one or more radius arced blades.

11) The impeller as defined in claim 10, wherein said ring is integrally formed with said one or more increasing radius arced blades.

12) The impeller as defined in any one of claims 1 to 11 where in said progressively tapered volume has a compound logarithmic taper.

13) An impeller couplable to a rotatable drive comprising:

a generally circularly shaped hub including a downwardly directed progressively tapered volume having coupled thereto toward a peripheral end region thereof one or more flaring arced blades arranged along a periodic pattern formed into said downwardly directed progressively tapered volume to project generally downwards from said peripheral edge region and to define a periodically flaring impeller radius along their length which allows for tangential fluid flow between adjacent blade ends.

14) The impeller as defined in claim 13, comprising at least two flaring arced blades.

15) The impeller as defined in either one of claim 13 or claim 14, wherein said periodic pattern formed into said downwardly directed progressively tapered volume comprises a plurality of spiraling grooves each flowing toward a corresponding one of said arced blades.

16) The impeller as defined in claim 15, wherein said spiraling grooves are defined by respective outer ridges and wherein each of said one or more flaring arced blades extends from a corresponding one of said outer ridges.

17) The impeller as defined in claim 16, wherein said spiraling grooves define helical

channels that flow toward said adjacent blade ends.

18) The impeller as defined in claim 17, wherein said spiraling grooves have a substantially semicircular profile.

19) The impeller as defined in either one of claim 17 or claim 18, wherein said spiraling grooves discharge between said adjacent blade ends.

20) The impeller as defined in any one of claims 15 to 19, wherein said spiraling grooves are logarithmically spiraling grooves.

21) The impeller as defined any one of claims 13 to 20, wherein said one or more flaring arced blades are integrally formed with said hub.

22) The impeller as defined in any one of claims 13 to 21, further comprising a ring coupled near the distal end region of said one or more flaring arced blades for connecting said one or more flaring arced blade ends.

23) The impeller as defined in claim 22, wherein said ring is integrally formed with said one or more flaring arced blades.

24) The impeller as defined in any one of claims 13 to 23 where in said progressively tapered volume has a compound logarithmic taper.

25) A method for mixing a fluid comprising:

introducing into a fluid an impeller coupled to a rotatable drive shaft;

said impeller comprising a generally circularly shaped hub, including a downwardly directed progressively tapered volume having coupled thereto a proximal end region of one or more flaring arced blades arranged along a periodic pattern formed into said downwardly directed progressively tapered volume wherein the number of periods corresponds to the number of blades;

each of said one or more flaring arced blades having an increasing radius to said arc towards a peripheral edge region of said hub;

said proximal end region of said one or more increasing radius flaring arced blades extending from said peripheral edge region of said hub along said downwardly directed progressively tapered volume to a predetermined point inward of said peripheral edge region;

said one or more flaring arced blades further being flared as extending from said progressively tapered volume such that a distal end region of each of said one or more increasing radius flaring arced blades, in combination, defines a larger circumference than that of said hub, thereby imparting a generally frusto-conical shape to the impeller;

causing the impeller to rotate in the direction of the predetermined point inward of said peripheral edge region;

by rotating of the impeller, creating a fluid vortex channeled upwards to a centre point of said progressively tapered volume so as to create a prewhirl to the fluid about a region near the hub, the velocity of which substantially matching the velocity of the fluid moving near the increasingly flaring arced blades; and

tangentially discharging said fluid between adjacent ends of said one or more increasingly arced blades so as mix said fluid.

26) A method for mixing a fluid comprising:

introducing into a fluid an impeller coupled to a rotatable drive shaft;

said impeller comprising a generally circularly shaped hub including a downwardly directed progressively tapered volume having coupled thereto toward a peripheral end region thereof one or more flaring arced blades arranged along a periodic pattern, said periodic pattern comprising periods formed into said downwardly directed progressively tapered volume to project generally downwards from said peripheral edge region and to define a periodically flaring impeller radius along their length which allows for tangential fluid flow between adjacent blade ends;

rotating of the impeller so as to create a fluid vortex channeled upwards to a centre point of said progressively tapered volume so as to create a prewhirl to the fluid about a region near the hub, the velocity of which substantially matching the velocity of the fluid moving near said one or more flaring arced blades; and tangentially discharging said fluid between adjacent ends of said one or more flaring arced blades so as mix said fluid.

27) The method as defined in either one of claim 25 or claim 26, wherein said impeller includes at least two flaring arced blades.

28) The method as defined in any one of claims 25 to 27, wherein said periods formed into said downwardly directed progressively tapered volume comprises a plurality of spiral helices.

29) The method as defined in claim 28, wherein said one or more flaring arced blades extend from ridges of said spiral helices.

30) The method as defined in claim 28, wherein said spiral helices are logarithmic spirals.

31) The method as defined in either one of claim 25 or 26, wherein grooves between

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said ridges define helical channels that flow toward said adjacent blade ends and provide a fluid travel path.

32) The method as defined in either one of claim 25 or claim 26, wherein said progressively tapered volume has a compound logarithmic taper.

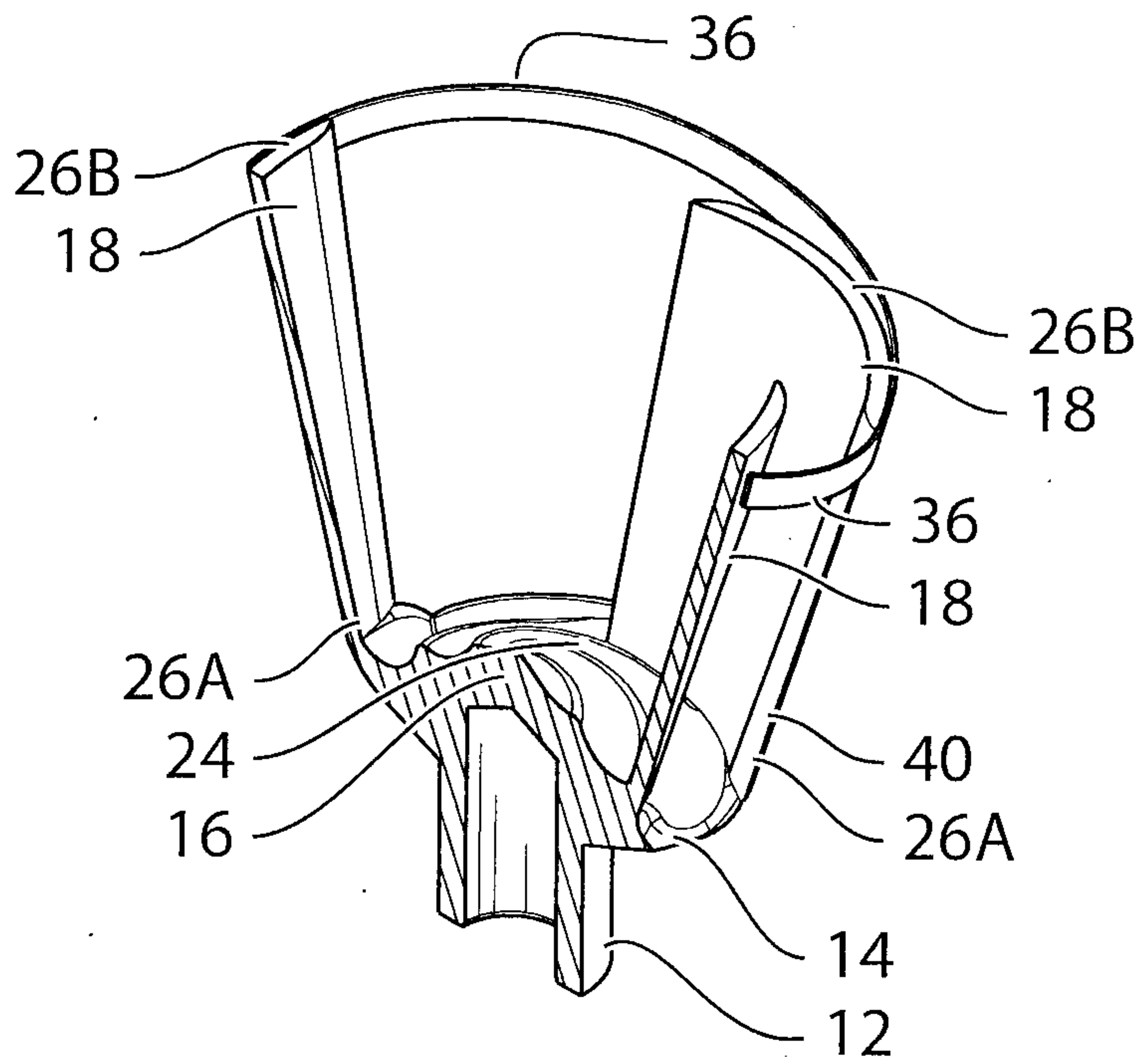

FIG. 1

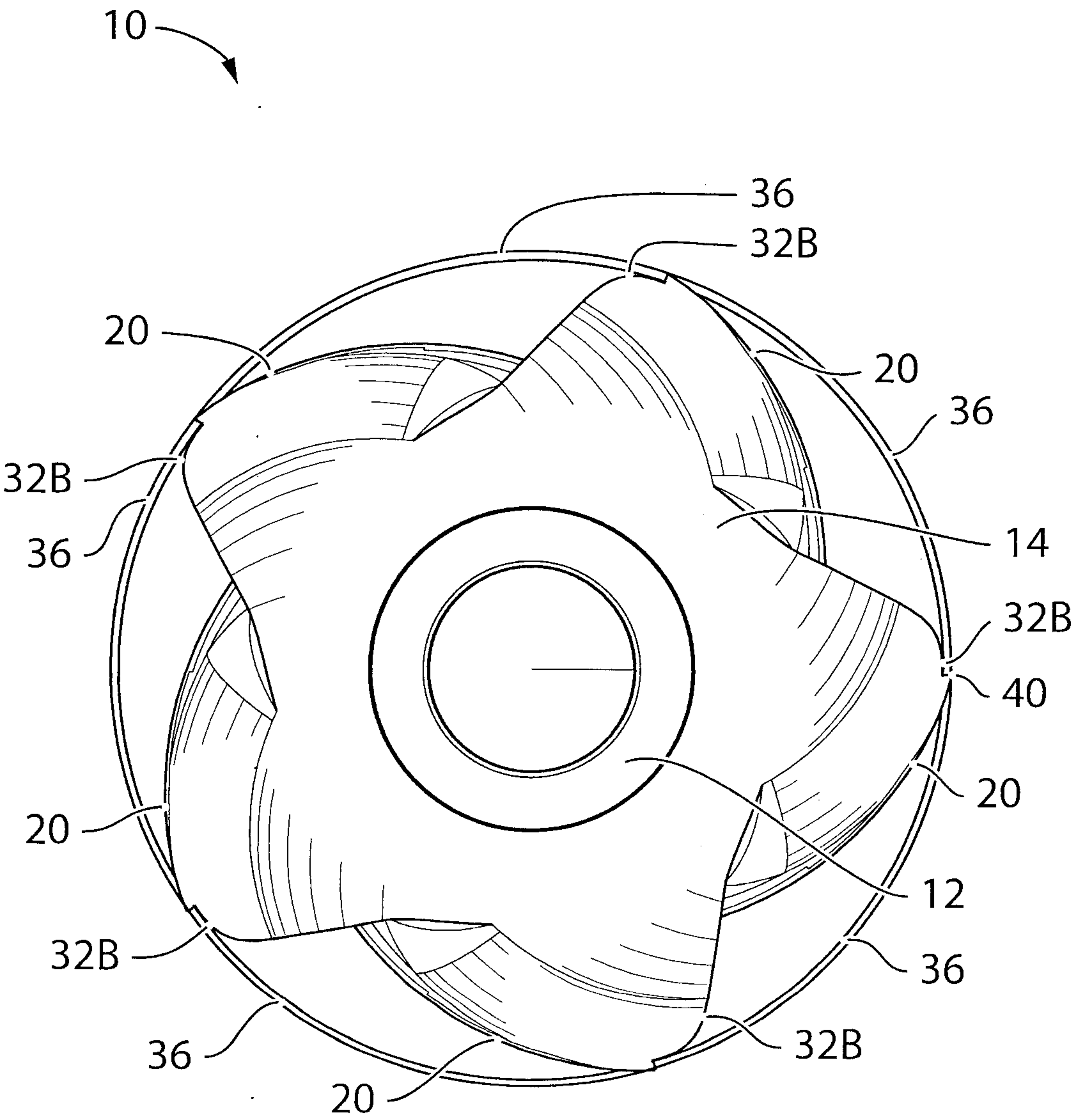

FIG. 2

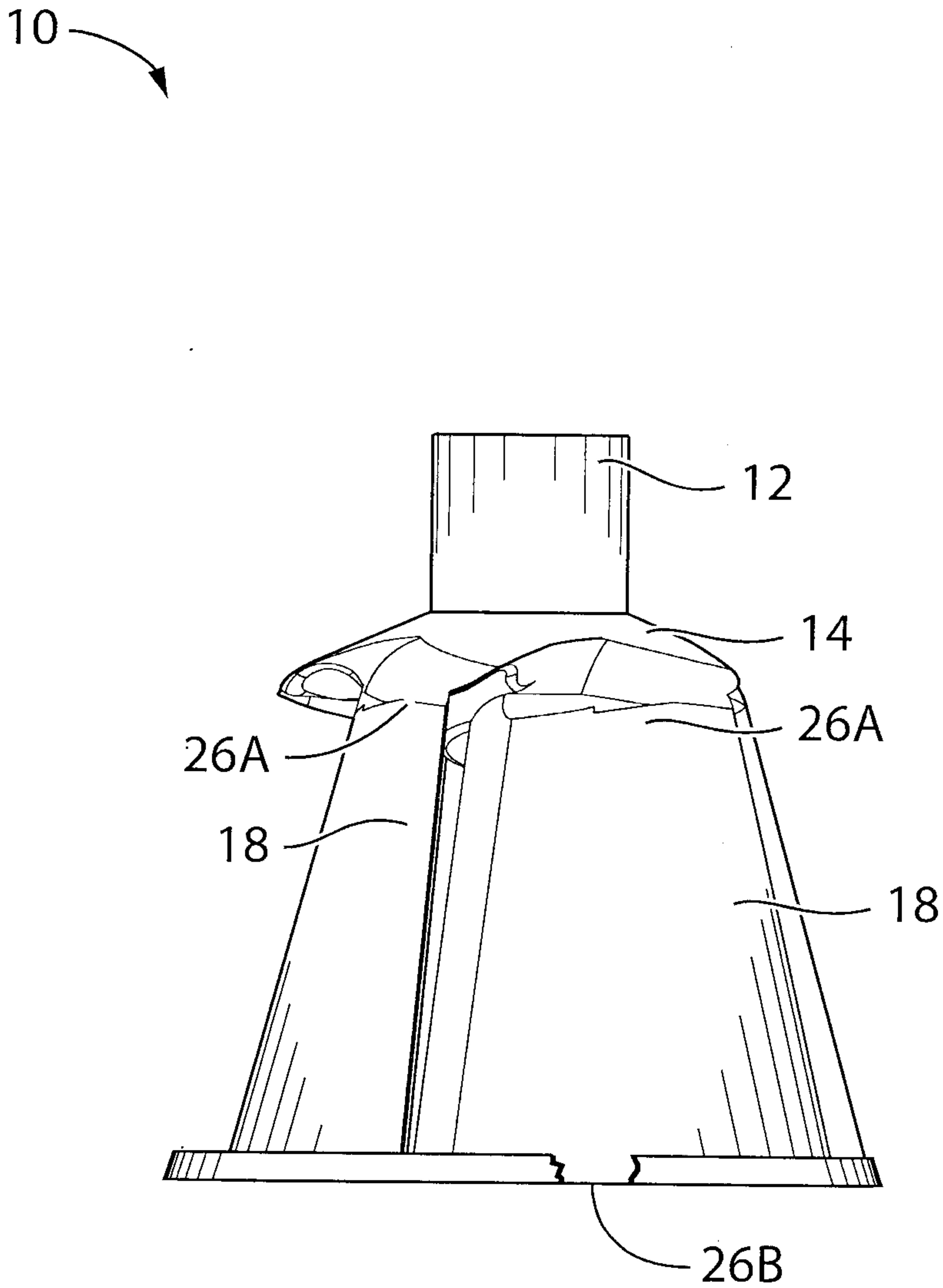

FIG. 3

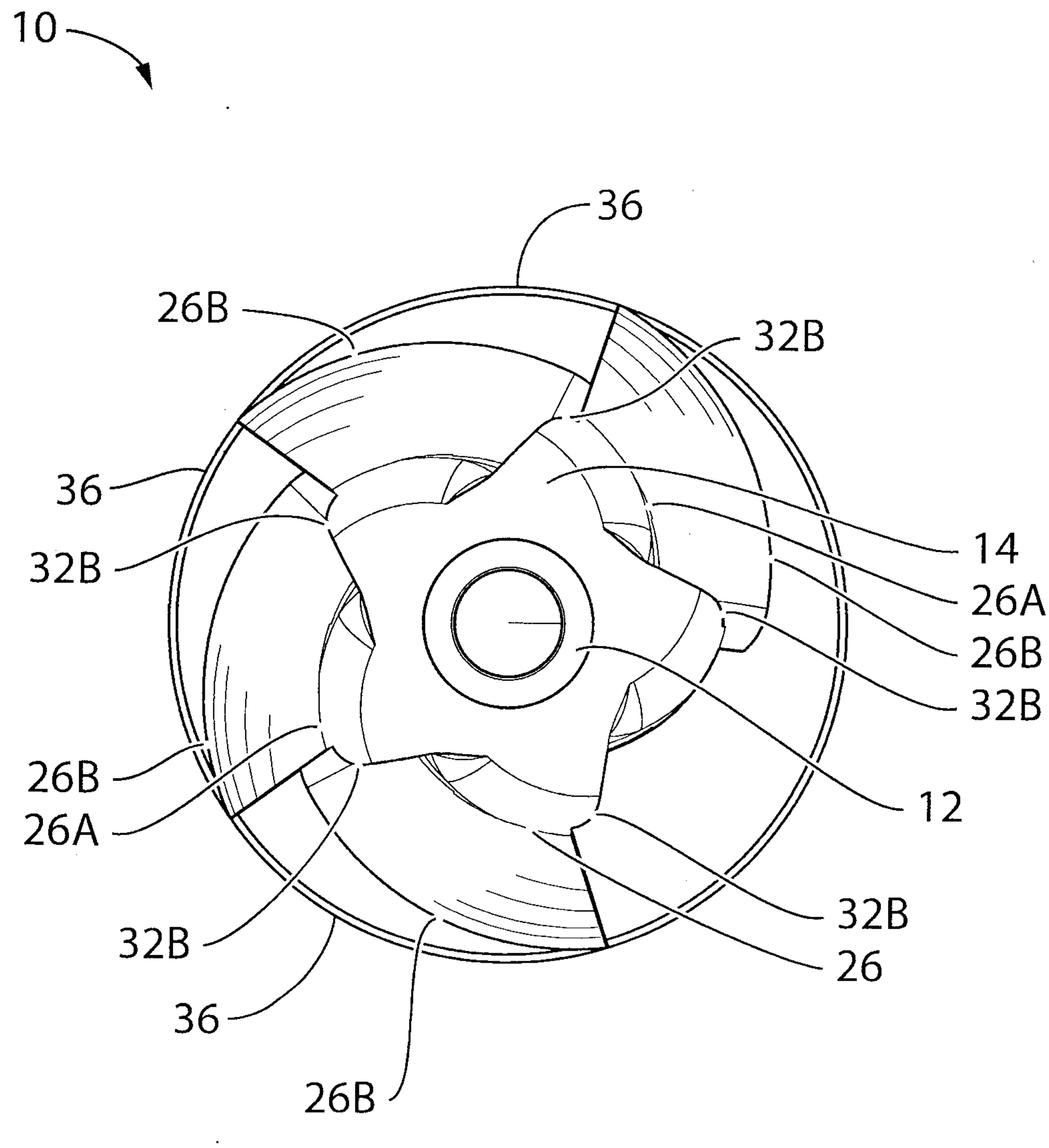

FIG. 4

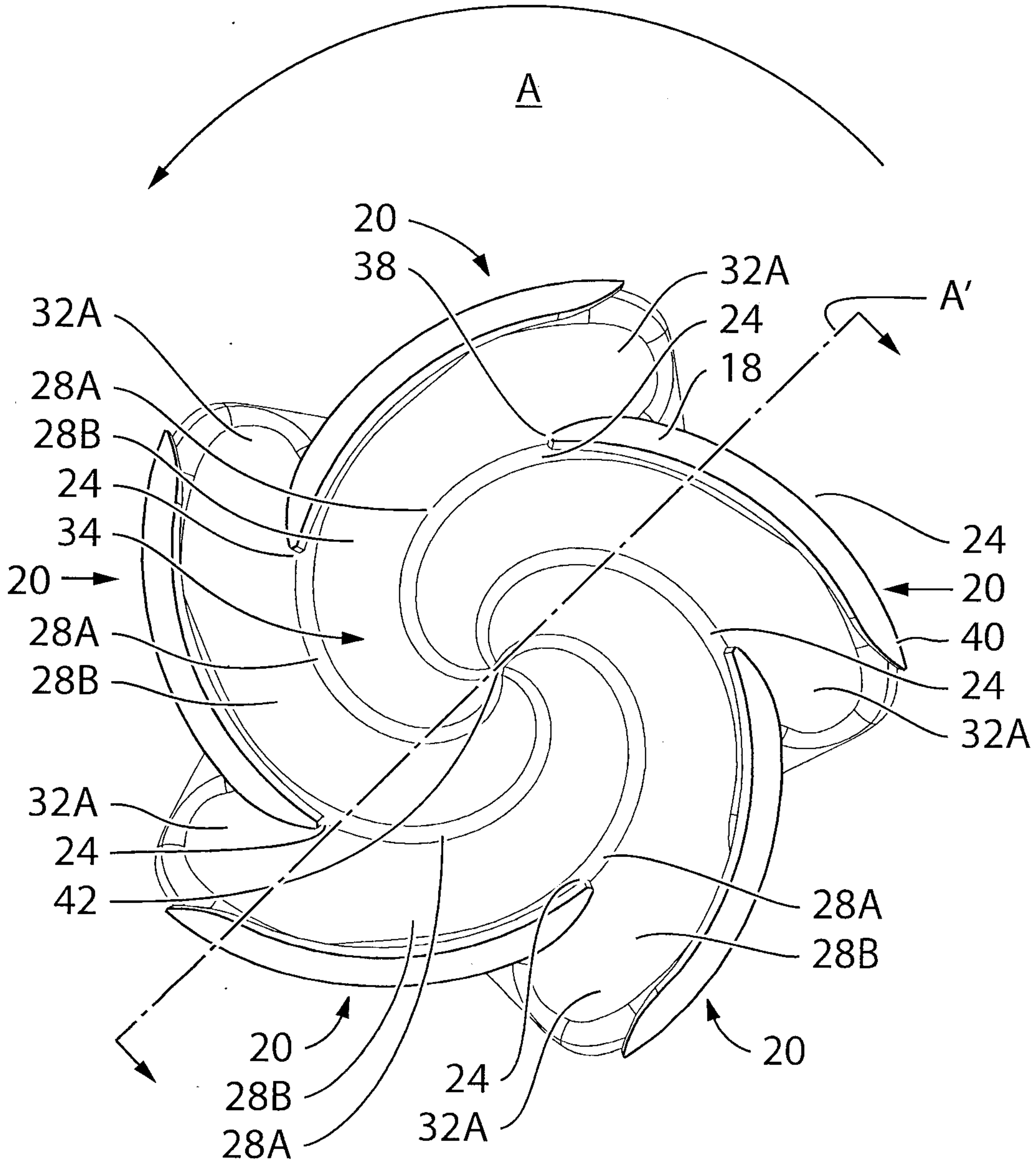
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FIG. 5

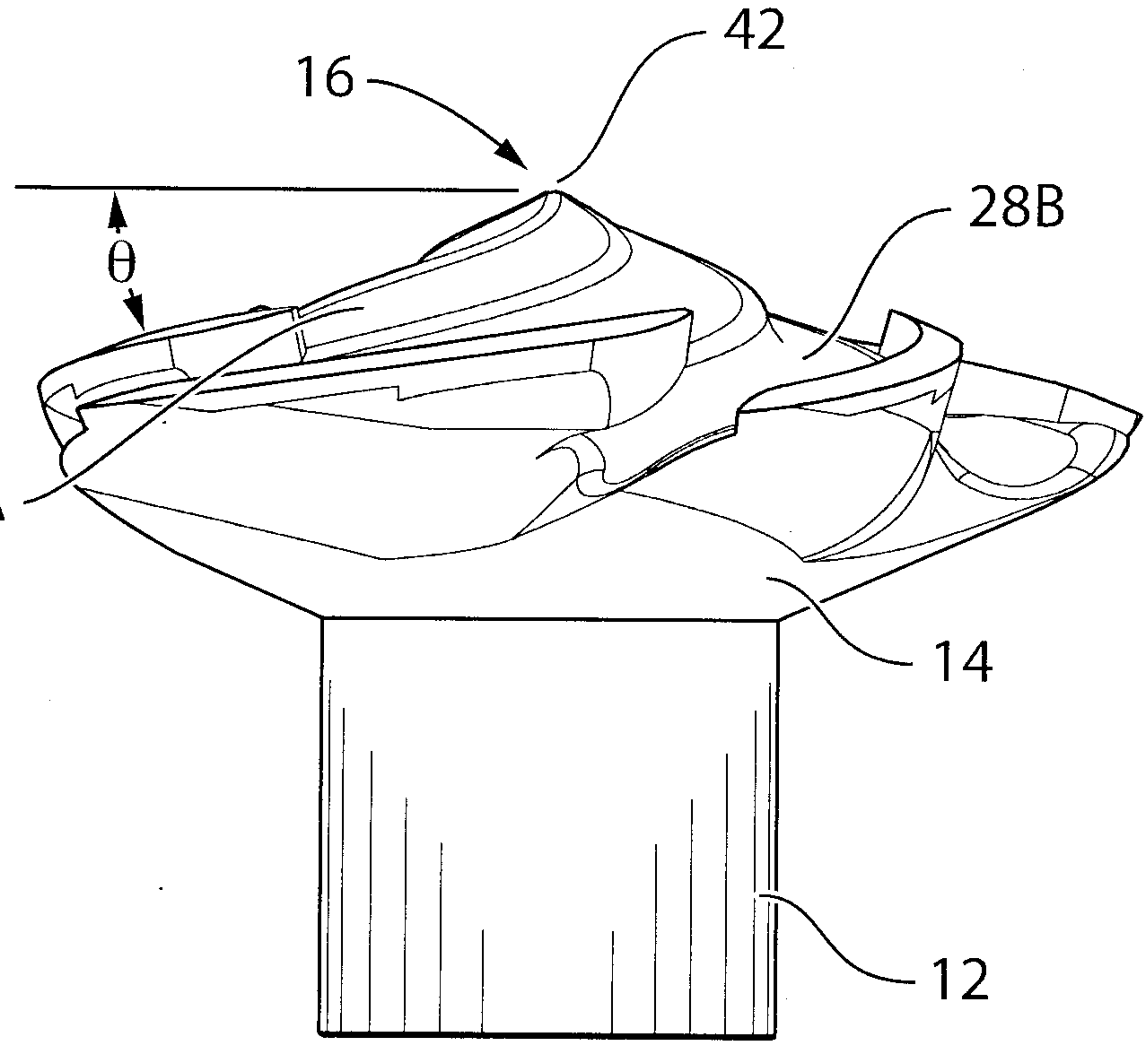


FIG. 6A

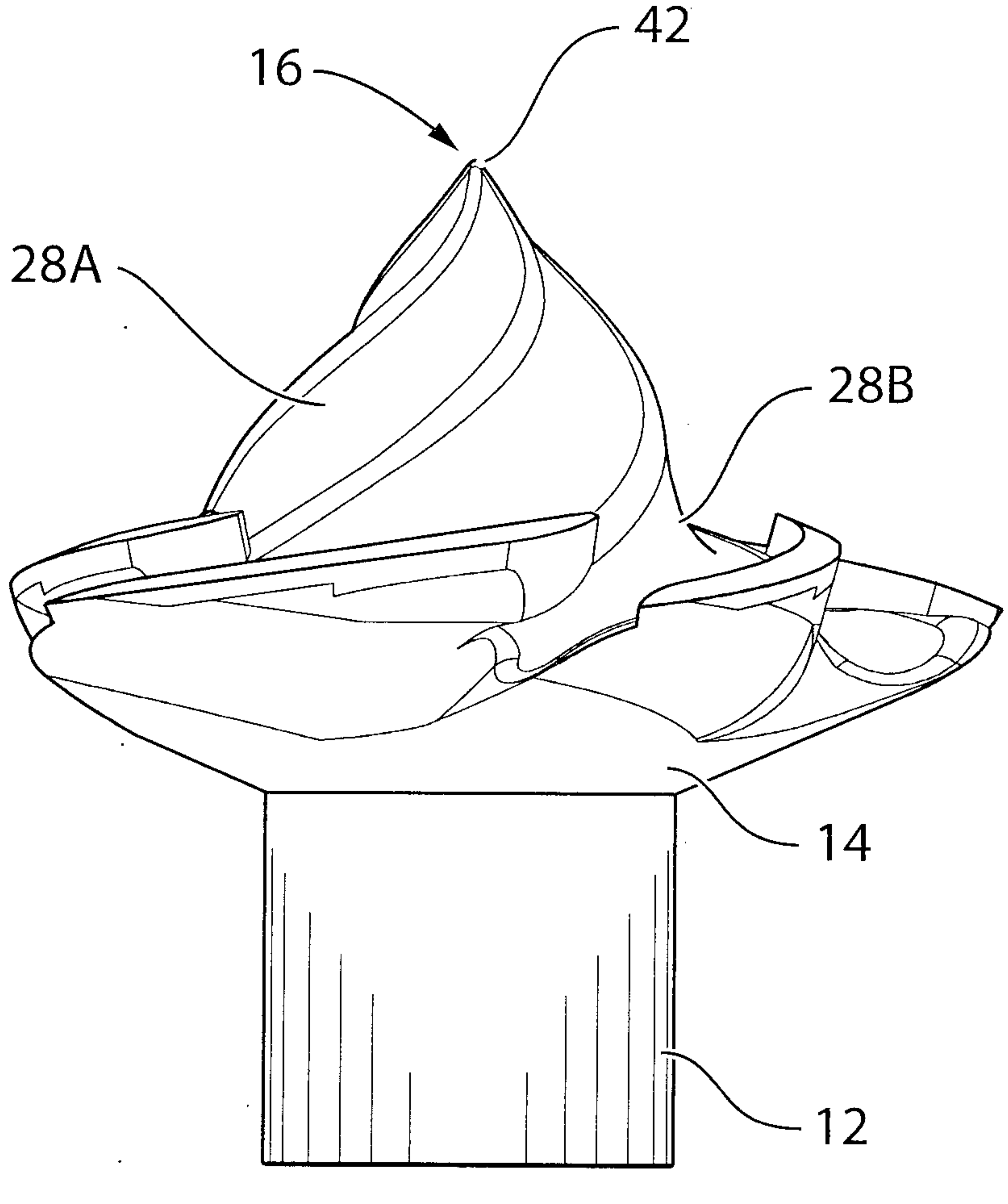


FIG. 6B

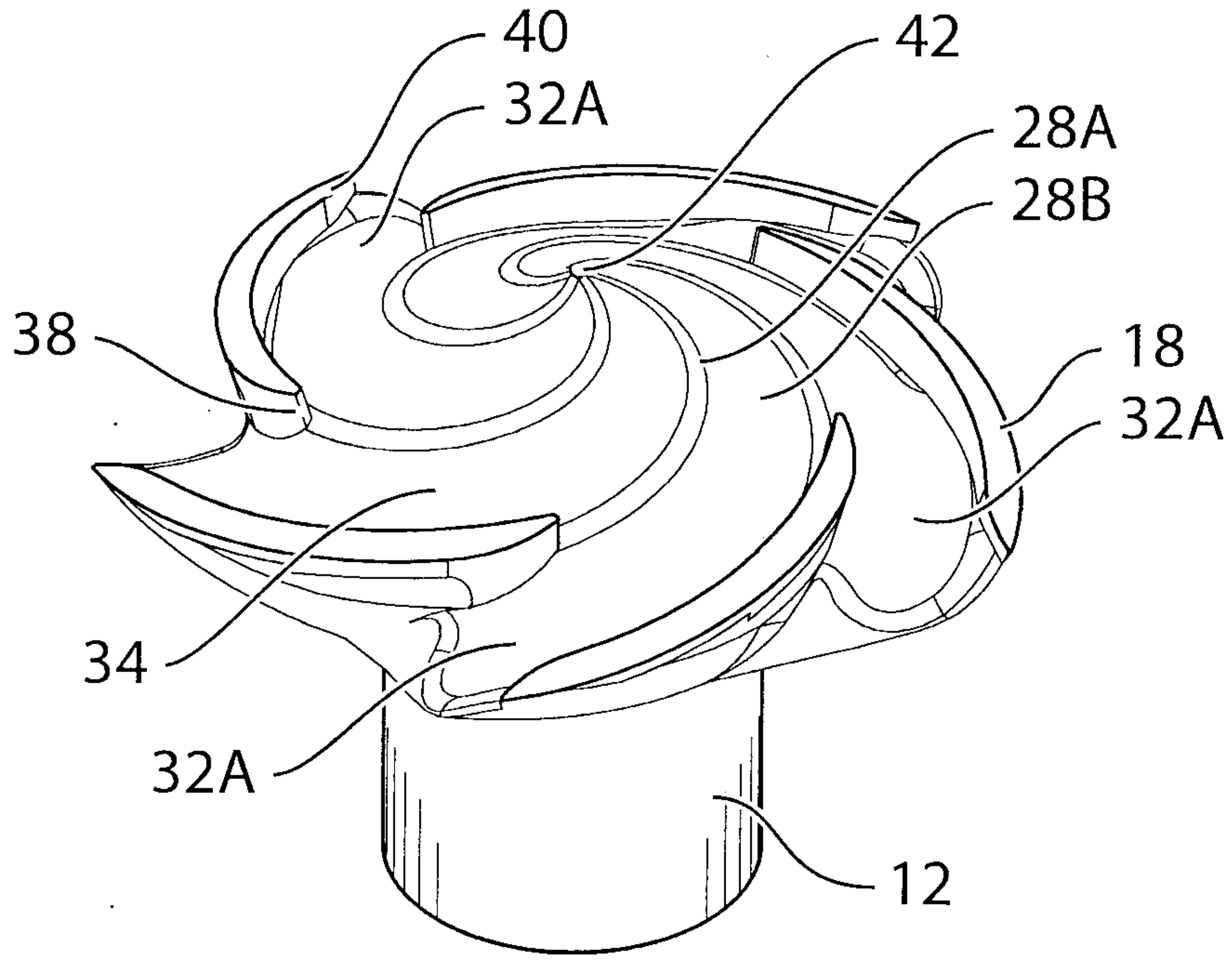


FIG. 7

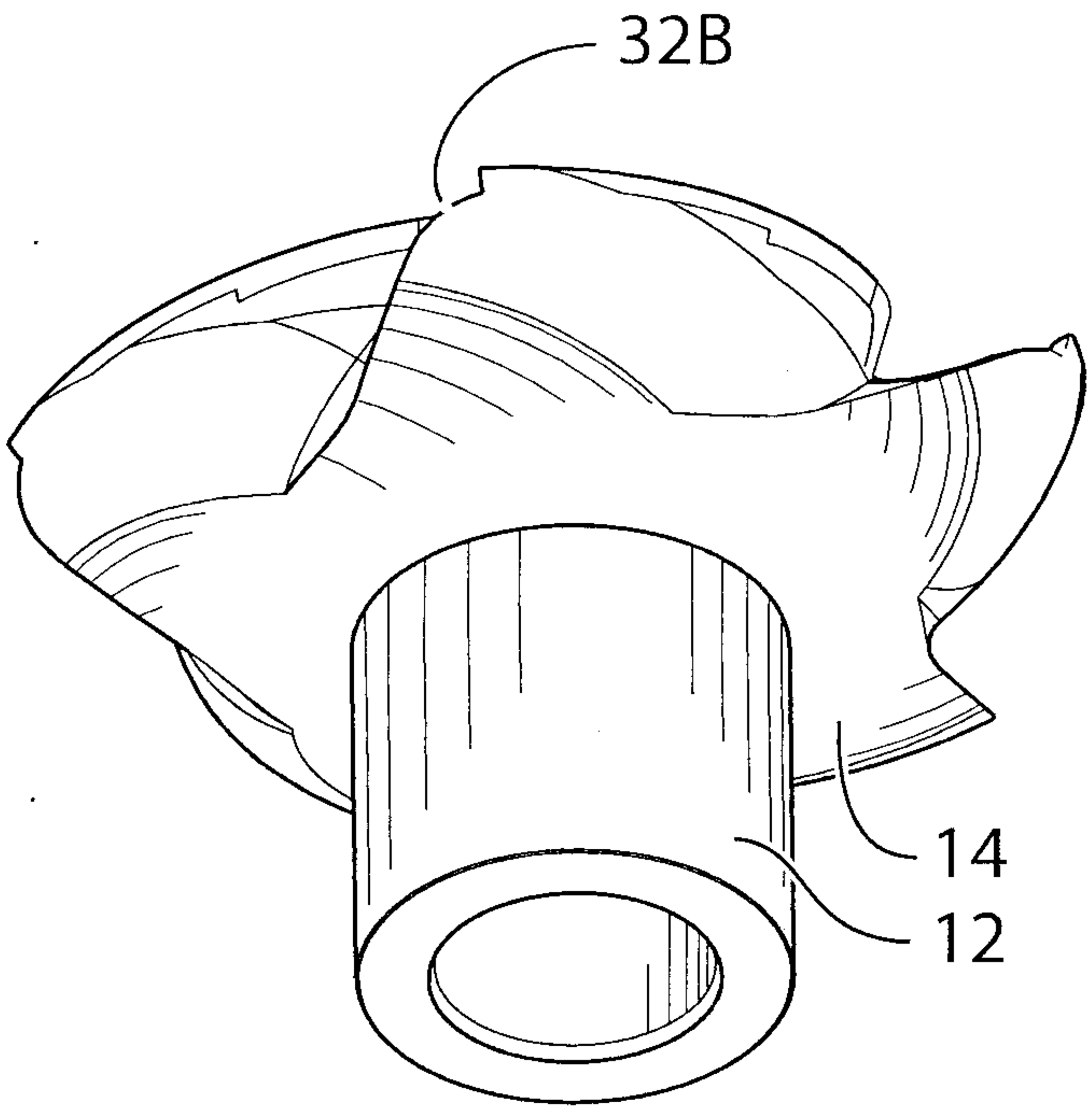


FIG. 8

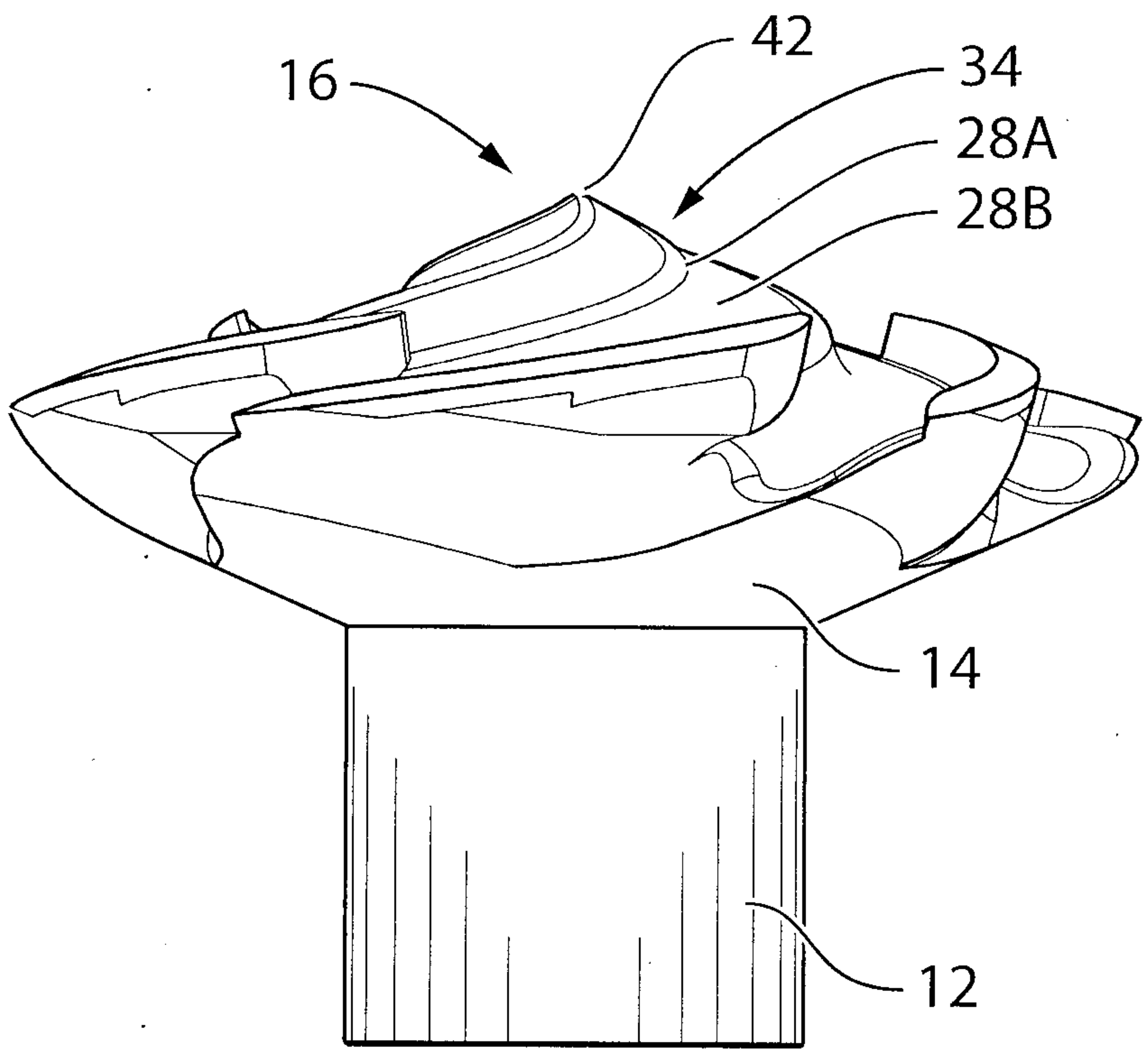


FIG. 9

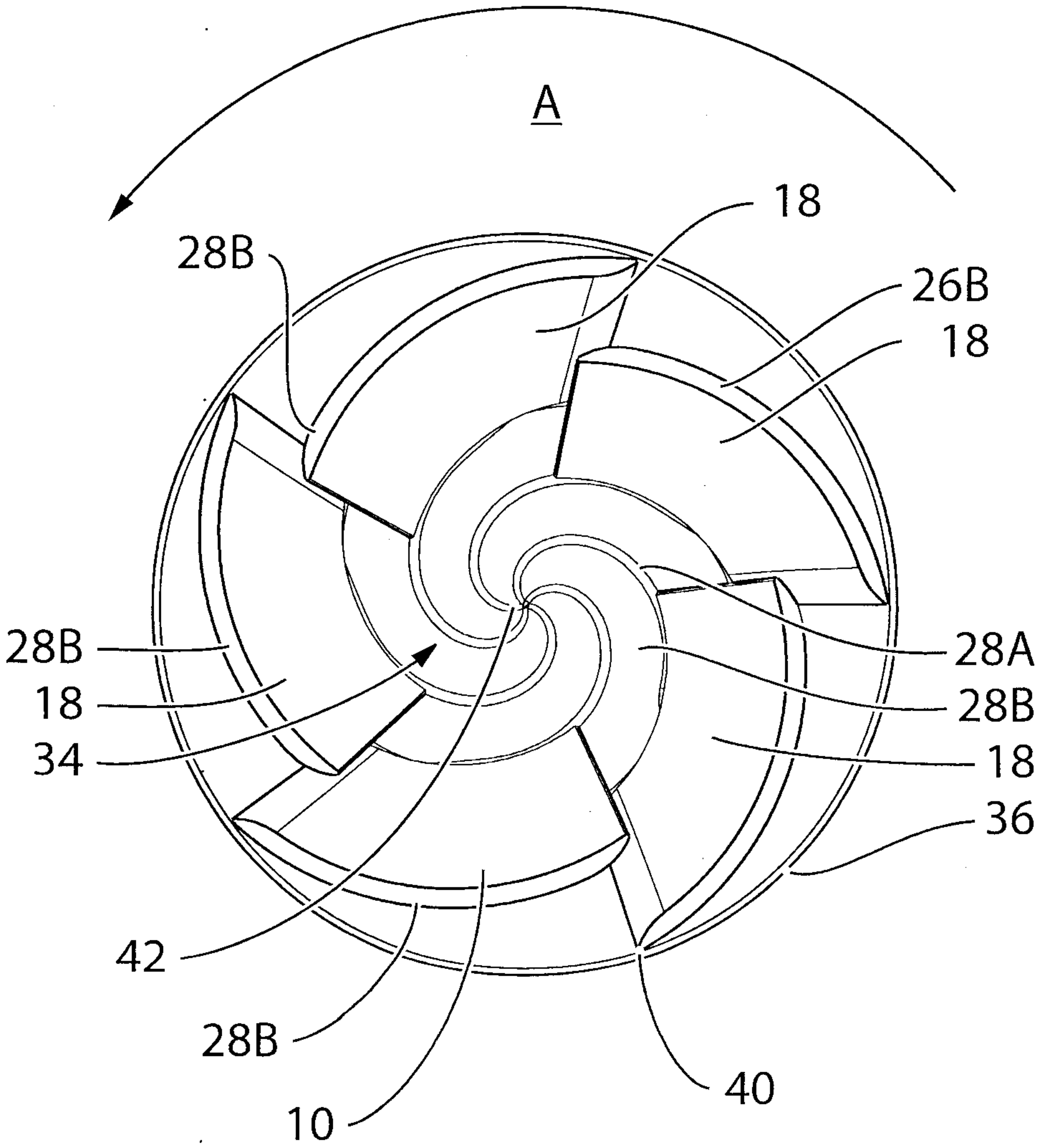


FIG. 10

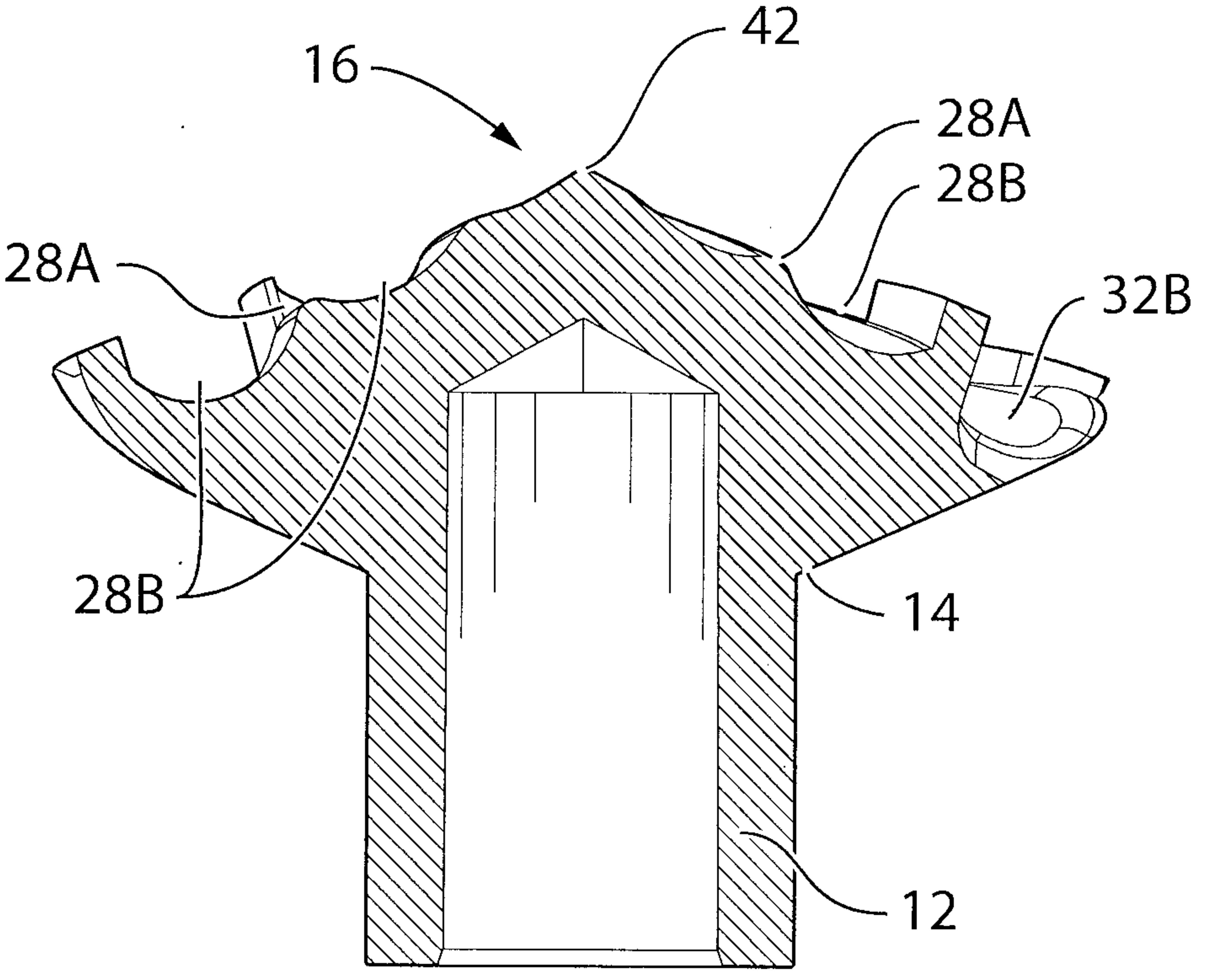


FIG. 11

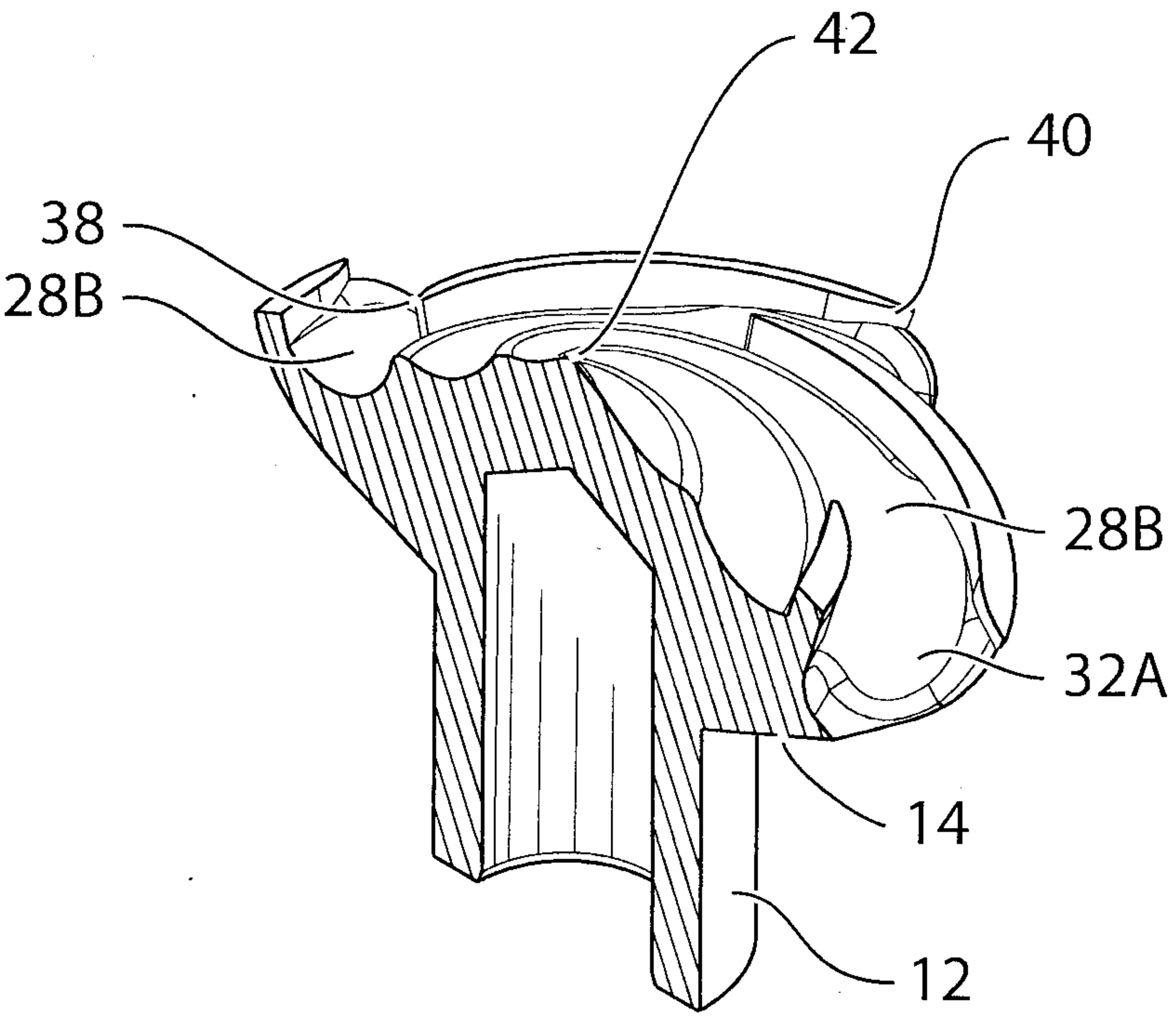
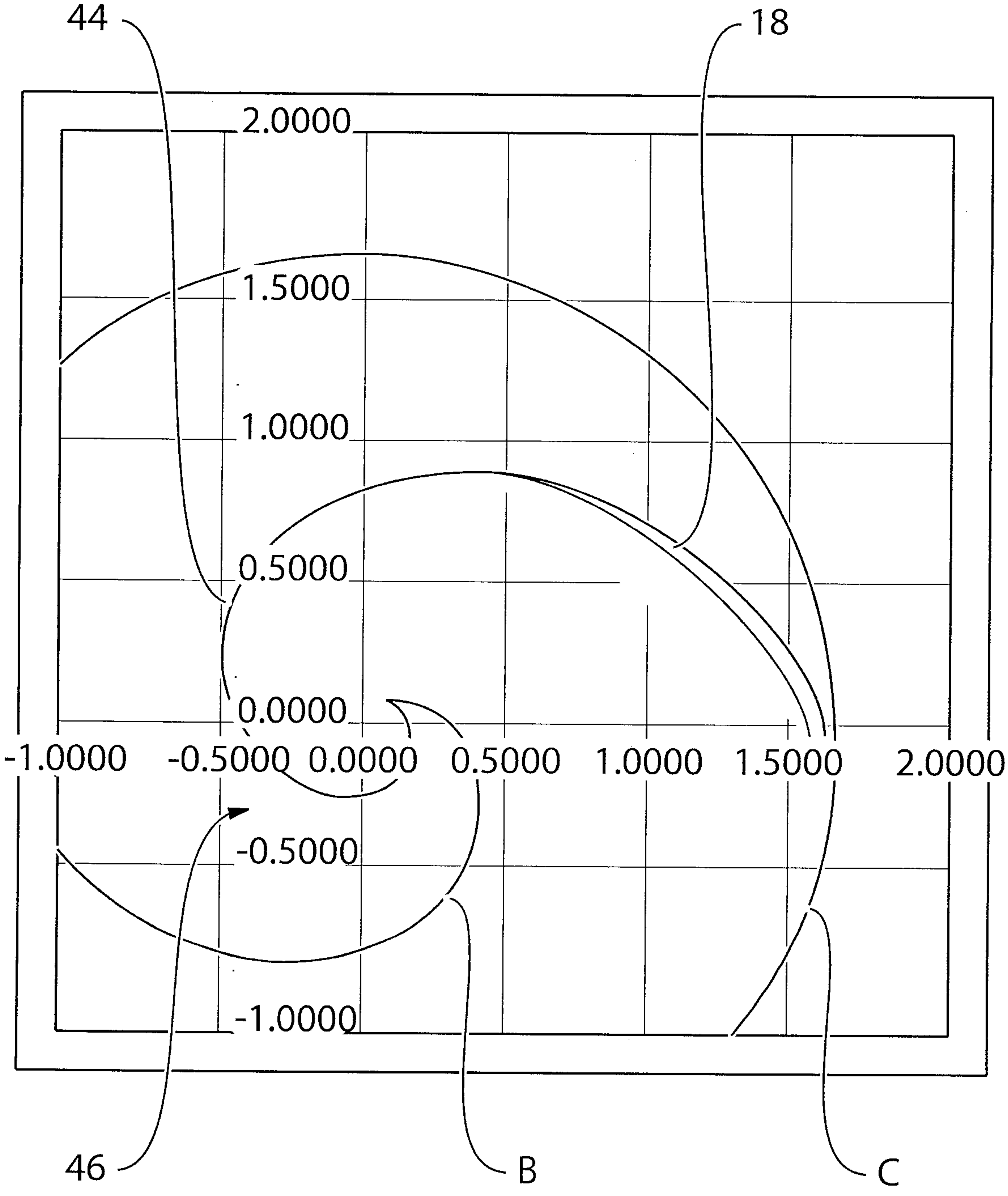


FIG. 12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B
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FIG. 13

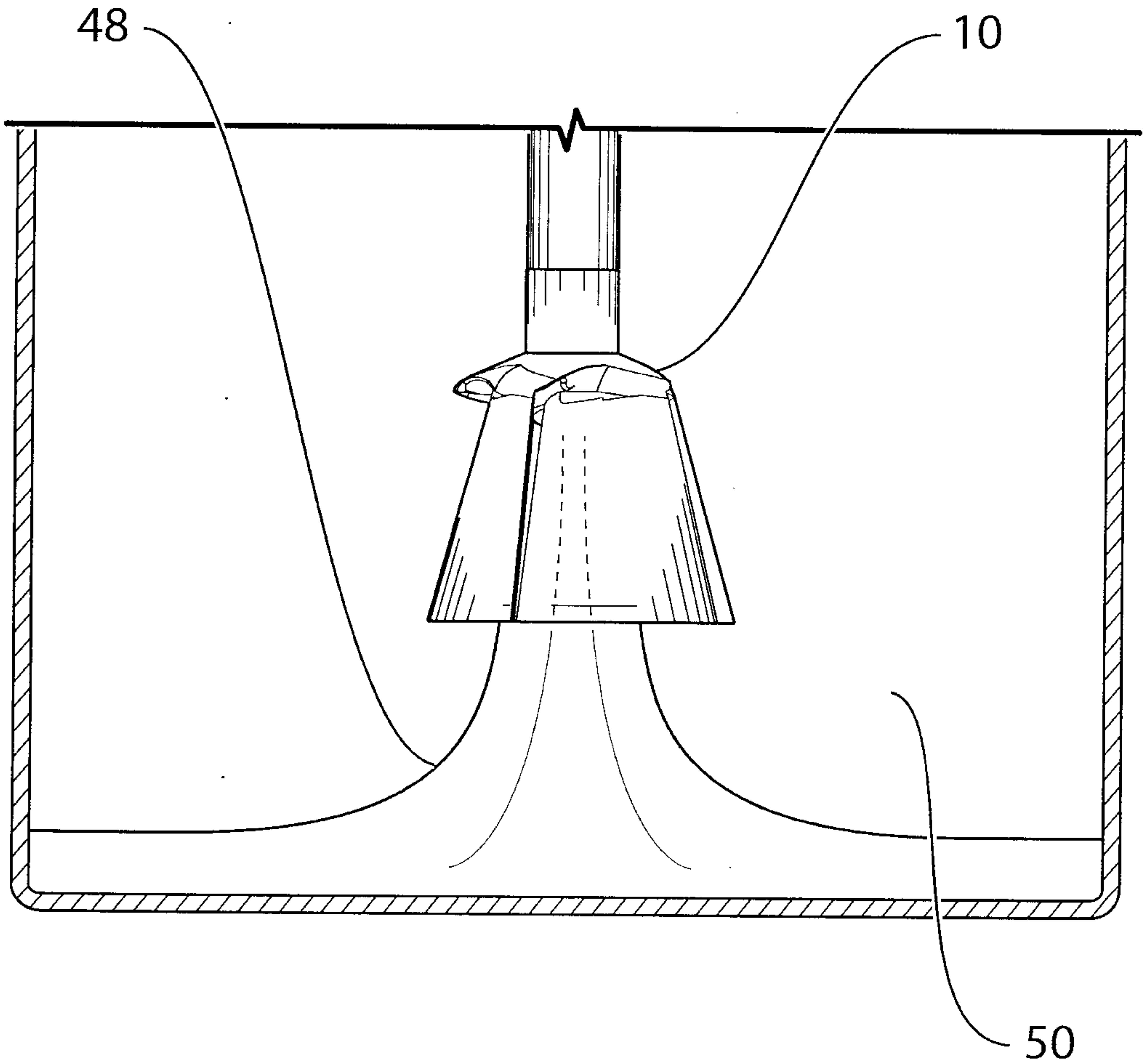
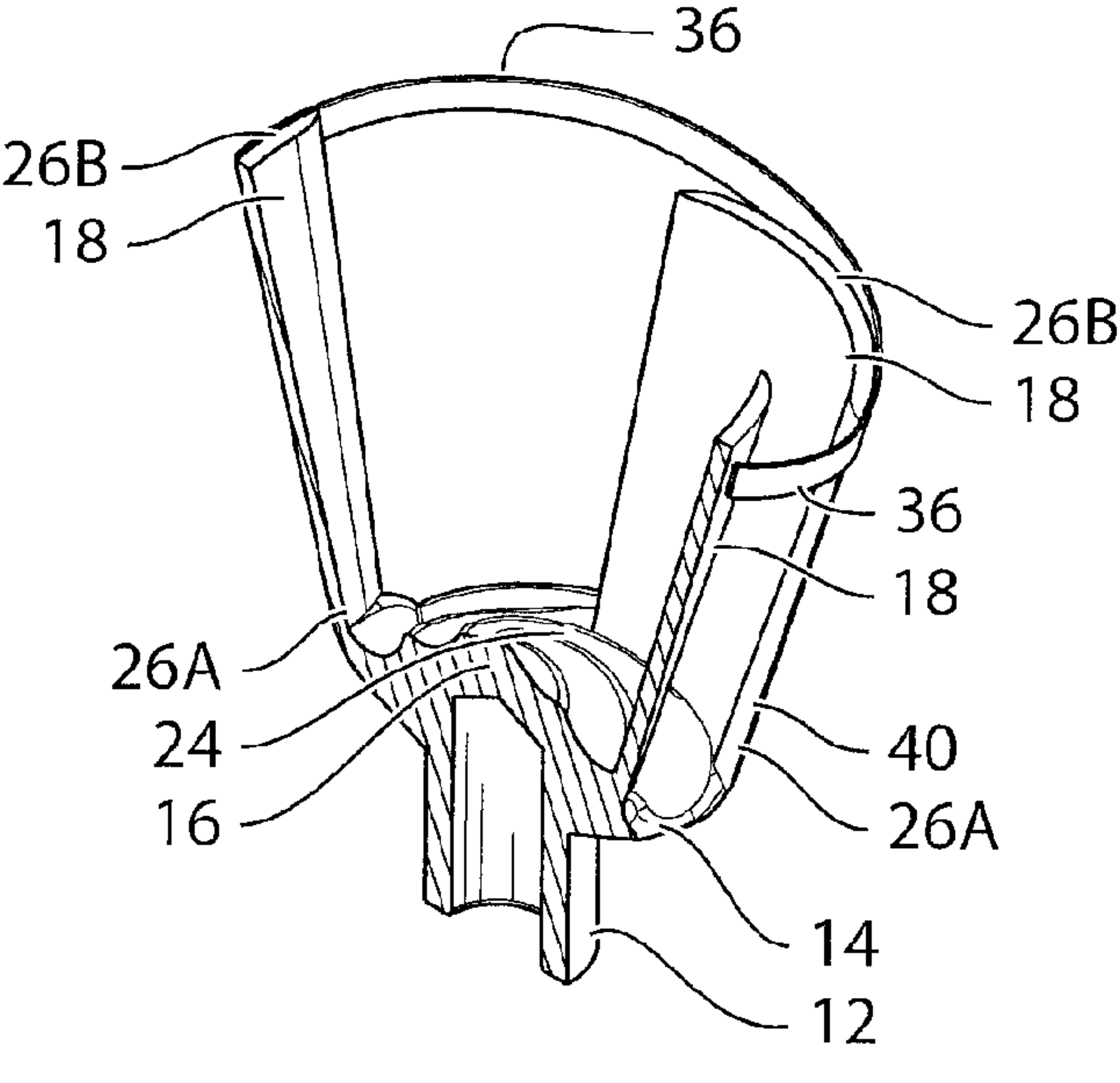


Fig. 14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