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(54) **COMPRESSOR IMPELLER WITH CURVED RIBS ON THE BACK SIDE OF THE BACKPLATE**

(57) A compressor wheel includes a hub, blades, and ribs. The hub has a primary side and a back side. The blades are on the primary side of the hub. The ribs are on the back side of the hub. The ribs curve forward in a

direction of rotation moving radially outward relative to an axis of the hub. The hub, the blades, and the ribs are integrally formed of a composite material.

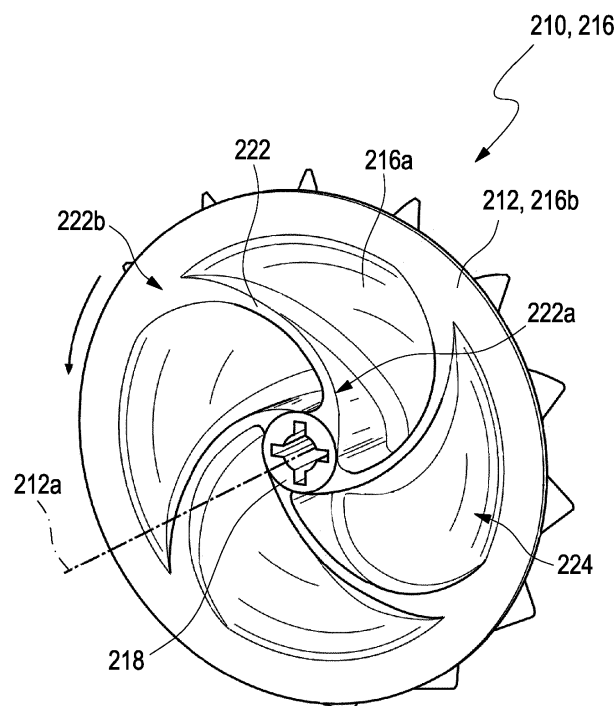


Fig. 2

Description

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] None.

BACKGROUND

[0002] Compressor wheels in forced induction devices (e.g., turbochargers or superchargers for internal combustion engines) accelerate at high rates (e.g., up to 200,000 rpm per second) and rotate in steady state at high speeds (e.g., up to 300,000 rpm), which can subject the compressor wheel to high stress. For example, during acceleration, the wheel may be subject to higher torsional loading and, thereby, higher stress (e.g., shear stress) as torque is transferred radially outward from a drive shaft to radially outer regions of the compressor wheel. More particularly, radially inward regions move ahead of radially outer regions, and stress (i.e., shear stress) builds in the material of the wheel that transfers the torque from the radially inward regions to the radially outer regions.

[0003] Conventional compressor wheels are typically made of a metal material and have a solid hub in which the metal material extends continuously in an axial direction from a primary side (e.g., first or front side or surface) to a back side (e.g., second or rear side or surface). The primary side is curved and includes a plurality of blades formed thereon, while the back side is planar and/or protrudes axially rearward away from the primary side. This type of material and structure allows the conventional compressor wheel to distribute and manage the torsional loading and stress during acceleration.

[0004] While compressor wheels have traditionally been made of metal materials, composite compressor wheels may offer various advantages, such as reduced mass and reduced moment of inertia, which can afford quicker response and/or allow for reduced motor size (e.g., in electric motor-driven forced induction devices), but may be subject to different strength considerations.

SUMMARY

[0005] One aspect of the disclosed embodiments is directed to a compressor wheel that a hub, blades, and ribs. The hub has a primary side and a back side. The blades are on the primary side of the hub. The ribs are on the back side of the hub. The ribs curve forward in a direction of rotation moving radially outward relative to an axis of the hub. The hub, the blades, and the ribs are integrally formed of a composite material.

[0006] The blades may have a face width that, from an intermediate radial region, widens moving radially inward and/or moving radially outward. The blades may have a substantially constant face width over a majority of a radial length thereof. The ribs may increase in thickness moving in an axial direction toward a back surface of the back side of the hub. The ribs may have a filleted transi-

tion to the back side of the hub, which may have a substantially constant radius over a majority of a radial length thereof.

[0007] A radially inner end of each rib may be offset relative to the axis. The compressor wheel may include a shaft coupling that protrudes radially rearward from the back side of the hub and that is integrally formed with the hub, and a trailing edge of each rib may be substantially tangential to the shaft coupling. An end of the shaft coupling may have a diameter that is a minimum radial dimension extending across the shaft coupling and perpendicular through the axis. The trailing edge of each rib may be tangential to the diameter of the end of the shaft coupling. A leading edge of each rib may intersect the trailing edge of another of the ribs adjacent thereto. The diameter of the shaft coupling may be determined at an intersection of the leading edge of the one of the ribs and the trailing edge of the other of the ribs adjacent thereto. The leading edge may be offset relative to the axis. The leading edge of each rib may be tangential to the shaft coupling in an opposite direction to which the trailing edge thereof is tangential to the shaft coupling.

[0008] The blades may curve in an opposite direction of the ribs at the primary surface on the primary side. The hub may include cavities on the back side thereof, each cavity being defined between two of the ribs.

[0009] The compressor wheel may be incorporated into a forced induction device, such as an exhaust driven turbocharger.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The description herein makes reference to the accompanying drawings, wherein like referenced numerals refer to like parts throughout several views, and wherein:

FIG. 1 is a cross-sectional view of a forced induction device.

FIG. 2 is a front perspective view of an embodiment of a compressor wheel of the forced induction device of FIG. 1

FIG. 2A is a schematic rear plan view of the compressor wheel shown in FIG. 2.

FIG. 2B is a cross-sectional view of the compressor wheel taken along line 2B-2B in FIG. 2A.

FIG. 2C is a cross-sectional view of the compressor wheel taken along line 2C-2C in FIG. 2A.

FIG. 2D is a cross-sectional view of the compressor wheel taken along line 2D-2D in FIG. 2A.

FIG. 3A is a rear perspective view of the compressor wheel of FIG. 2.

FIG. 3B is a rear perspective view of another embodiment of a compressor wheel for use in the forced induction device of FIG. 1.

FIG. 3C is a rear perspective view of another embodiment of a compressor wheel of the forced induction device of FIG. 1.

FIGS. 4A, 4B, and 4C are rear perspective views of the compressor wheels shown in FIGS. 3A, 3B, and 3C, respectively, which depict stress in the compressor wheels during acceleration conditions.

FIGS. 5A, 5B, and 5C are rear perspective views of the compressor wheels shown in FIGS. 3A, 3B, and 3C, respectively, which depict stress in the compressor wheels during steady state conditions.

FIGS. 6A, 6B, and 6C are rear perspective views of the compressor wheels shown in FIGS. 3A, 3B, and 3C, respectively, which depict displacement of the compressor wheels during steady state conditions.

DETAILED DESCRIPTION

[0011] As disclosed herein, a compressor wheel for a forced induction device is formed of a polymer or composite material and is configured to distribute and/or otherwise manage torsional loading, so as to reduce or otherwise manage stress induced by acceleration of the compressor wheel. More particularly, the compressor wheel includes curved strengthening ribs on a back side thereof, which are configured to be compressed during acceleration to transfer torque and limit stress. The curved strengthening ribs may also be configured to provide substantially even radial growth of the compressor wheel at its outermost portions.

[0012] As shown in FIG. 1, a forced induction device 100 includes a compressor wheel 210, a housing 140 in which the compressor wheel 210 is positioned, and an electric motor (not shown) that spins the compressor wheel 210. In use, the forced induction device 100 may be configured as part of a powertrain of a vehicle and be arranged to supply compressed air to an internal combustion engine of the powertrain. The forced induction device 100 may instead drive (e.g., spin or rotate) the compressor wheel 210 using exhaust gas from the engine (e.g., a turbocharger) or mechanical power from the engine (e.g., a supercharger).

[0013] Referring to FIGS. 2 and 3A, another embodiment of a compressor wheel 210 is a unitary, polymer or composite member. For example, the compressor wheel 210 may be molded (e.g., injection or insert molded) of composite material, such as glass-filled nylon.

[0014] The compressor wheel 210 includes a hub 212, which forms a primary body (e.g., member or structure) of the compressor wheel 210. The hub 212 has a primary side 214 (e.g., front or first side) and a back side 216 (e.g., rear or second side). The compressor wheel 210 is configured to rotate (e.g., spin) about an axis 212a (e.g., central axis, or axis of rotation).

[0015] A shaft coupling 218 (e.g., coupling or annular protrusion, portion, region, segment, structure, or member) is formed integrally with the hub 212. The shaft coupling 218 may also be considered part of the hub 212. The shaft coupling 218 is configured to couple to a drive shaft 152 (shown in FIG. 1) for rotatably supporting the compressor wheel 210. The drive shaft 252 is in turn

coupled to and driven by the electric motor (or other drive source).

[0016] The shaft coupling 218 is a member or structure that extends axially rearward from the back surface 216a of the hub 212. The shaft coupling 218 has an axial face (e.g., end) that may be considered to have a circular shape. The diameter of the axial face is considered the minimum radial dimension extending across the axial face of the shaft coupling 218 and perpendicular through the axis 212a. It should be noted, however, that because ribs 222 (discussed in further detail below) may be formed integrally with the shaft coupling 218 as a continuous body, no physical division may be present between the shaft coupling 218 and the ribs 222. Rather, an imaginary line having the diameter of the shaft coupling 218 divides (e.g., forms an artificial boundary or demarcation) that portion considered the shaft coupling 218 from those portions considered the ribs 222. In some embodiments, the shaft coupling 218 may also be considered as having a cylindrical shape, or in other embodiments a frusto-conical shape. The outer diameters of the cylindrical or frusto-conical shape are again those minimum dimensions extending through the shaft coupling and through the axis 212a, and form an imaginary line dividing that portion of the integral body considered the shaft coupling 218 and those considered the ribs 222.

[0017] The shaft coupling 218 may include a recess (e.g., cross-shaped as shown), which is configured to receive the drive shaft and be driven thereby.

[0018] The primary side 214 of the hub 212 includes (e.g., defines or forms) a primary surface 214a (e.g., front or first surface). In a cross-sectional plane containing the axis 212a, the primary surface 214a follows a curved profile that narrows moving axially away from the back side 216 (e.g., the primary surface 214a flares wider or increases in diameter moving toward the back side 216). The primary side 214 includes a plurality of blades 220 extending from the primary surface 214a, which draw air from an intake (not labeled) and expel the air from an outlet (not labeled) at a higher pressure for forced induction of an internal combustion engine. The plurality of blades 220 are formed integrally with the hub 212 (e.g., as part of the molding process).

[0019] The back side 216 of the hub 212 includes (e.g., defines or forms) a back surface 216a (e.g., rear or second surface) arranged axially opposite the primary surface 214a. The back side 216 includes one or more recesses 224 that are defined between the back surface 216a, the shaft coupling 218, and adjacent ones of the ribs 222. The recesses 224 extend in an axially forward direction from a back end of the shaft coupling 218. The recesses 224 allow for the hub 212 to have a thin and/or consistent wall thickness (i.e., extending axially between the primary surface 214a and the back surface 216a), which may be advantageous in forming the compressor wheel 210 with an injection molding process. By including the recess 224, the hub 212 may be considered hollow, which is in contrast to the solid hub design of conventional compres-

or wheels described above.

[0020] The back side 216 of the compressor wheel 210 additionally includes the ribs 222 (e.g., strengthening ribs, structures, walls, etc.). The ribs 222 are configured to transfer torque from radially inner portions to radially outer portions of the compressor wheel 210, so as to reduce stress in the hub 212 during acceleration of the compressor wheel 210, as compared to other compressor wheel designs (discussed in further detail below).

[0021] The ribs 222 each include a radially inner end 222a coupled to the shaft coupling 218 (e.g., being integrally formed therewith) and extend radially outward to a radially outer end 222b coupled to (e.g., being integrally formed with) a radially outer region 216b of the back surface 216a of the compressor wheel 210.

[0022] The ribs 222 are evenly distributed circumferentially about the axis 212a of the hub 212. For example, as shown, the compressor wheel 210 includes four ribs 222 spaced at 90 degree intervals. The compressor wheel 210 may, however, include fewer or more ribs (e.g., three at 120 degree intervals, five at 72 degree intervals, six or more).

[0023] Each of the ribs 222 has a curved (e.g., arcuate) shape. More particularly, in a plane perpendicular to the axis 212a, the rib 222 curves forward in a direction of rotation (indicated by curved arrows in FIGS. 2 and 3A) of the compressor wheel 210 moving radially outward along the rib 222. By being curved in the direction of rotation moving radially outward, torque is transferred during acceleration of the compressor wheel 210 from radially inner regions to radially outer regions as a compressive load along the ribs 222. The direction of curvature of the ribs 222 may be the opposite the curvature of the blades 220 along the primary surface 214a, which curve rearward in the direction of rotation moving radially outward.

[0024] The ribs 222 may be configured in different manners, for example, according to curvature, cross-sectional shape, and/or location relative to other portions of the compressor wheel 210. The curvature of the ribs 222 in a plane perpendicular to the axis 212a may be configured for the rib 222, during acceleration, to be loaded primarily in compression and minimize any bending load or moment. The curvature of the ribs 222 may still further be configured to prevent drawing lubricants (e.g., oil or grease) from bearings positioned adjacent the back side 216 of the compressor wheel 112, for example, by creating a small positive pressure on the back side 216 of the compressor wheel 210.

[0025] Referring to FIG. 2A, each rib 222 may have a curvature with a substantially constant radius (e.g., a simple curve). A radially inner edge 222c (e.g., inner or leading edge face), a radially outer edge 222d (e.g., outer or trailing edge or face), and/or a center 222e of the rib 222 (e.g., midway between the radially inner edge 222c and the radially outer edge 222d; indicated by dashed line) may have a substantially constant radius over a majority of the radial length of the rib 222 (e.g., 50% or more of

the overall length of the rib 222), such as over a radially intermediate region or portion extending from the radially inner end 222a to the radially outer end 222b of the rib 222. The inner end 222a and the outer end 222b may have a different curvature, for example, having a tighter or reducing radius as compared to the majority and/or intermediate portion of the rib 222. According to other embodiments, the ribs 222 may have another curvature, such an elliptical or exponential curvature, or other shape that decreases in radius moving radially outward, or alternatively increases in radius moving radially outward.

[0026] Still referring to FIG. 2A, moving in the radial direction, each of the ribs 222 may have a substantially constant end or face width or thickness (i.e., measured at the end surface of the rib 222 between the inner edge 222c and the outer edge 222d) over a majority of the radial length of the rib 222 (e.g., 50% or more of the overall length of the rib 222), such as over the radial intermediate region extending from the radially inner end 222a to the radially outer end 222b of the rib 222. The axial ends or faces of the ribs 222 may be substantially coplanar with the end of the shaft coupling 218 and/or the outer portion 216b of the back side 216 of the hub 212.

[0027] Instead or additionally, the ribs 222 may vary in face width moving in the radial direction. For example, the radially inner end 222a may flare (e.g., widen) moving radially inward, for example, to form a fillet that gradually transitions into (e.g., intersects) the shaft coupling 218. The curvature of the rib 222 may change the curvature over the radially inner end 222a due to the fillet as compared to other portions of the rib 222. The radially outer end 222b may also flare (e.g., wide) moving radially outward, for example, as the rib 222 transitions into (e.g., intersects) the outer region 116b of the back surface 216a of the hub 212. Having a greater face width at the radially outer end 222b of the rib 222 may also allow for the rib 222 to have more material, which may offset reduced material of the blades 220 that thin moving radially outward, so as to further limit stress concentrations.

[0028] Referring to the cross-sections shown in FIGS. 2B-2D, the cross-sectional shape of the ribs 222 may be configured in various manners. The cross-sectional shape of the ribs 222 may have a substantially constant thickness (i.e., the shortest distance through the rib 222 in a plane perpendicular to the axis 212a) over radially intermediate portions thereof (e.g., moving in an axial direction from the end faces of the ribs 222 toward the primary side 214). The ribs 222 may additionally include a gradual transition (e.g., fillet) to the back surface 216a of the hub 212 (e.g., moving deeper into the recesses 224), resulting in the thickness of the ribs 222 increasing moving in the axial direction toward the primary side 214. The transition may have a constant radius moving toward the back surface 216a and/or radially along the rib 222.

[0029] At the radially outer end 222b, the end face of the rib 222 may coincide with the gradual axial transition, such that the rib 222 has a greater face width than at radially intermediate positions (compare FIG. 2D to

FIGS. 2B and 2C); the radially inner end 222a may similarly have a greater face width than at radially intermediate positions.

[0030] The position of the ribs 222 relative to other portions of the compressor wheel 210 may also be configured in various manners. For example, the ribs 222 may each be offset relative to the axis 212a of the hub 212 (e.g., such that the center 222e does not intersect the axis 212a). The rib 222 may extend substantially tangentially relative to the shaft coupling 218. In one example, the radially outer edge 222d of the rib 222 is substantially tangential with a radially outer edge of a circle or cylinder defining at least a portion of the shaft coupling 218. The radially inner edge 222c of the rib 222 may also be offset relative to the axis 212a of the hub 212, but may include a fillet (as shown) transitioning to the shaft coupling 218 (e.g., such that the inner edge 222c is tangential to the shaft coupling 218 in an opposite direction than the radially outer edge 222d). The radially inner edge 222c of one of the ribs 222 may intersect the radially outer edge 222d of an adjacent one of the other ribs 222 (e.g., at the location where the diameter of the shaft coupling 218 is determined).

[0031] As referenced above, the curved shape of the ribs 222 is configured to reduce stress in the hub 212 during acceleration, as compared to similarly configured compressor wheels without such curved ribs. Computer simulations were performed in both accelerating and steady state conditions for the compressor wheel 210 and other compressor wheels 310 and 410. The compressor wheel 310 is configured similarly to the compressor wheel 210 by having a hollow hub (refer to recesses 224 in FIG. 2), but without any ribs (i.e., having a single recess on its back side that circumscribes the shaft coupling), see, e.g., FIG. 3B.

[0032]). Another compressor wheel 410 differs from the compressor wheel 210 by having ribs that instead extend straight radially outward from a central axis of the compressor wheel 410, see, e.g., FIG. 3C.

[0033] Referring to FIGS. 4A to 4C, computer simulations of acceleration conditions were performed to determine stress concentration. The outer peripheries of the compressor wheels were held in place, while torque was applied to the coupling portion. In Figs. 4A to 4C, regions having different shading indicate different levels of stress (see legend associated with FIG. 4A). As shown in FIG. 4B, the compressor wheel 310 (without ribs) experiences large stress concentrations of greater than 200 MPa in large areas surrounding the shaft coupling and in radially inward regions of the hub. The stress gradually reduces moving radially outward. Stress reduction is also visible in regions associated with blades on the opposite side of the compressor wheel 310. As shown in FIG. 4C, the compressor wheel 410 (straight ribs) also experiences large stress concentrations of greater than 200 MPa in large areas in the shaft coupling, radially inward regions of the hub, and in transitions between the ribs and the hub. In contrast, as shown in FIG. 4A, the compressor

wheel 210 experiences substantially smaller stress concentrations of greater than 200 MPa in relatively small areas localized at transitions between the ribs 222 and the shaft coupling 218.

[0034] Referring to FIGS. 5A to 5C, computer simulations of steady state conditions were performed in which a 1 bar load was applied the blades (i.e., representing aerodynamic loading), a centrifugal load of 70,000 RPM was applied, and the shaft coupling was restrained against rotation. As shown in FIG. 5B, the compressor wheel 310 (no ribs) experienced the lowest magnitude stress concentrations, peaking at approximately 70,000 MPa. As shown in FIG. 5C, the compressor wheel 410 (straight ribs) experienced peak stress concentrations of approximately 100,000 MPa in transition regions between the ribs and the back surface (e.g., as the ribs constrain radial growth of the hub). As shown in FIG. 5A, the compressor wheel 210 (curved ribs) experienced peak stress concentrations of approximately 100,000 MPa in transition regions between the ribs 222 and the back surface 216a with highest stress concentrations at the radially outer face 222d (e.g., as the ribs 222 expand radially outward to straighten).

[0035] Referring to FIGS. 6A to 6C, computer simulations of steady state conditions were also performed to indicate radial displacement (e.g., growth). In Figs. 6A to 6C, regions having different shading indicate different amounts of radial growth (see legend associated with FIG. 6A). As compared to metal compressor wheels, growth of polymer or composite compressor wheels may be up to 20 times. As shown in FIG. 6B, the compressor wheel 210 (no ribs) experiences substantially even radial growth circumferentially therearound. Aerodynamic loading of the blades 220 tends to compress the compressor wheel radially inward, so as to partially offset centrifugal forces. As shown in FIG. 6C, the compressor wheel 410 (straight ribs) experiences uneven radial growth circumferentially therearound with the ribs constraining growth at 90 degree intervals. As shown in FIG. 6A, the compressor wheel 210 (curved ribs), experiences even radial growth circumferentially therearound but in slightly greater magnitude than the compressor wheel 310.

[0036] In view of the foregoing computer simulations, the compressor wheel 210 (curved ribs) experienced substantially markedly reduced stress than the compressor wheel 310 (no ribs) and the compressor wheel 410 (straight ribs) during acceleration, but experiences higher stress than the compressor wheel 310 during steady state conditions. Additionally, the compressor wheel 210 experienced slightly greater radial growth than the compressor wheel 310 (no ribs), and substantially more even radial growth than the compressor wheel 410 (straight ribs), during steady state rotation. As a result, the compressor wheel 210 may provide a better compromise of stress in acceleration and steady state conditions, while providing substantially even radial growth, which may be provide better durability and/or fatigue life of the com-

pressor wheel 210 formed of a polymer or composite material. Furthermore, the use of ribs 222 that are curved in the compressor wheel 210 may be particularly advantageous in different applications, such as in exhaust-driven turbochargers that operate the compressor wheel 210 at higher pressures and/or at higher temperatures (e.g., as compared to electronic or mechanically driven forced induction devices) that may cause greater stress and/or shape distortion of the compressor wheel used therein.

[0037] As referenced above, the ribs 222 may also be configured to maintain or create a positive pressure at the back side 216 of the compressor wheel 210. In applications in which one or more bearings support the drive shaft 152 and are lubricated (e.g., in turbocharger applications), the bearings are lubricated and a lower pressure region on the back side 216 (e.g., caused by the shape of the ribs 222, such as if straight) may draw oil or other lubrication from such bearings.

[0038] It is to be understood that the present disclosure is not to be limited to the disclosed embodiments but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the scope of the appended claims, which scope is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures as is permitted under the law.

Claims

1. A compressor wheel comprising:

a hub having a primary side and a back side;
 blades on the primary side of the hub; and
 ribs on the back side of the hub;
 wherein the ribs curve forward in a direction of
 rotation moving radially outward relative to an
 axis of the hub; and
 wherein the hub, the blades, and the ribs are
 integrally formed of a composite material.

2. The compressor wheel according to claim 1, wherein the blades have a face width that, from an intermediate radial region, widens moving radially inward and widens moving radially outward.

3. The compressor wheel according to any of the preceding claims, wherein the ribs increase in thickness moving in an axial direction toward a back surface of the back side of the hub.

4. The compressor wheel according to any of the preceding claims, wherein a radially inner end of each rib is offset relative to the axis.

5. The compressor wheel according to claim 4, further comprising a shaft coupling that protrudes axially rearward from the back side of the hub and is inte-

grally formed with the hub, wherein a trailing edge of each rib is substantially tangential to the shaft coupling.

6. The compressor wheel according to any of the preceding claims, wherein the blades curve in an opposite direction of the ribs at the primary surface on the primary side.

7. The compressor wheel according to any of the preceding claims, wherein the hub includes cavities on the back side thereof, each cavity being defined between two of the ribs.

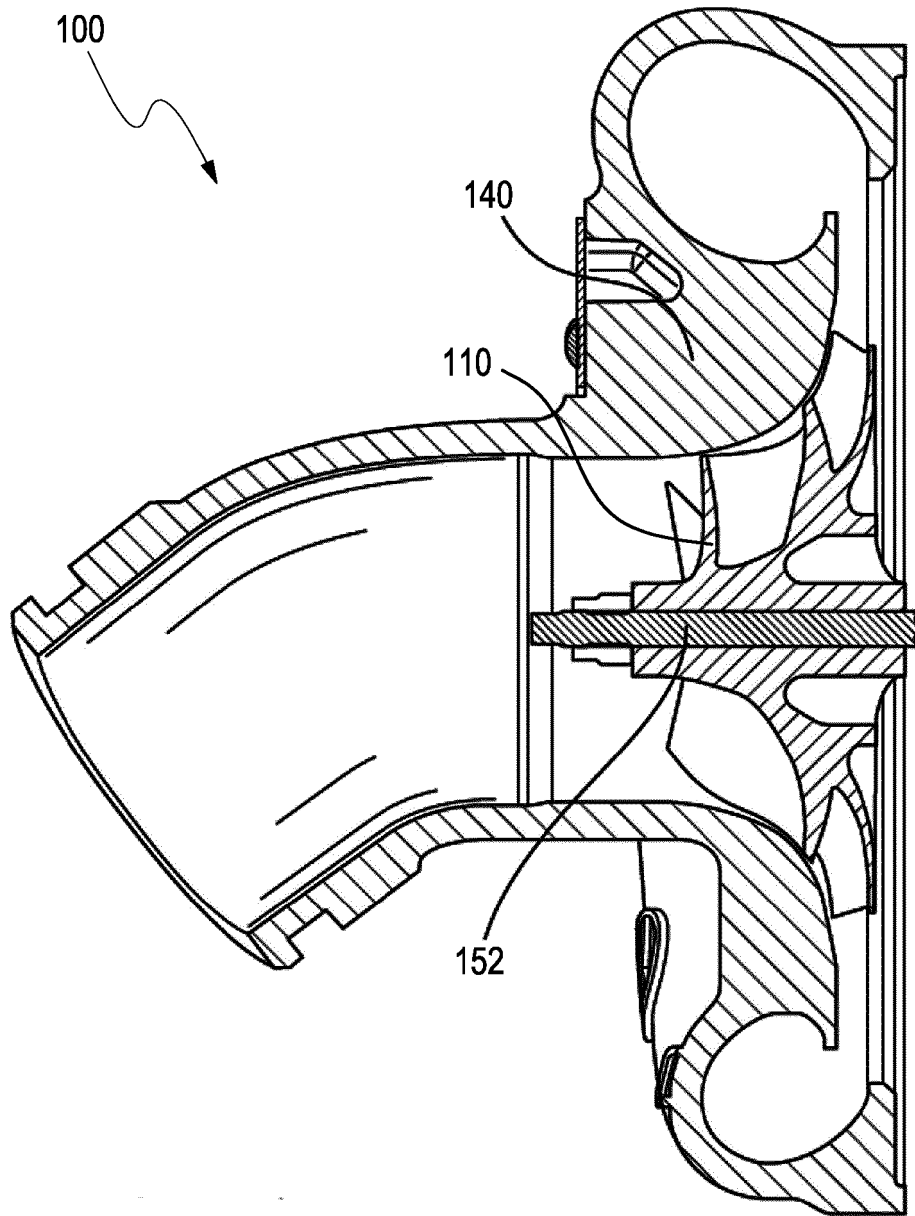


Fig. 1

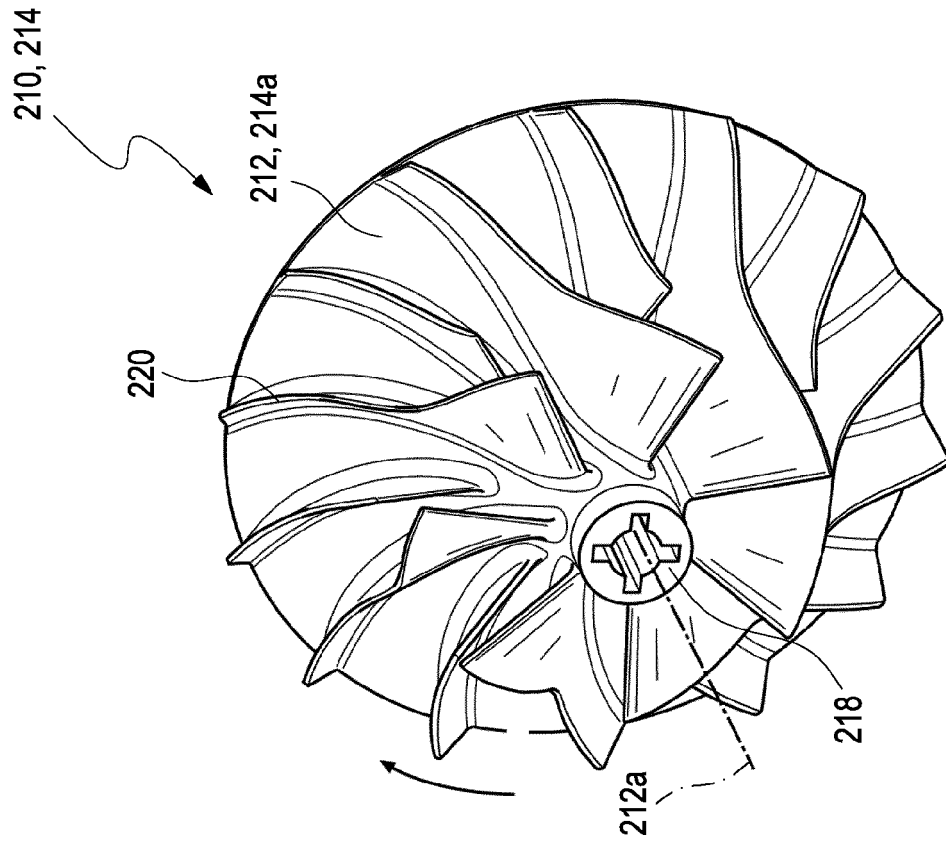


Fig. 3 A

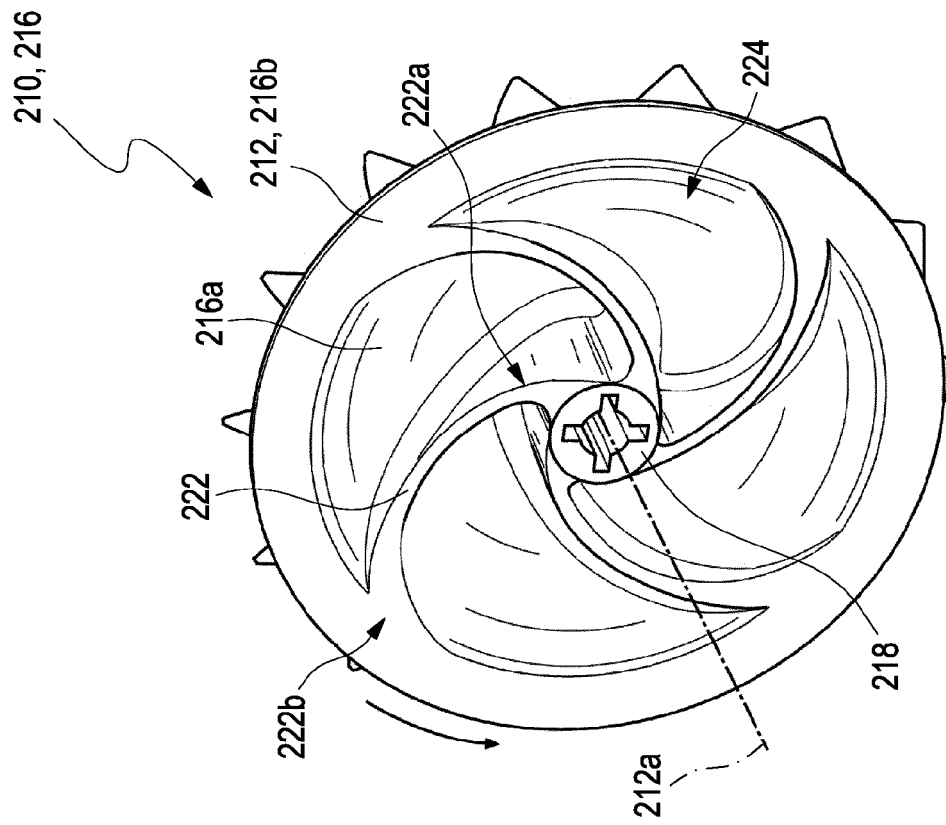


Fig. 2

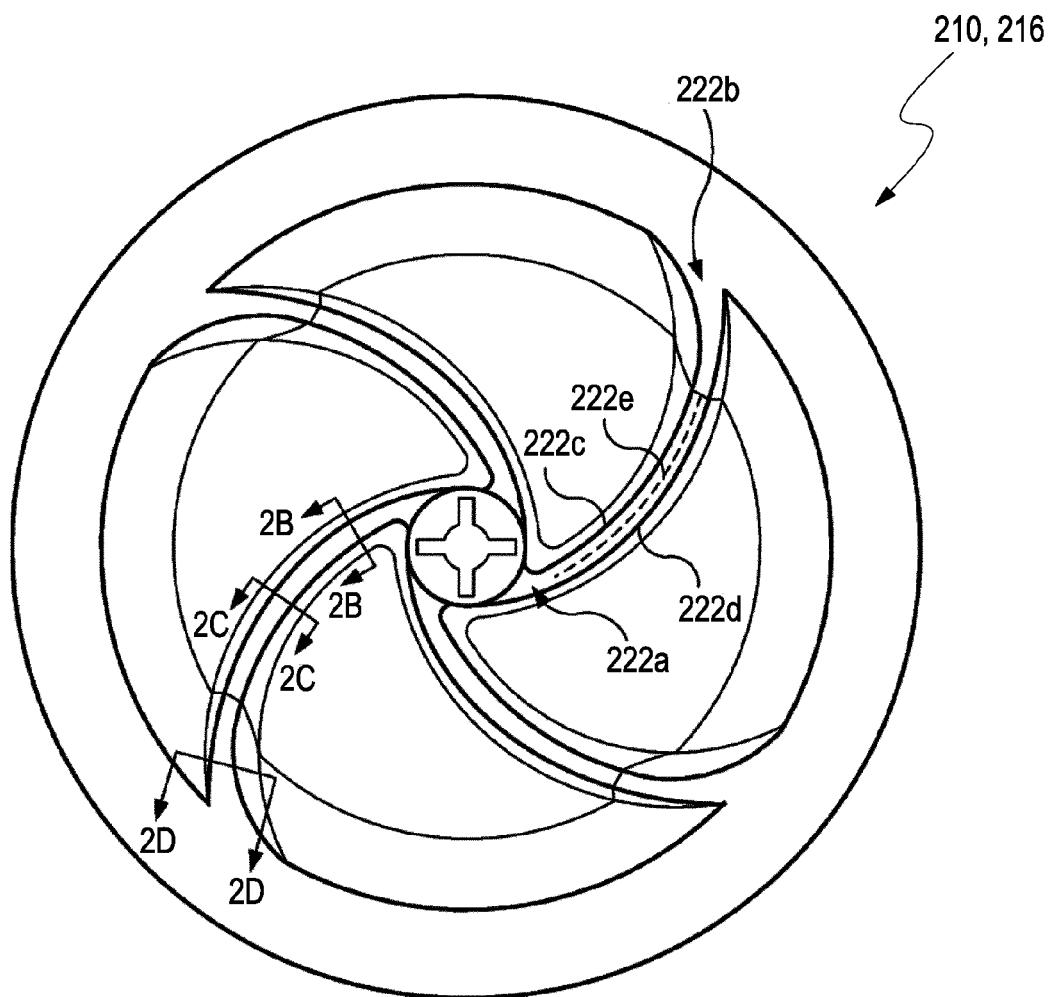


Fig. 2 A

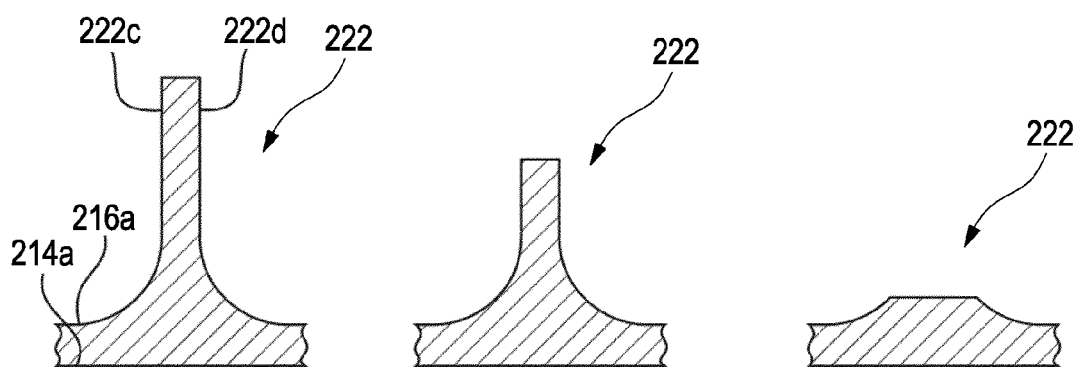


Fig. 2 B

Fig. 2 C

Fig. 2 D

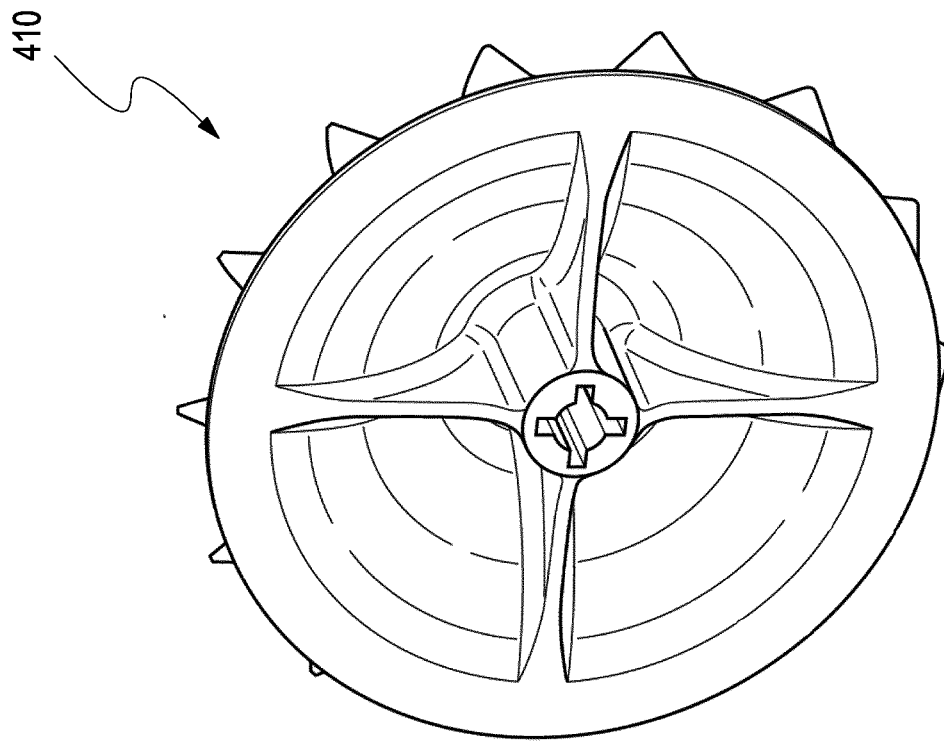


Fig. 3 C

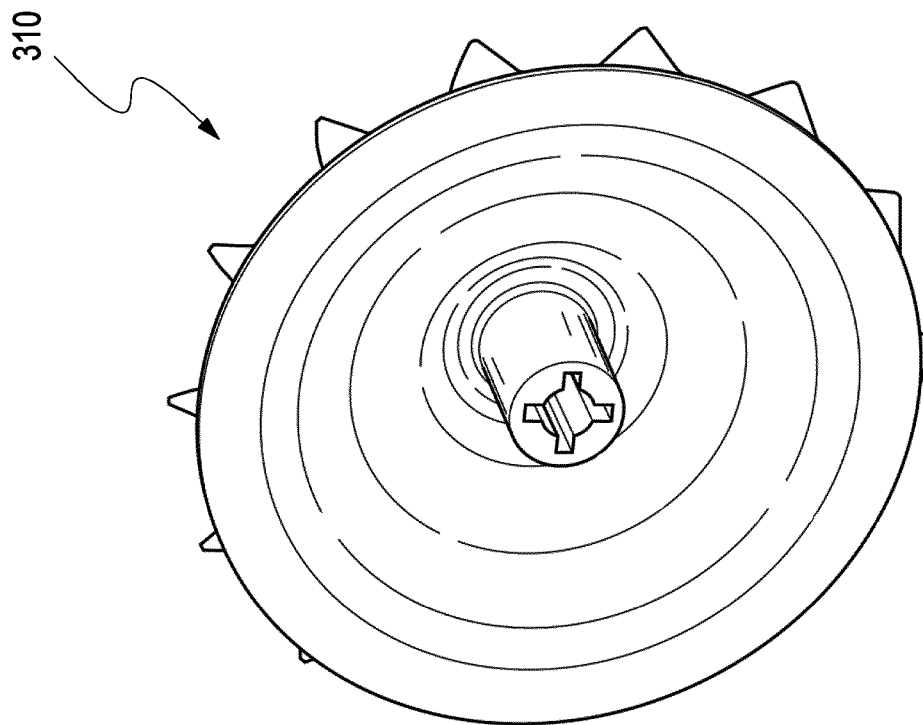
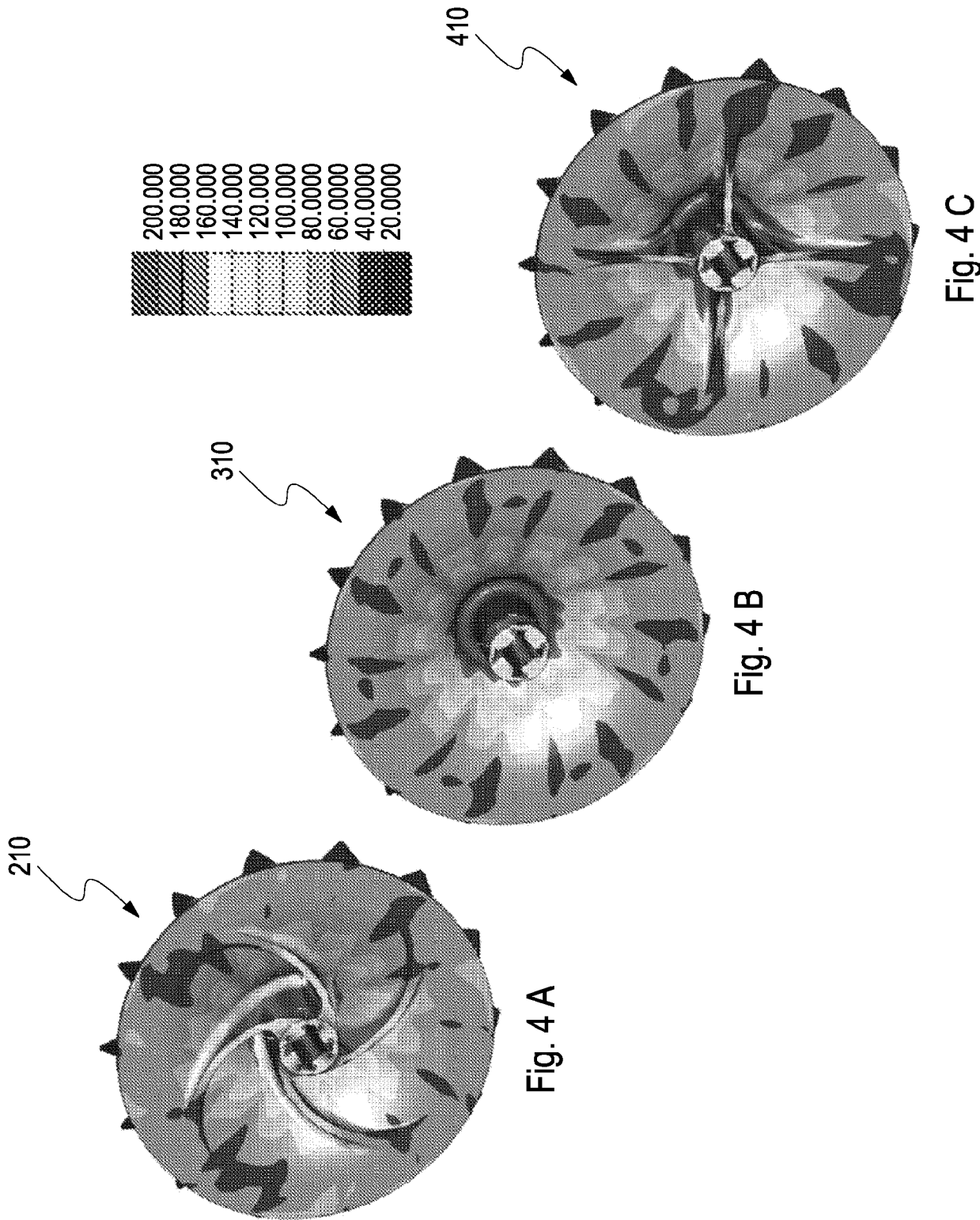


Fig. 3 B



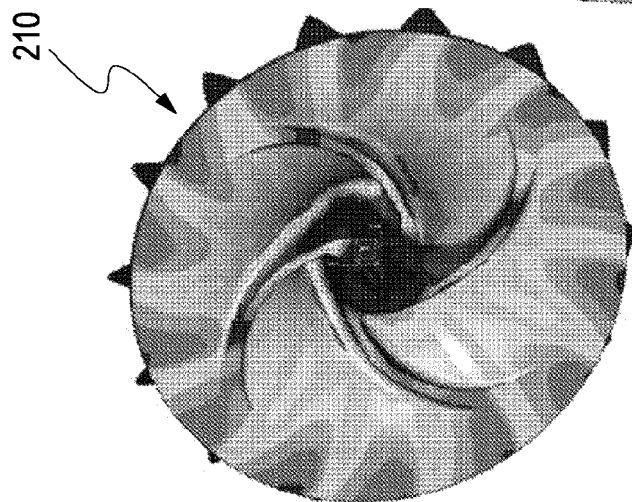


Fig. 5 A

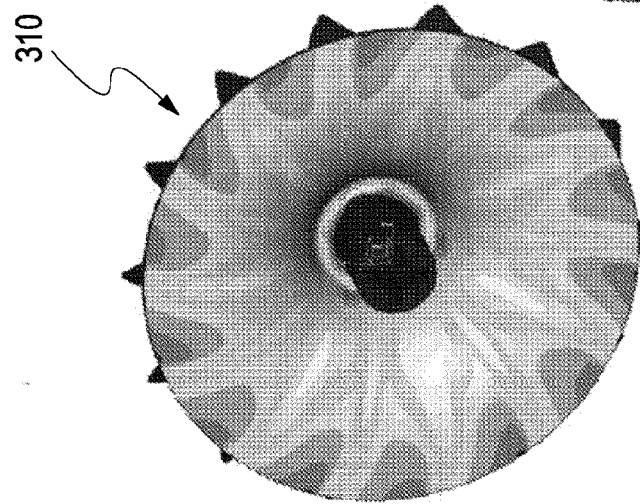


Fig. 5 B

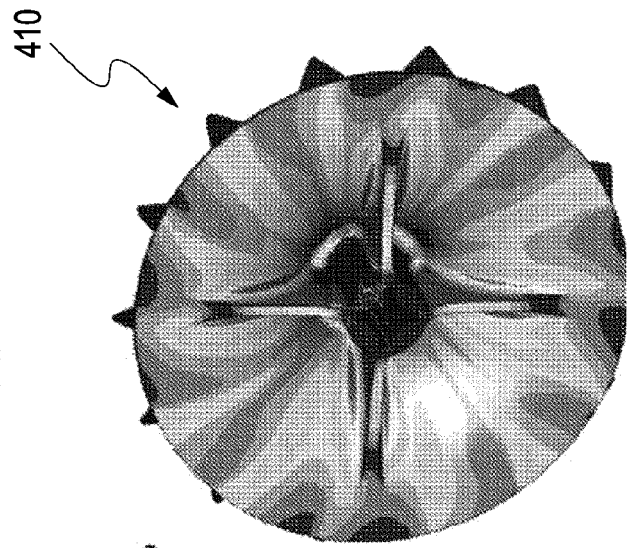
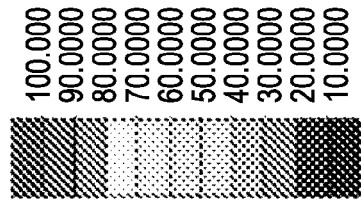


Fig. 5 C

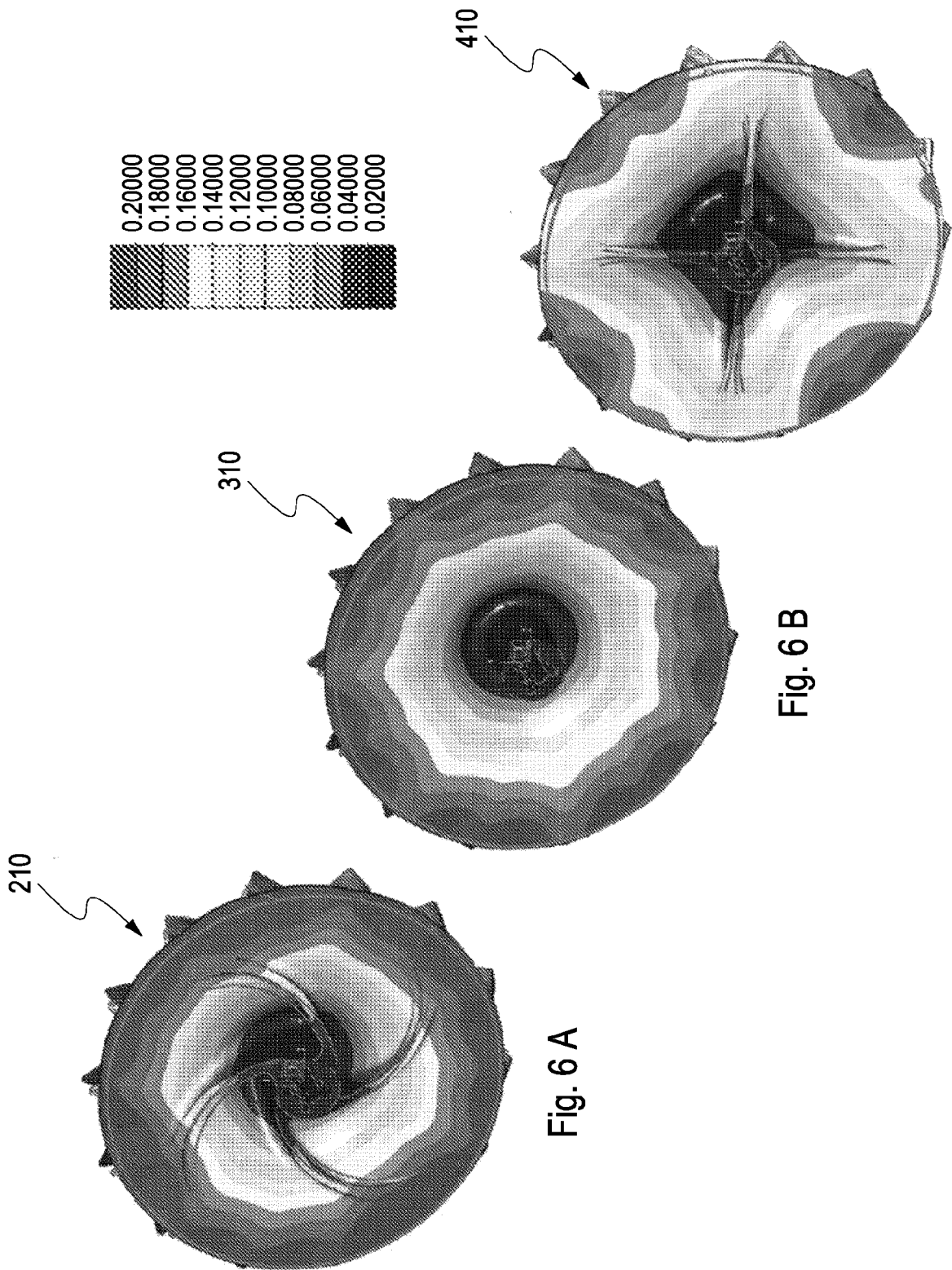


Fig. 6 C

Fig. 6 B

Fig. 6 A



EUROPEAN SEARCH REPORT

 Application Number
 EP 18 15 6653

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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			TECHNICAL FIELDS SEARCHED (IPC)
			F04D
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 2 July 2018	Examiner Brouillet, Bernard
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 18 15 6653

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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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02-07-2018

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