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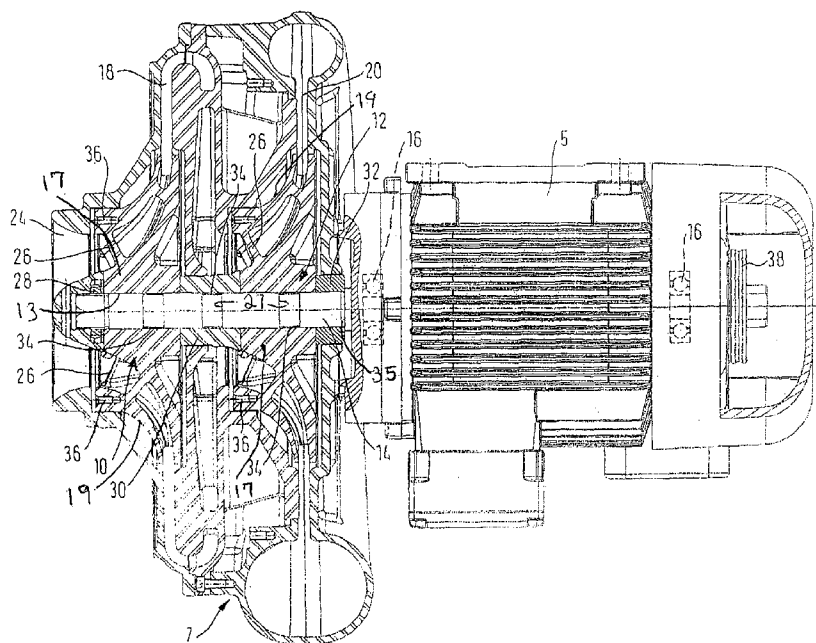
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(54) Title: RADIAL COMPRESSOR



(57) Abstract: A pair of one piece cast impellers having radially extending curved and twisted three dimensional blades and being in a compressor housing which is connected to a drive motor and the impellers being mounted onto a motor drive shaft by jamming or press fitting the impellers on the shaft to provide a two stage radial compressor wherein the drive motor (5), a drive shaft (14) on which there is arranged two impellers (10, 12) there is envisaged that the drive motor (5) is a fast-running asynchronous motor with a speed in excess of 10,000 rpm and a power of around 5 to 10 kW.

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Radial Compressor

The invention relates a small compact radial compressor impeller and a small compact radial compressor that contains the impeller characterised
5 by the impeller having a central bore sized to be jammed or press fitted onto a motor drive shaft.

BACKGROUND ART

10 Small radial compressors are known that have a drive power in the range of 5 to 10 kW and which can be used to provide compressed air to other machines such as, for example, a book binding or other production machines. Standard compressors of this power range produce a total pressure differential of around 80 mbar for a volume flow rate of around 2,000 m³/h, the
15 efficiency being comparatively low.

Also, in small size multi-stage compressors it is common practice to machine some material away to bring the centre of gravity to the axis of rotation. Normally the small size multistage compressors have their impellers
20 manufactured in at least two parts - a hub with impeller blades and an impeller shroud enclosing the impeller blades. The first part is a cast impeller hub with a plurality of 2- dimensional blades radially extending from the impeller hub. While the 2- dimensional blades are advantageous with respect to the fabrication effort, the efficiency of the impeller suffers under
25 this kind of simple blade design. The second part is the impeller shroud which is generally welded to the impeller hub. This two part impeller

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makes it more difficult to balance the impeller on the motor shaft and also increases the fabrication costs. Further, the known small size multi-stage compressors generally have blades in their diffusers.

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DISCLOSURE OF THE INVENTION

We provide a two-stage radial compressor having a drive motor, a drive shaft on which there are arranged two impellers, the drive motor being a fast-running asynchronous motor with a speed in excess of 10,000 rpm and
10 a power in the range of around 5 to 10 kW. The combination of a two-stage compressor and operating at a speed above the critical speed provides a very high performing compressor that produces an overall pressure differential exceeding 200 mbar at a volume flow rate of 700 to 900 m³/h.

15 In one embodiment our two impellers are identical one piece impellers. This ideally reduces fabrication costs as it allows a larger number of impellers to be manufactured for the same number of radial compressors.

In another embodiment our one piece impellers are identical except for
20 their impeller bores which are not identical. Each of the impeller bores are frustums for at least 75% of the length of the bore with the second impeller bore closest to the motor being larger than the first impeller bore furthest away from the motor. This allows the impellers to be relatively easily removed from the motor drive shaft.

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Our impellers have integral impeller blades that are integral with the impel-

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ler hub and are 3 dimensional blades that radially and axially extend from the impeller hub. The impeller are spatially twisted. The deviation of the centre line on a small radius exceeds the deviation on a bigger radius.

- 5 Our impellers are lightweight and consist of one single piece of a cast aluminium alloy to provide integral impeller hub, impeller blades and impeller shroud. This allows the blades to be manufactured with our 3-dimensional curved shapes. To this end, lost cores are used. The low specific weight of the cast aluminium alloy used provides a low total weight. The outside surface of the impeller is machined to provide a smooth uniform surface i.e. by a chip-forming process.

In another embodiment the impellers are attached to the motor drive shaft by jamming or press fitting the impeller onto the drive shaft. This makes it possible to dispense with feather keys etc. which, at the high drive speed of the impellers, would create special problems in terms of unbalance and strength.

In another embodiment we ensure that the impeller retains a precisely defined and preferable centred position relative to the drive shaft, by providing a tolerance ring between the drive shaft and the impeller.

In still another embodiment, the compressor has a pair of one piece impellers that are identical, except for their bores. The impeller hub bore of the first impeller is a frustum with its first end, which is the end furthest from the compressor motor, having a smaller diameter than its second end. The

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impeller hub bore of the second impeller is also a frustum with its first end, which is the end furthest from the compressor motor, having a smaller diameter than its second end. The first end of the second impeller bore has a larger diameter than the second end of the first impeller bore. The diameter
5 of the first end of the second impeller bore is also larger than any portion of the motor drive shaft that extends beyond the second impeller so that second impeller can easily be removed from the motor drive shaft for repairs or replacement.

10 In another embodiment, the one piece motor drive shaft has spaced frustums thereon that are slightly larger than the corresponding frustum bores of the first and second impellers so that the impeller can be press fitted thereon.

15 In still another embodiment, we provide our impellers with a plurality of balancing bores into which balancing members i.e. bolts, screws, or disks may be selectively attached. Since the impellers are driven at a speed above the critical speed, extremely careful balancing after the compressor is assembled is essential. This can only occur after the radial compressor has
20 been assembled because even with previously perfectly balanced impellers, the unbalance which could occur during installation of the impellers, e.g. by a slight eccentric arrangement of the drive shaft, could have fatal consequences during operation. The balancing bores of the first impeller, the impeller furthest away from the motor, are accessible on the suction side of
25 the compressor so that, after balancing, no work of any kind is required on rotating parts. It has been shown that it is fully sufficient to only use the balancing bores of the first impeller for final balancing. The balancing

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bores of the second impeller, the impeller closest to the motor, which are no longer accessible after installation of the first impeller, are not required.

According to another embodiment we provide downstream of the impeller
5 an outlet diffuser which has parallel walls and no blades. The outlet diffuser ensures a reduction of the flow velocity of the medium exiting from the impeller, which increases the static pressure. Omitting the blades in the diffuser yields a wide range of performance with good efficiency, bladed diffusers are known to improve the efficiency even further, but the range in
10 terms of possible flows is limited.

According to a still further embodiment, the drive shaft is held in two roller bearings one of which is arranged between the impellers and the drive motor, and the other on the drive motor side facing away from the impellers.
15 In other words the two impellers are arranged on the freely projecting drive shaft. This arrangement of the bearings, which is unexpected given the potentially possible oscillations of the impeller, has the advantage that only a few joints, namely two, are necessary between both bearings. The two bearing sleeves are arranged inside the end plates of the drive motor, each
20 of which is directly mounted on the motor housing. If, in contrast, a bearing were necessary on both sides of the impellers, all parts of the compressor housing would have to be manufactured with very high precision as the housing is comprised of several parts and it would be necessary to prevent the housing tolerances adding up such that inadmissibly incorrect positions
25 of the two bearing axes result.

To improve the bearing arrangement of the drive shaft the roller bearings

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have bearing rings made of steel and rollers made of ceramics. Hybrid bearings of this kind have low requirements in terms of lubrication and offer a long service life.

- 5 Also in another embodiment, a balancing disk is arranged on the side of the drive motor facing away from the impellers. With respect to the speed, which is above the critical speed, of the drive motor and the impellers, it has proven advantageous to have the balancing disk as additional means of balancing the assembly comprising the drive shaft, the impellers and the
10 electric motor.

The balancing disk is preferably in a heat-conducting connection with the neighbouring roller bearing such that the produced frictional heat and the heat dissipated away from the electric motor into the roller bearing may be
15 released into the environment via the balancing disk.

In the following, the invention will be described on the basis of a preferred embodiment with reference to the drawings attached.

20 **BRIEF DESCRIPTION OF THE DRAWINGS**

Figure 1 a radial compressor according to the invention in a first perspective view;

Figure 2 the radial compressor of Figure 1 in a second perspective view;

25 Figure 3 one embodiment of the radial compressor of Figure 1 in a partial

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sectional view;

Figure 4 a first schematic view of a blade of an impeller of the radial compressor according to the invention; and

Figure 5 a second schematic view of the blade.

5 Figure 6 is a perspective view of the impeller of the present invention.

Figure 7 is a partial schematic sectional view of another embodiment of the radial compressor of the present invention

DETAILED DESCRIPTION OF THE INVENTION

10

Referring to Figures 1 and 2, our two-stage radial compressor has a drive motor 5, a drive motor external cooling fan 6, a compressor housing 7, a compressor housing outlet 22 and a compressor housing inlet 24.

15 The drive motor 5 is a fast-running asynchronous motor with a frequency inverter, the motor having a drive speed of around 15,000 rpm.

Referring to Figure 3, which shows one of our embodiments, the drive motor 5 has a drive shaft 14 made of one single continuous piece, preferably
20 of steel. The drive shaft 14 is held in two roller bearings 16 which are in two end plates - one on the front and the other on the rear of the drive motor 5. The roller bearings 16 are hybrid bearings with bearing rings made of steel and rollers made of ceramics. Since there are a low number of joints between the components accommodating the roller bearings 16, the roller
25 bearings 16 can be aligned relative to each other with high accuracy.

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Connected to the drive motor 5 is the compressor housing 7. The compressor housing is made of several parts. The compressor housing 7 houses our first compressor impeller 10 and our second compressor impeller 12. There are double-walled outlet diffusers 18, 20 that lead to the outlet 22 (see Figures 1 and 2). On the side facing away from the drive motor 5, the inlet 24 is concentric with the drive shaft 14.

Each of the two impellers 10, 12 are cast aluminium alloy and are produced using the sand casting method. Each of the impellers is an integral one piece casting with an impeller hub 17, a cylindrical bore 13 defined by the impeller hub, a plurality of essentially radial impeller blades 26 integrally extending from an impeller hub 17 and enclosed by an integral shroud 19. Flow channels extend between the impeller blades. The flow channels and hence the blades 26 are defined during casting by means of lost cores. Each blade 26 is designed to be three-dimensionally curved. The angle of the blade when using the blade centre line with the centre line of the drive shaft 14, increases from a value of around 45° to be parallel to the centerline of the drive shaft on the outlet side. As stated above, the deviation of the centreline on a small radius exceeds the deviation on a bigger radius. The blade itself is twisted in approximately a screw-shaped way. Our three-dimensional blades provide very high fluid flow efficiency.

Figures 4 and 5 show the three dimensional curved shape of the blades 26. Figure 5 shows view Y of Figure 4 in a developed view. E denotes the inlet edge, A denotes the outlet edge, and D denotes the contour on the cover disk and N the contour of the hub.

As shown in Figure 3, the drive shaft 14 has a plurality of grooves 27.

There is at least one groove for each impeller 10,12 and spacer 30. A tolerance ring 34 is mounted in each shaft groove 27. The tolerance rings 34 are arranged in each case in the area of the plane of their centre of gravity prior to the impellers and spacer ring being placed on the shaft. The tolerance rings are essentially a stiff spring lock washer with a cross-section, which has a wave-shape. The tolerance ring eliminates the play between the drive shaft and the impeller, which is needed for assembly. The tolerance rings contribute to torque transmission between the drive shaft and the impeller and are used to as much as possible, to centrally position the two impellers 10, 12 and maintain their position during operation. The diameter of the drive shaft is slightly larger than the diameter of the impeller bores.

The two impellers 10, 12 are identical one piece impellers and are fastened on the drive shaft 14 solely by jamming them onto the drive shaft. Prior to placing the impellers 10, 12 and spacer 30 on the drive shaft 14, they are statically balanced. After the static balancing, the second impeller 12 and spacer ring 30 are jammed onto the shaft 14 and then the first impeller 10 is jammed onto the shaft 14. The two impellers 10, 12 are fastened on the drive shaft solely by this tight fit between the drive shaft and the impeller bores 13. In this embodiment of Figure 3, the contact ring 32 is placed on the shaft to abut the shaft shoulder 35, then the second impeller 12 and spacer ring 30 are jammed onto the drive shaft and finally the first impeller 10 is jammed onto the shaft 14. The final tightening is achieved using a jam nut 28 to tighten the two impellers 10, 12 via the spacer ring 30 and the contact disk 32 against a shoulder 35 of the drive shaft 14.

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In addition, dynamic balancing is performed after assembly. For this purpose there are provided in each impeller a plurality of balancing bores 36, into which balancing members such as screws, bolts or disks may be selectively attached. When screws or bolts are desired, the bores are appropriately threaded. When disks or other types of balancers are preferred, then the bores are appropriately configured. The dynamic balancing is only done on the first impeller 10. The balancing bores of the second impeller may exist only because, for fabrication reasons, both impellers 10, 12 are manufactured identically.

In addition, there is provided on the drive motor 5 side facing away from the impellers 10, 12 a balancing disk 38. The balancing disk 38 is used so that any unbalances can be reduced further. The balancing disk 38 additionally serves to cool the roller bearing 16 arranged on this side. For this purpose, the roller bearing 16 has a heat-conducting connection with the balancing disk 38, which in turn is located inside the cooling air flow of the external fan 6.

Referring to Figure 6, this is our one piece cast impeller with a plurality of balancing slots or bores 36, a hub 17, impeller blades 26, and a shroud 19.

In another and preferred embodiment, as shown in Figure 7, our two-stage radial compressor has two one piece cast impellers 41 and 42 and a drive shaft 43. Figure 7 shows only a partial view of the compressor and does not show all of the features of impellers mounted in a compressor housing. Figure 7 shows the important features of our preferred impeller and motor

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drive shaft structure. In Figure 7 we use the same numbers as used in Figures 1-3 to identify identical parts of the various items. The impellers of Figure 7 have the same general structure as the impellers of Figure 3 except for the shape of the impeller hub bores. The two impellers 41, 42 are cast aluminium alloy and are produced using the sand casting method. Each impeller 41 and 42 has a hub 17, a plurality of spatially curved radially extending three dimensional blades 26, and a shroud 19. The integral blades 26 have flow channels formed between them. The flow channels and hence the blades 26 are defined during casting by lost cores. Each blade 26, as shown in Figures 4 and 5 are three dimensionally curved.

The two impellers 41 and 42 are identical to each other except for their bores 43 and 44. The impeller bore 43 of the first impeller 41 is a frustum with a first end 46 having a smaller diameter than its second end 47. The bore 44 of the second impeller 42 is a frustum with a first end 48 having a smaller diameter than its second end 49. The first end 48 of the bore 44 of the second impeller 42 has a larger diameter than the second end 47 of the impeller bore 43 of the first impeller 41. The diameter of the first end 48 of the bore 44 of the second impeller 42 is also larger than any portion of the drive shaft 50 which extends beyond the second impeller 42 towards the first impeller 41 so that the second impeller 42 can easily be removed in the direction of arrow 51 from the drive shaft 50 and replaced on drive shaft 50 or of course another impeller identical to the second impeller 42 placed on drive shaft 50.

25

The drive shaft 50 has a frustum section 52 that is adjacent to the shaft end connected to the motor. This frustum section 52 expands towards the mo-

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tor. The frustum section 52 is slightly larger than the frustum bore 44 of impeller 42 so that the impeller can be press fitted thereon.

5 The drive shaft also has another frustum section 53 that is adjacent the end of the shaft that is opposite to the shaft end connected to the motor. This shaft frustum section 53 is slightly larger than the frustum bore 43 of impeller 41 so that the impeller 41 can be press fitted onto the shaft 50.

10 Both frustum sections 52 and 53 of the shaft 50 each have their outer surfaces in contact respectively with more than 75% of the surfaces of the respective impeller bores 43 and 44. To permit our desired press fit between the drive shaft and the impeller frustum bores, the diameter of the shaft is slightly larger at its point of contact with the impeller bores

15 This press fitting of the impellers onto the shaft allows the impellers to be secured to the driver shaft without unnecessary external members and permits better operation balancing of the impellers.

20 The impeller bores are preferably formed during casting but can be formed by machining after casting if desired.

The two impellers 41, 42 are fastened onto the drive shaft 50 solely by press fitting them onto the drive shaft frustums 52, 53. Prior to placing the impellers 41, 42 and spacer 55 onto drive shaft 50, they are statically balanced. In this embodiment, instead of having a shoulder on the shaft, the compressor housing 7 near its end closest to the motor has a groove formed therein. The groove holds a contact ring 54 and a retainer ring 56. After the

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static balancing, the second impeller 42 is hand forced onto the shaft . Then the final press fitting of the second impeller 42 onto the shaft frustum 53 is accomplished by turning the jam nut 28(a) . Then the spacer ring 55 and the first impeller 41 are hand pressed onto the drive shaft with the impeller
5 41 engaging the shaft frustum 52. Therafter, jam nut 28 is turned half a turn to accomplish the final press fit such that the impellers 41 and 42 are abutting the spacer ring 55. The above is a "way controlled" press fit where the impeller is moved a defined distance. However we could do this by a "force controlled" press fit where a set force is applied to the impeller.

10

In addition, as was discussed above with the embodiment of Figure 3, dynamic balancing is performed after assembly. For this purpose there are provided in each impeller a plurality of balancing bores 36, into which balancing members such as screws, bolts or disks may be selectively attached.

15

When screws or bolts are desired, the bores are appropriately threaded. When disks or other types of balancers are preferred, then the bores are appropriately configured. The dynamic balancing is only done on the first impeller 41. The balancing bores of the second impeller exist only for fabrication reasons and may be eliminated if desired.

20

Owing to the comparatively low weight of the impellers 10,12, 41 and 42 and also because of the high balancing accuracy that can be maintained with our impellers, our impellers can be driven at a speed above the critical speed although, in the area of the impellers, the drive shaft is designed in a
25 freely projecting manner.

Claims

1. A small compact compressor impeller having a hub (17) and a plurality of radially extending impeller blades (26) connected to the hub (17)
5 and a shroud (19) surrounding the impeller blades (26), characterised by said hub(17) having a bore(13,43) sized to be jammed or press fitted onto a drive shaft(14; 50).
2. The impeller of claim 1 characterised in that the impeller blades (26) are integral with the hub (17).
- 10 3. The impeller of claim 1 or 2 characterised by the impeller blades are spatially curved and three-dimensional impeller blades (26).
4. The impeller of any one of claims 1-3 characterised in that the hub bore(43,44) has a frustum section extending at least 75% of the length of the hub bore.
- 15 5. The impeller of any one of claims 1-4 characterised in that the impeller shroud (19) has a plurality of balancing connections (36) to bring the center of gravity of the impeller to the axis of rotation.
6. The impeller of claim 5 characterised in that the balancing connections are a plurality of threaded holes (36) around the periphery of the impeller inlet.
20
7. The impeller of any one of claims 1-6 characterised in that the impeller is a one piece impeller.
8. The impeller of claim 7 characterised in that the impeller is a one-piece cast aluminum alloy impeller.

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9. The impeller of any one of claims 1-8 characterised in that there are a pair of the impellers (10,12; 41,42) in a two-stage radial compressor and they are axially mounted on the motor drive shaft.
10. The impeller of claim 9 characterised in that the impellers are mounted on the motor drive shaft (14; 50) that is connected to a fast running motor with a speed in excess of 10,000 rpm and a power of about 5 to 10 kw.
11. The impellers of any one of claims 1 - 10 characterised in that there are a pair of the impellers in two-stage radial compressor having a drive motor (5), a drive shaft (14,50), on which there are arranged two impellers (10, 12; 41, 42).
12. The impellers of claim 9,10 or 11 characterised in that the impellers (10, 12) are identical and between the shaft (14) and the impeller (10, 12) there is arranged a tolerance ring (34).
13. The impellers of any one of claim 9 - 12, characterised in that the impellers (10, 12;41, 42) have a plurality of balancing bores (36) into which balancing members may be selectively attached.
14. The impellers of any one of claim 9 - 13, characterised in that downstream of the impellers there is arranged an outlet diffuser (18, 20).
15. The impellers of claim 14, characterised in that the outlet diffuser (18, 20) is designed to have parallel walls and no blades.
16. The impellers of any one of claim 9 – 15, characterised in that the shaft (14,50) is held in two roller bearings (16) one of which is mounted between the impellers (10, 12, 41,42) and the drive motor (5) and the other on the drive motor side facing away from the impellers.).

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17. The impellers of any one of claim 9 - 16, characterised in that, for holding the drive shaft (14,50), roller bearings (16) are used whose bearing rings are made of steel and whose rollers are made of ceramics.

18. The impellers of any one of claim 9 - 17, characterised in that a balancing disk (38) is arranged on the drive motor (5) side facing away from the impellers.

19. The impellers of claim 18, characterised in that the balancing disk (38) is in a heat-conducting connection with a neighbouring roller bearing (16).

FIG. 1

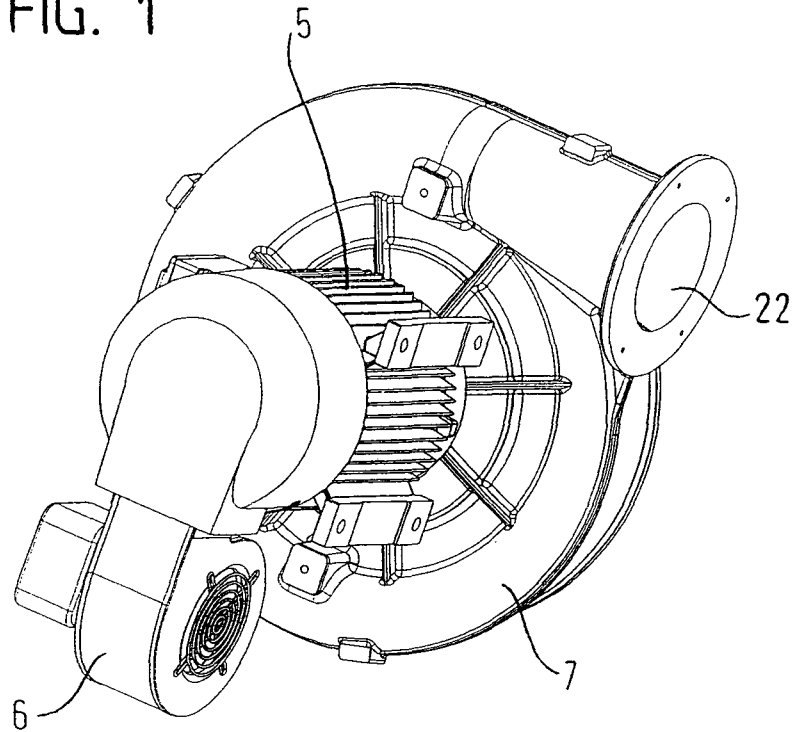
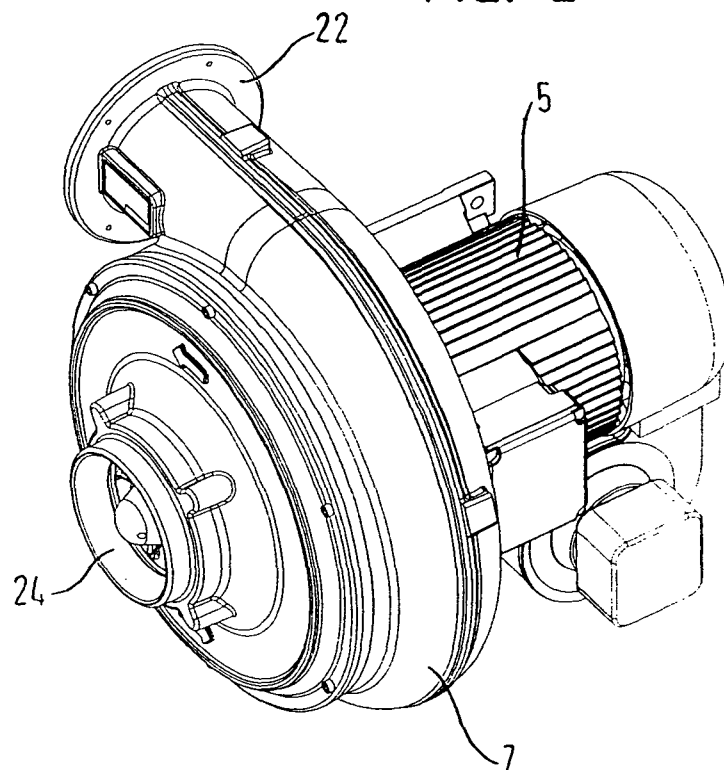


FIG. 2



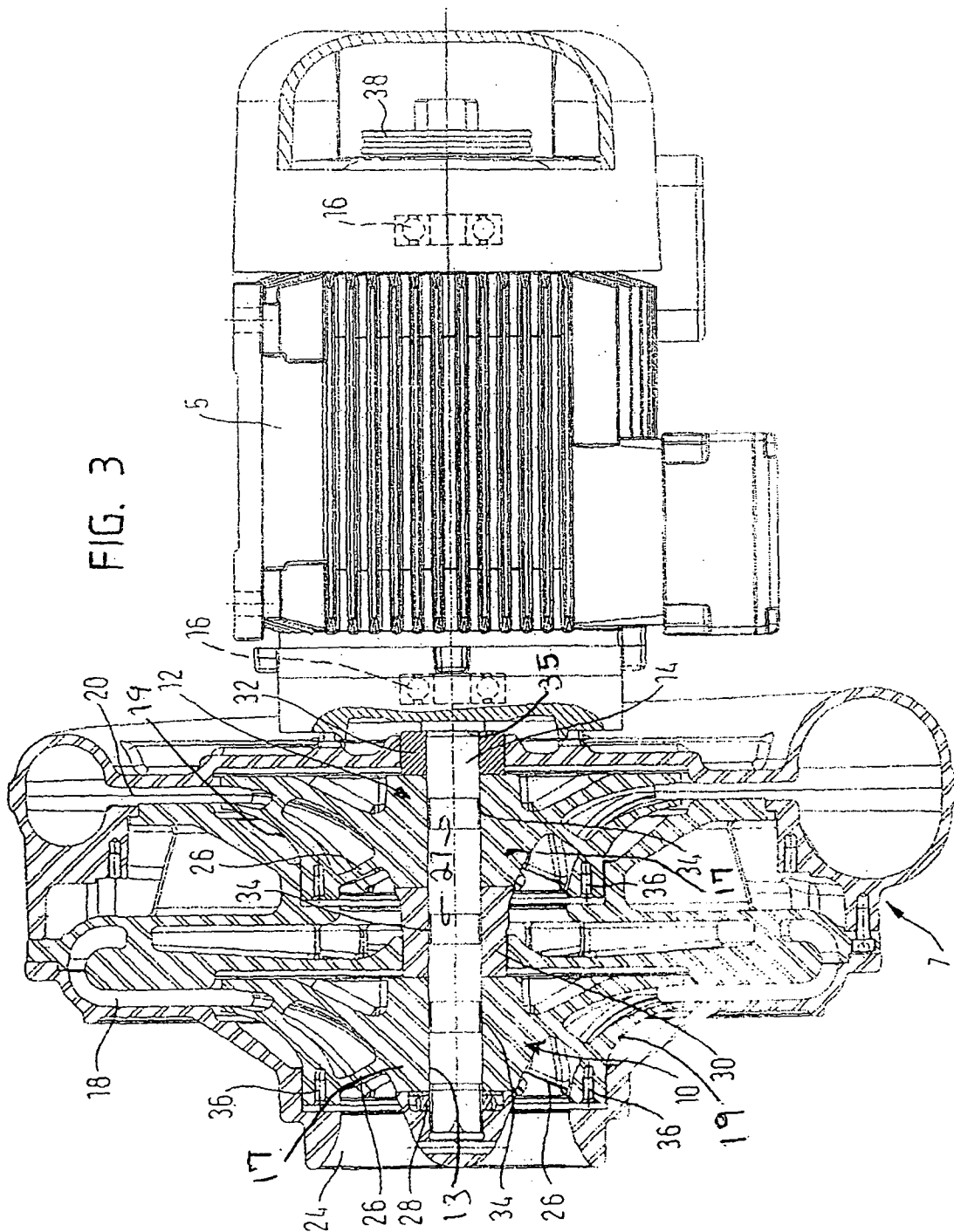


FIG. 4

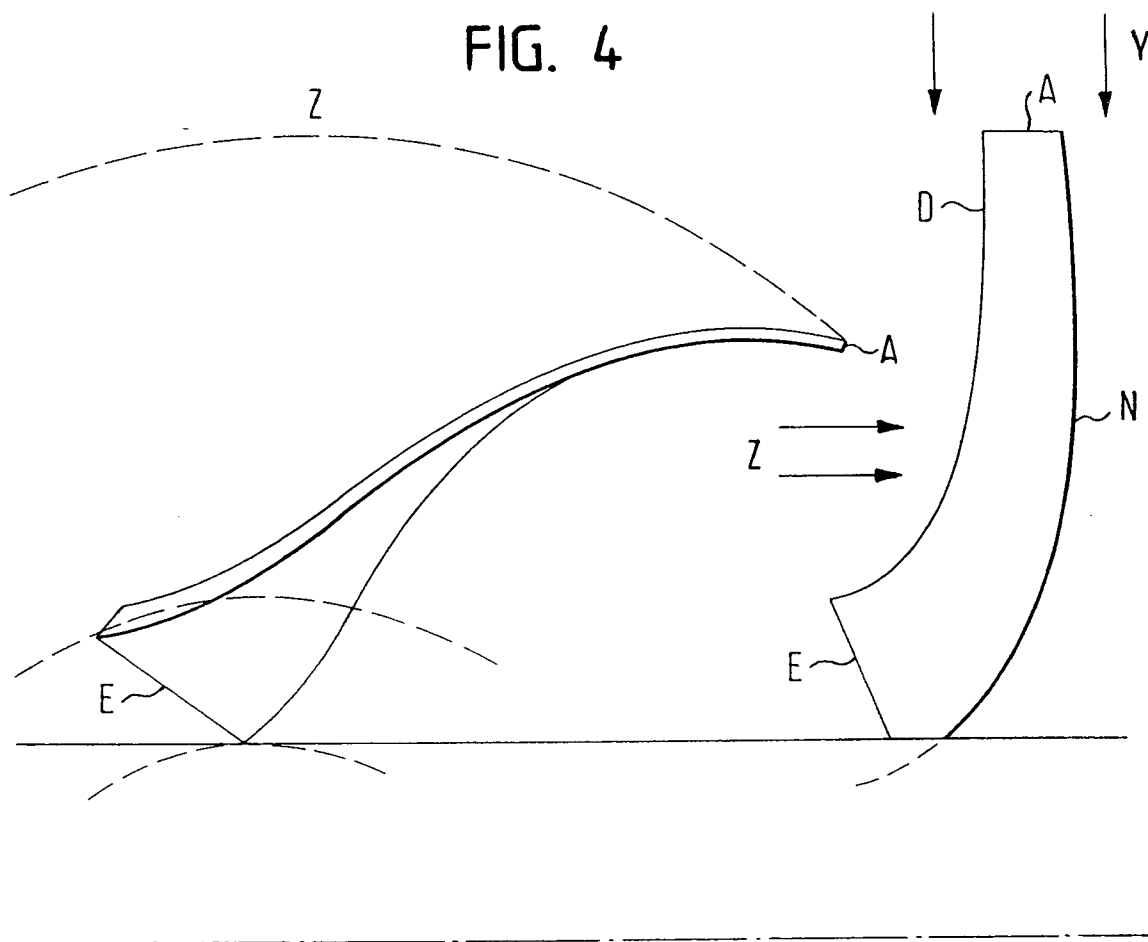
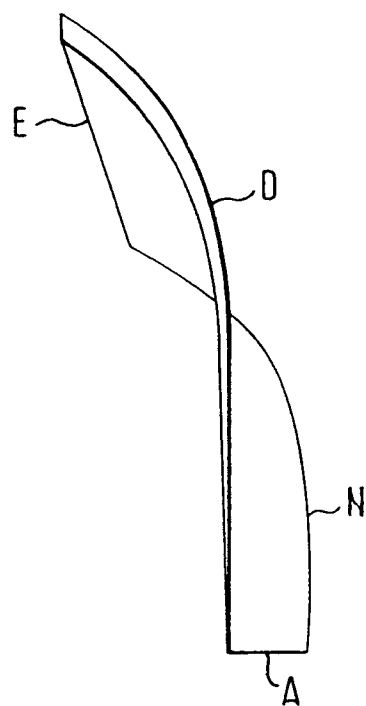
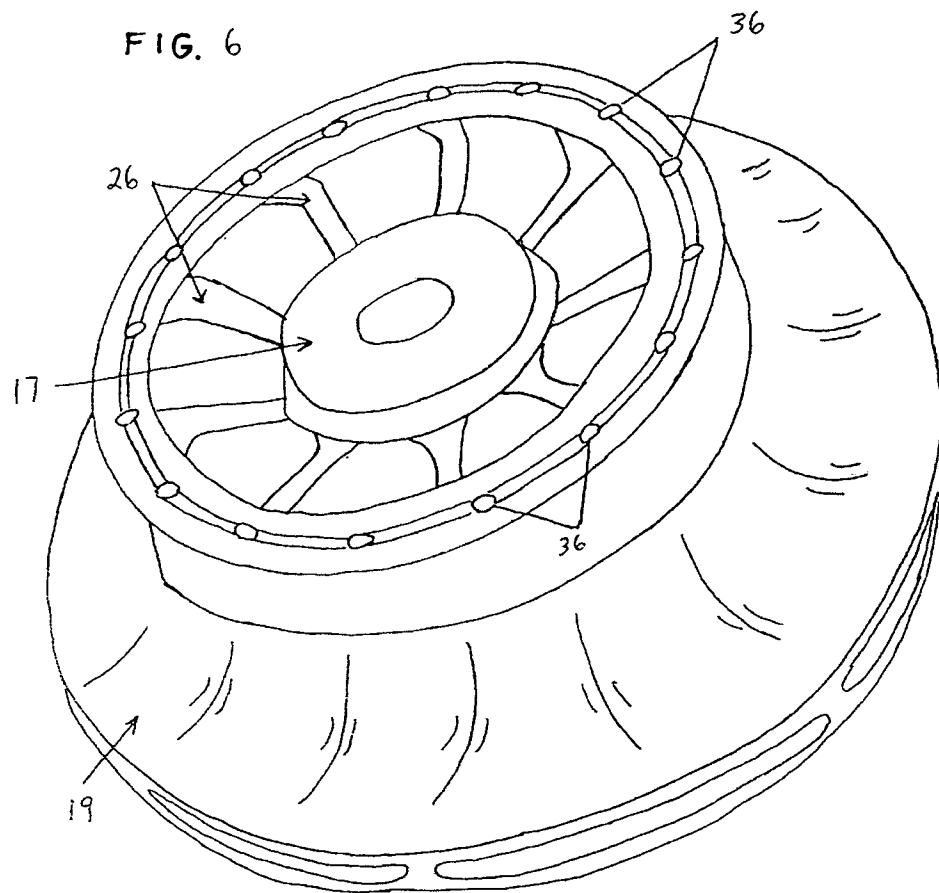


FIG. 5





INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2006/007100

A. CLASSIFICATION OF SUBJECT MATTER
INV. F04D17/12 F04D29/26

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F04D

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

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

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 481 917 B1 (CHEN ROBERT P [US] ET AL) 19 November 2002 (2002-11-19) the whole document	1-3,7,10
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☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2006/007100

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