(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 025 942 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
**18.02.2009 Bulletin 2009/08**

(21) Application number: **08161663.3**

(22) Date of filing: **01.08.2008**

(51) Int Cl.:
***F04D 1/06*** *(2006.01)* ***F04D 29/22*** *(2006.01)*
***F04D 13/08*** *(2006.01)*

(84) Designated Contracting States:
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MT NL NO PL PT RO SE SI SK TR**
Designated Extension States:
**AL BA MK RS**

(30) Priority: **01.08.2007 US 953386 P**

(71) Applicant: **Franklin Electric Co., Inc.**
**Bluffton IN 46714 (US)**

(72) Inventors:
- **Bookout, Russell**
  **Fort Wayne, IN 46807 (US)**
- **Volk, James J.**
  **Fort Wayne, IN 46814 (US)**

(74) Representative: **Newstead, Michael John et al**
**Page Hargrave**
**Southgate**
**Whitefriars**
**Lewins Mead**
**Bristol BS1 2NT (GB)**

(54) **Submersible multistage pump with impellers having diverging shrouds**

(57) A centrifugal pump may include plural pump stages (300), each comprising an impeller assembly (304), a stationary disc assembly (306) and a diffuser assembly (302), all disposed about an impeller shaft (102) that is driven by a motor. The impeller assembly (304) may include upper and lower impeller shrouds (338,334) having facing surfaces, and a plurality of impeller vanes (344) extending between the surfaces of the shrouds (338,334) to define a plurality of flow passages (346) for liquid to flow outwardly from a central hub (340) of the impeller assembly (304). To assist in pressure recovery of the pump, the distance between the surfaces of the impeller shrouds (338,334) may increase as the radial distance from the central hub (340) increases.

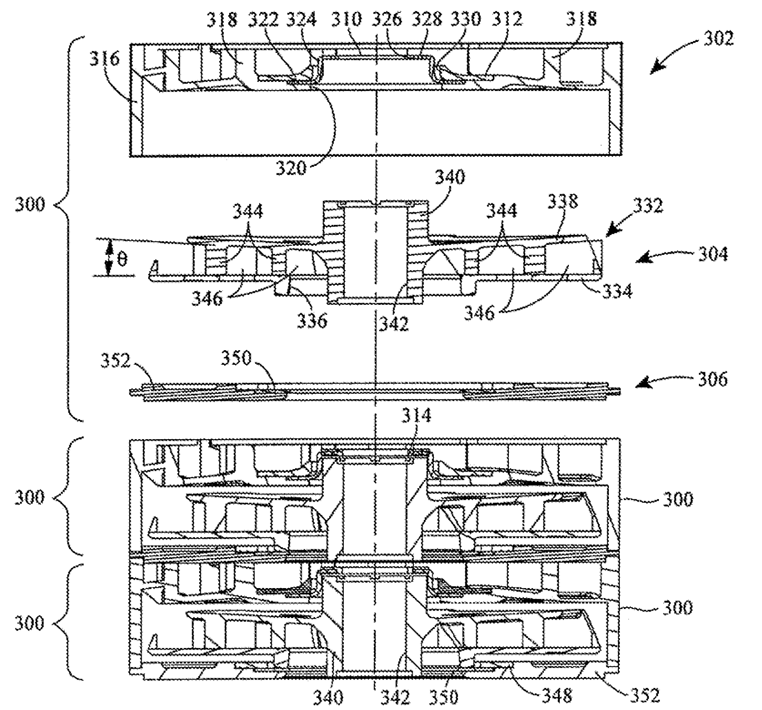


*FIG. 8*

EP 2 025 942 A2

## Description

### Technical Field

**[0001]** The present invention relates generally to pumps, and in particular to multistage submersible pumps for pumping non-compressible fluids.

### Background

**[0002]** Submersible pumps are used throughout the world to pump water out of various well configurations. Small submersible centrifugal pumps generally consist of several general design elements. A bracket connects the pump to the driving motor and provides a screened intake for fluid to enter the pump. The pumped non-compressible fluid feeds into a stack of pump stages that are stacked in a series on a long shaft with each stage fractionally increasing the pressure of the pumped fluid until the desired pressure, or "head," is achieved. The last stage in the series connects to a discharge element that adapts the pump to the drop line that provides a flow passage to the surface and generally includes a shaft bearing element and often a check valve. In general, a submersible pump will incorporate a number of stages that may vary in their respective diameters and port openings. Such pumps are commonly referred to as multistage pumps, and may also be used in pumping other non-compressible fluids.

**[0003]** Each pump stage consists of a rotating element, typically referred to as an impeller, that imparts energy from the motor to the fluid, and a stationary element, typically referred to as a diffuser, that aids in the recovery of the energy in the form of static pressure. The diffuser also channels the fluid to the inlet of the impeller of the next stage. In smaller pumps of this type, the stages are typically enclosed in a tube or shell that holds the diffusers in intimate axial contact, thereby allowing the diffusers to seal at their interface to keep the high pressure pumped fluid inside. Some pumps are constructed with straps that perform this function, with the outside of the diffusers forming the outer surface of the pump instead of the shell.

**[0004]** One example of a multistage pump assembly 100 is depicted in Figs. 1-7 and is described further in U.S. Patent Publ. No. 2006-0269404, published on November 20, 2006 from an application by Volk. The pump assembly 100 includes a main impeller shaft 102 rotatably driven by a motor 104. Plural pump stages 106 are disposed about main shaft 102 within a cylindrical pump case 108. The pump stages 106 driven by the main shaft 102 move fluid from a pump fluid inlet 110 to a pump fluid outlet 112.

**[0005]** Each pump stage 106 comprises three sub-assemblies as depicted in Figs. 2 through 6. These sub-assemblies each comprise a diffuser assembly 150, an impeller assembly 152 and a disc assembly 154. When assembled, the diffuser assembly 150 and disc assembly 154 are fixed within and non-rotatable with respect to pump case 108, while impeller assembly 152 is secured to the main shaft 102 for rotation therewith and the main shaft rotates with respect to the diffuser assembly 150 and the disc assembly 154.

**[0006]** As shown in Fig. 2, the diffuser assembly 150 of each stage 106 includes a cylindrical diffuser body 170, a hub seal 172 mounted thereon, a retainer ring 174 and a thrust washer 176. The diffuser body 170 and retainer ring 174 may be made of polycarbonate or other suitable plastic. The hub seal 172 may be made of one of a variety of materials including, for example, stainless steel. The thrust washer 176 may be made of one of a variety of materials including, for example, carbon phenolic.

**[0007]** Now referring also to Fig. 4, the diffuser body 170 includes a generally-cylindrical outer wall 178 and an outer section including a set of one or more circumferentially spaced outer diffuser fins or vanes 180 extending along a somewhat spiral path from a main shaft opening 182 to the outer wall 178. The hub seal 172 may be characterized as a circular disk shaped member 173 having plural, circumferentially spaced radially projecting tabs 173a formed thereon and sized to fit into a cooperating lower hub seal seat 184 formed in the diffuser body 170 about the main shaft opening 182. The disc shaped member or flange 173 of seal 172 includes a cup shaped hub portion 173b having a circular opening 173c formed in transverse wall or face 173d. Retainer ring 174 includes a central bore 186 sized to fit closely around the hub portion 173b of the hub seal 172. The hub seal 172 is also disposed in seat 184 for limited lateral excursion with respect to the shaft 102 and body 170. The retainer ring 174 may be secured to diffuser body 170 by, for example, sonic welding, although other appropriate securement methods may be used. The retainer ring 174 has an inner diffuser section that may include diffuser fins or vanes 188 circumferentially spaced apart, extending radially from the bore 186 and adapted to be aligned with the outer diffuser vanes 180 in the diffuser body 170.

**[0008]** The centrifugal closed impeller assembly 152, as depicted in Fig. 5, comprises an upper impeller body 200 and a lower impeller disc 202 having a fluid inlet opening or eye 203 formed therein. The upper impeller 200 and lower impeller disc 202 may be made of, for example, a polymer material, such as acetal. The upper impeller 200 comprises a generally-planar upper impeller disc part 204 disposed about a generally-cylindrical central hub 206. Central hub 206 includes, for example, a main shaft bore 208 and is shaped and sized to receive main shaft 102 in close fitting relationship. A plurality of circumferentially spaced spiral impeller blades or vanes 210 extend generally from central hub 206 to the radial outermost edges of impeller disc 204 (Fig. 7). In certain embodiments, the upper impeller 200 and lower impeller disc 202 may be secured to one another by sonic welding, although other appropriate securement methods may be used. Secured in this manner, the impeller disc 204, impeller vanes 210 and lower impeller disc 202 form plural impeller fluid flow passages 212.

**[0009]** Now referring to Fig. 6, disc assembly 154 includes a retainer ring 220, a wear ring 222 and a disc 224. Retainer ring 220 and disc 224 may be made of a variety of materials including, for example, polycarbonate or other suitable plastic. The wear ring 222 may be made of a variety of materials, including stainless steel. The wear ring 222 includes plural circumferentially spaced radially projecting tabs 222a which fit in cooperating recesses 224a formed in disc 224 for securing the wear ring non-rotatable with respect to the disc. Retainer ring 220 may be suitably secured to disc 224 by sonic welding to retain wear ring 222 secured on the disc.

**[0010]** The multistage centrifugal pump assembly 100 illustrated in Figs. 1-7 and described above is one example of a multistage pump that may be used to pump water and other non-compressible fluids. Other configurations of multistage pumps are known in the art. Examples of other configurations of multistage pumps or pump stages may be found in U.S. Patent Nos. 3,116,696 (Deters), 3,288,074 (Hall), 4,678,399 (Vandevier et al.) and 4,802,819 (Bevington et al.).

**[0011]** As can be seen in the drawing figures, the upper impeller body 200 and the lower impeller disc 202 are generally planar and perpendicular to the longitudinal axis of the main shaft 102 and pump case 108. Configured in this way, the upper impeller body 200 and lower impeller disc 202 are generally horizontal when the pump assembly 100 is disposed in the well, with the distance between the upper impeller body 200 and the lower impeller disc 202 being relatively constant as the impeller assembly 152 extends radially from the main shaft 102. For purposes of the remaining discussion, the upper impeller body 200 and the lower impeller disc 202 may also be referred to as the upper impeller shroud 200 and the lower impeller shroud 202 defining the upper and lower boundaries, respectively, of the impeller flow passages 212. The upper and lower impeller shrouds in the above-identified patents are either flat in the radial direction in a similar manner as shown in Figs. 1-7, are both angled such that they are non-horizontal but maintain a relatively constant spacing in the radial direction, or slightly converge in the radial direction.

**[0012]** In small multistage pumps of the type described above, the pressure recovery is relatively poor for the typical diffuser that is made to fit within the size constraints of the wells in which the pumps are designed to operate. It is known that in a typical conical diffuser the optimum recovery angle of divergence for pressure recovery is approximately 5°. Consequently, conical diffusers are typically designed to keep the hydraulic diameter expansion angle as close to 5° as possible within the physical constraints of the system to reduce the likelihood of stalling the flow in the diffuser. The hydraulic diameter is defined as follows:

$$HydraulicDiameter = \frac{4 * (CrossSectionalFlowArea)}{FlowPassageWettedPerimeter}$$

Where: FlowPassageWettedPerimeter = length of diffuser in contact with the water as measured perpendicular to the flow

**[0013]** Stall occurs in the diffuser when the flowing fluid no longer follows the walls of the flow passage and begins to separate from the walls, and thereby creating erratic flow patterns and reducing the pressure recovery of the diffuser.

**[0014]** In typical impellers presently known in the art, the method used to create a diverging flow passage for pressure recovery is to increase the distance between the vanes the further along the flow passage that the fluid moves. One example of the typical impeller vane geometry with two-dimensional expansion of the fluid channel is illustrated in Fig. 7 and highlighted by the increasing diameter circles. To achieve the desired exit angle at the impeller vane tips, the amount of hydraulic diameter divergence, and thus pressure recovery, that can be built into the impeller is limited. Therefore, a need exists for multistage pump impeller designs that improve the pressure recovery within the impeller flow passage.

## Summary

**[0015]** In one aspect, the invention is directed to a pump stage for a centrifugal pump having a main impeller shaft with a longitudinal axis driven by a motor. The pump stage may include a diffuser assembly having a diffuser body with a generally-cylindrical outer wall and a main shaft opening configured to receive the main impeller shaft, and an impeller assembly disposed within the outer wall of the diffuser assembly. The impeller assembly may include an upper impeller body having a generally-cylindrical central hub with a main shaft bore shaped and sized to receive the main impeller shaft in close fitting relationship so that the impeller assembly rotates with the main impeller shaft, and an upper impeller shroud extending radially from the central hub and having a bottom surface, and a lower impeller shroud having a central fluid inlet opening and a top surface facing the bottom surface of the upper impeller shroud. The top and bottom surfaces may be oriented such that the distance between the bottom surface of the upper impeller shroud and the top surface of the lower impeller shroud increases as the radial distance from the central hub increases. The pump stage may further include a disc assembly having a central opening configured to receive the central hub of the upper impeller body and the main impeller shaft, with the disc assembly enclosing the impeller assembly within the diffuser assembly.

**[0016]** In another aspect, the invention is directed to a centrifugal pump having a motor, a main impeller shaft having a longitudinal axis and being coupled to and driven by the motor, and at least one pump stage. The pump stage may include a diffuser assembly having a diffuser body with a generally-cylindrical outer wall and a main shaft opening configured to receive the main impeller shaft, and an impeller assembly disposed within the outer wall of the diffuser assembly. The impeller assembly may include an upper impeller body having a generally-cylindrical central hub with a main shaft bore shaped and sized to receive the main impeller shaft in close fitting relationship so that the impeller assembly rotates with the main impeller shaft, an upper impeller shroud extending radially from the central hub and having a bottom surface, and a lower impeller shroud having a central fluid inlet opening and a top surface facing the bottom surface of the upper impeller shroud. The top and bottom surfaces may be oriented such that the distance between the bottom surface of the upper impeller shroud and the top surface of the lower impeller shroud increases as the radial distance from the central hub increases. The pump stage may further include a disc assembly having a central opening configured to receive the central hub of the upper impeller body and the main impeller shaft, with the disc assembly enclosing the impeller assembly within the diffuser assembly.

**[0017]** In a further aspect, the invention is directed to an impeller assembly for a pump stage of a centrifugal pump having a main impeller shaft with a longitudinal axis driven by a motor, the pump stage including a diffuser assembly having a diffuser body with a generally-cylindrical outer wall and a disc assembly, the diffuser assembly and the disc assembly being configured to receive the main impeller shaft. The impeller assembly may include an upper impeller body having a generally-cylindrical central hub with a main shaft bore shaped and sized to receive the main impeller shaft in close fitting relationship so that the impeller assembly rotates with the main impeller shaft, and an upper impeller shroud extending radially from the central hub and having a bottom surface. The impeller assembly may further include a lower impeller shroud having a central fluid inlet opening and a top surface facing the bottom surface of the upper impeller shroud, and the impeller assembly may be disposed within the outer wall of the diffuser assembly and enclosed therein by the disc assembly. The top and bottom surfaces may be oriented such that the distance between the bottom surface of the upper impeller shroud and the top surface of the lower impeller shroud increases as the radial distance from the central hub increases.

**[0018]** Additional aspects of the invention are defined by the claims of this patent.

## Brief Description of the Drawings

**[0019]** Fig. 1 is a longitudinal central section view of an example of a multi-stage pump;

**[0020]** Fig. 2 is a detail longitudinal central section view of a pump stage of the pump shown in Fig. 1;

**[0021]** Fig. 3 is an exploded perspective view of the pump stage of Fig. 2;

**[0022]** Fig. 4 is an exploded perspective view of the diffuser assembly of the pump stage of Figs. 2 and 3;

**[0023]** Fig. 5 is an exploded perspective view of the impeller assembly of the pump stage of Figs. 2 and 3;

**[0024]** Fig. 6 is an exploded perspective view of the disc assembly of the pump stage of Figs. 2 and 3;

**[0025]** Fig. 7 is a bottom view of the upper impeller body of Fig. 5;

**[0026]** Fig. 8 is a detail longitudinal central section view of a plurality of pump stages incorporating impellers having diverging shrouds in accordance with the present disclosure, and with an uppermost pump stage being shown in an exploded view; and

**[0027]** Fig. 9 is a graph of performance test results for impellers having varying degrees of shroud divergence.

## Detailed Description of Various Embodiments

**[0028]** Although the following text sets forth a detailed description of numerous different embodiments of the invention, it should be understood that the legal scope of the invention is defined by the words of the claims set forth at the end of this patent. The detailed description is to be construed as exemplary only and does not describe every possible embodiment of the invention since describing every possible embodiment would be impractical, if not impossible. Numerous alternative embodiments could be implemented, using either current technology or technology developed after the filing date of this patent, which would still fall within the scope of the claims defining the invention.

**[0029]** It should also be understood that, unless a term is expressly defined in this patent using the sentence "As used herein, the term '___' is hereby defined to mean..." or a similar sentence, there is no intent to limit the meaning of that term, either expressly or by implication, beyond its plain or ordinary meaning, and such term should not be interpreted to be limited in scope based on any statement made in any section of this patent (other than the language of the claims). To the extent that any term recited in the claims at the end of this patent is referred to in this patent in a manner consistent with a single meaning, that is done for sake of clarity only so as to not confuse the reader, and it is not intended that such claim term be limited, by implication or otherwise, to that single meaning. Finally, unless a claim element is defined by reciting the word "means" and a function without the recital of any structure, it is not intended that the scope of any claim element be interpreted based on the application of 35 U.S.C. § 112, sixth paragraph.

**[0030]** A multistage pump for non-compressible fluids in accordance with the present disclosure includes an impeller assembly having upper and lower impeller shrouds that diverge as the radial distance from the main shaft increases. The lower impeller shroud may have a plane perpendicular to the longitudinal axis of the main shaft, and the upper impeller shroud may have a conical shape and be oriented such that the distance between the shrouds increases in the radial direction. The angle between the shrouds may be referred to as the shroud divergence angle. Alternatively, both impeller shrouds may be conical in shape and oriented such that the distance between the shrouds and the corresponding diffuser assembly decreases and the distance between the shrouds and the corresponding disc assembly increases as the radial distance from the main shaft increases. In this embodiment, the pitch of the upper impeller shroud is steeper than that of the lower impeller shroud to create the desired shroud divergence angle. The divergence of the shrouds allows the hydraulic diameter of the impeller flow passages to be increased within the constraints on the distance between the impeller vanes. The divergence of the shrouds and the corresponding increase in the hydraulic diameter slows the fluid at the outlets of the flow passages, thereby increasing the pressure recovery and efficiency of the pump stage.

**[0031]** Fig. 8 illustrates an example of multiple pump stages 300 incorporating diverging impeller shrouds in accordance with the present disclosure. The pump stages 300 may be implemented in a submersible multistage centrifugal pump for pumping non-compressible fluids such as, for example, the pump assembly 100 depicted in Figs. 1-7. Of course, the pump stages 300 may also be implemented in other multistage pumps, such as those illustrated in the patents referenced above. The pump stages 300 may be configured to receive the main impeller shaft 102 rotatably driven by the motor 104, with the pump stages 300 being disposed about the main shaft 102 and within the cylindrical pump case 108. When driven by the main shaft 102, the pump stages 300 move fluid from the pump fluid inlet 110 to the pump fluid outlet 112.

**[0032]** Similar to the pump stages 106 described above, each pump stage 300 comprises three sub-assemblies: a diffuser assembly 302, an impeller assembly 304 and a disc assembly 306. When assembled, the diffuser assembly 302 and disc assembly 306 are fixed within and non-rotatable with respect to pump case 108, while impeller assembly 304 is secured to the main shaft 102 for rotation therewith, and the main shaft rotates with respect to the diffuser assembly 302 and the disc assembly 306. The diffuser assembly 302 of each stage 300 includes a cylindrical diffuser body 308, a hub seal 310 mounted thereon, a retainer ring 312 and a thrust washer 314. The diffuser body 308 and retainer ring 312 may be made of polycarbonate or other suitable plastic. The hub seal 310 may be made of one of a variety of materials including, for example, stainless steel. The thrust washer 314 may be made of one of a variety of materials including, for example, carbon phenolic.

**[0033]** The diffuser body 308 includes a generally-cylindrical outer wall 316 and an outer section including a set of one or more circumferentially spaced outer diffuser vanes 318 extending along a somewhat spiral path from a main shaft opening 320 to the outer wall 316. The hub seal 310 may be characterized as a circular disk shaped member 322 similar to that described above and having plural, circumferentially spaced radially projecting tabs formed thereon and sized to fit into a cooperating lower hub seal seat formed in the diffuser body 308 about the main shaft opening 320. The disc shaped member or flange 322 of seal 310 includes a cup shaped hub portion 324 having a circular opening 326 formed in a transverse wall or face 328. The retainer ring 312 includes a central bore 330 sized to fit closely around the hub portion 324 of the hub seal 310. The hub seal 310 is also disposed in the hub seal seat of the diffuser body 308 for limited lateral excursion with respect to the shaft 102 and body 308. The retainer ring 312 may be secured to diffuser body 308 by, for example, sonic welding, although other appropriate securement methods may be used. The retainer ring 312 has an inner diffuser section that may include diffuser vanes circumferentially spaced apart, extending radially from the bore 330 and adapted to be aligned with the outer diffuser vanes 318 in the diffuser body 308.

**[0034]** The centrifugal closed impeller assembly 304 comprises an upper impeller body 332 and a generally-planar lower impeller shroud 334 having a fluid inlet opening or eye 336 formed therein. The upper impeller 332 and lower impeller shroud 334 may be made of, for example, a polymer material, such as acetal. The upper impeller 332 comprises a conical upper impeller shroud 338 disposed about a generally-cylindrical central hub 340 and having a bottom surface facing a top surface of the lower impeller shroud 334. The upper impeller shroud 338 is oriented such that the distance between the bottom surface of the upper impeller shroud 338 and the top surface of the lower impeller shroud 334 increases as the radial distance from the main shaft 102 increases. The amount of divergence between the shrouds 334, 338 is indicated by a shroud divergence angle $\theta$. The central hub 340 includes, for example, a main shaft bore 342 and is shaped and sized to receive the main shaft 102 in close fitting relationship, with the longitudinal axes of the main shaft 102 and central hub 340 being substantially coincident. A plurality of circumferentially spaced spiral impeller vanes 344 extend generally from the central hub 340 to the radial outermost edges of upper impeller shroud 338. The impeller vanes 344 may have a configuration similar to that shown in Fig. 7, with the distance between the vanes 344 increasing the further along the flow passage the fluid moves. In certain embodiments, the upper impeller body 332 and the lower impeller shroud 334 may be secured to one another by sonic welding, although other appropriate securement methods may be used and will be apparent to those skilled in the art. Secured in this manner, the upper impeller shroud 338, the impeller vanes 344 and lower impeller shroud 334 form plural impeller fluid flow passages 346.

**[0035]** The disc assembly includes a retainer ring 348, a wear ring 350 and a disc 352. The retainer ring 348 and disc 352 may be made of a variety of materials including, for example, polycarbonate or other suitable plastic. The wear ring 350 may be made of a variety of materials, including stainless steel. The wear ring 350 may include plural circumferentially spaced radially projecting tabs which fit in cooperating recesses formed in disc 352 for securing the wear ring 350 non-rotatably with respect to the disc 352. The retainer ring 348 may be suitably secured to the disc 352 by sonic welding or other appropriate attachment mechanism to retain the wear ring 350 secured on the disc 352.

**[0036]** The above-described impeller design further increases the effective shroud divergence angle by creating the angle θ between the upper and lower shrouds 338, 334, causing them to also diverge as the non-compressible fluid flows away from the center of the impeller assembly 304. This further decreases the speed of the fluid in the impeller flow passages 346 and increases pressure recovery within the impeller assembly 304, where the pressure recovery can be achieved more efficiently.

**[0037]** Impeller assemblies having diverging shrouds have been the subject of prototyping and testing. Fig. 9 presents charts of performance curves for test pumps having impellers of varying shroud divergence angles θ. The performance curves include the head capacity curves 354, the efficiency curves 356 and the horsepower curves 358 that are known to those skilled in the art as indicating the performance characteristics of centrifugal pumps. The flow rate through the stage in gallons per minute (GPM) is provided along the horizontal axis. In the prototype pump stages, the vane profile, the entrance vane height and the diffuser are constant, and shroud divergence angles of 0°, 2° and 4° were tested.

**[0038]** The chart illustrates that head capacity, the efficiency and the horsepower all show at least moderate increases for the 2° and 4° divergence angles θ, with the efficiency showing the greatest increase. Further, increasing the divergence angle θ moves the best efficiency point to a higher flow rate. Additional testing of other prototype pump stages with varying configurations yields similar results as the shroud divergence angle θ is increased. The improved performance continues up to a divergence angle θ of approximately 5°, after which separation between the shroud walls and the pumped fluid appears to occur.

**[0039]** By using this method of constructing impellers, fewer pump stages are typically required to generate the same head and flow performance found in comparable previously known pumps. As discussed above, impellers having diverging shrouds may be implemented in other configurations of multistage centrifugal pumps in addition to the configuration illustrated herein. For example, the pumps in U.S. Patent Nos. 3,116,696, 3,288,074, 4,678,399 and 4,802,819 may be reconfigured with the upper shrouds diverging from the lower shrouds. Additionally, the shrouds may diverge even where the lower impeller shroud is not generally planar, and instead is conical-shaped such that the distance between the lower shroud and the corresponding diffuser assembly decreases as the radial distance from the main shaft increases. In this embodiment, the pitch of the upper impeller shroud may be steeper than that of the lower impeller shroud in order to create the desired shroud divergence angle θ there between.

**[0040]** Moreover, while the illustrated embodiment shows the distance between the surfaces of the shrouds 334, 338 increasing at substantially linearly as the radial distance from the from the central hub 340 increases, those skilled in the art will understand that the divergence may have non-linear characteristics for some or all of fluid flow within the flow passages 346. For example, the surface of the upper shroud 338 may be curved or parabolic, resulting in a non-linear rate of change of the distance between the surfaces of the shrouds 334, 338, and a varying divergence angle θ angle along the flow passages 346. In such configurations, the distance between the surfaces of the shrouds 334, 338 may increase at a greater rate as the distance from the central hub 340 increases. In some implementations, it may also be desired for the surfaces of both shrouds 334, 338 to be curved while still diverging in the radial direction. Still further, the surfaces may have incremental changes in slope such that a first portion of the surface proximate the central hub 340 has a first constant divergence angle θ, and second portion of the surface distal to the central hub 340 has a second constant divergence angle θ that is greater than that of the first portion, and so on such that the rate of change of the distance between the surfaces is not constant across the entire length of the flow passages 346. Other configurations of multistage centrifugal pump impellers assemblies having diverging shrouds will be apparent to those skilled in the art and are contemplated by the inventors as having use in centrifugal pumps in accordance with the present disclosure.

**[0041]** In a further alternative configuration of the pump stage, the diffuser assembly may also be configured to have vertical divergence between upper and lower diffuser shrouds and correspondingly within the diffuser flow passages. As seen in Fig. 8, a space below the lower radial surface of the diffuser assembly 302 is opened up by the conical or angled upper shroud 338 of the impeller assembly 304. This spacing may allow the shrouds of the diffuser assembly 302 to be made to diverge in the opposite direction, with the distance between the diffuser shrouds increasing as the radial distance decreases from the outer wall 316 toward the main shaft opening 320. Consequently, the diffuser vanes 318 may be relatively shorter near the outer diameter of the diffuser 302 and relatively taller near the inner diameter of the diffuser 302. As discussed, the lower diffuser shroud may be relatively conical-shaped such that the lower surfaces of the diffuser flow passages slope downward from the outer diameter toward the main shaft opening 320 to utilize the spacing above the upper impeller shroud 338. Alternatively, the lower diffuser shroud may be relatively-planar and the upper diffuser shroud may be conical-shaped to cause the divergence, or both the upper and lower diffuser shrouds may be conical-shaped, with the pitch of the upper diffuser shroud being steeper than that of the lower diffuser shroud to create the desired shroud divergence angle there between.

**[0042]** Configured in this way, the pressure recovery in the return passages of the diffuser assembly 302 may be improved as the fluid is directed to the inlet of the impeller of the next stage in a similar manner as described for the impeller divergence. The pressure recovery improvement occurs due to the further reduction of the fluid velocity in the diffuser return passages and to the reduced flow losses. The increasing hydraulic diameter of the return passages reduces the velocity of the fluid and makes the passages more nearly square, which decreases the surface-to-cross-section ratio of the return passages when compared to the typical more rectangular-shaped return passages of the standard diffuser.

**[0043]** While the preceding text sets forth a detailed description of numerous different embodiments of the invention, it should be understood that the legal scope of the invention is defined by the words of the claims set forth at the end of this patent. The detailed description is to be construed as exemplary only and does not describe every possible embodiment of the invention since describing every possible embodiment would be impractical, if not impossible. Numerous alternative embodiments could be implemented, using either current technology or technology developed after the filing date of this patent, which would still fall within the scope of the claims defining the invention.

## Claims

**1.** An impeller assembly for a pump stage of a centrifugal pump having a main impeller shaft with a longitudinal axis driven by a motor, the pump stage including a diffuser assembly having a diffuser body with a generally-cylindrical outer wall and a disc assembly, the diffuser assembly and the disc assembly being configured to receive the main impeller shaft, the impeller assembly comprising:

an upper impeller body having a generally-cylindrical central hub with a main shaft bore shaped and sized to receive the main impeller shaft in close fitting relationship so that the impeller assembly rotates with the main impeller shaft, and an upper impeller shroud extending radially from the central hub and having a bottom surface, and

a lower impeller shroud having a central fluid inlet opening and a top surface facing the bottom surface of the upper impeller shroud,

wherein the impeller assembly is disposed within the outer wall of the diffuser assembly and enclosed therein by the disc assembly, and wherein the top and bottom surfaces are oriented such that the distance between the bottom surface of the upper impeller shroud and the top surface of the lower impeller shroud increases as the radial distance from the central hub increases.

**2.** An impeller assembly in accordance with claim 1, wherein the top surface of the lower impeller shroud is generally planar and approximately perpendicular to the longitudinal axes of the main impeller shaft and the central hub, and the bottom surface of the upper impeller shroud is conical so that the distance between the bottom and top surfaces increases as the radial distance from the central hub increases.

**3.** An impeller assembly in accordance with claim 1 or 2, wherein the top surface of the lower impeller shroud and the bottom surface of the upper impeller shroud are conical so that the distance between the bottom and top surfaces and the disc assembly increases as the radial distance from the central hub increases, and so that the distance between the bottom and top surfaces increases as the radial distance from the central hub increases.

**4.** An impeller assembly in accordance with any preceding claim,
wherein an angle of divergence $\theta$ between the bottom surface of the upper impeller shroud and the top surface of the lower impeller shroud is approximately 5°.

**5.** An impeller assembly in accordance with any preceding claim,
wherein a shroud divergence angle $\theta$ between the bottom surface of the upper impeller shroud and the top surface of the lower impeller shroud is greater than 0° and no more than 5°.

**6.** An impeller assembly in accordance with any preceding claim,
wherein a shroud divergence angle $\theta$ between the bottom surface of the upper impeller shroud and the top surface of the lower impeller shroud is in the range of 2° to 5°.

**7.** An impeller assembly in accordance with any preceding claim,
wherein the diffuser assembly comprises a plurality of circumferentially spaced spiral impeller vanes extending between the bottom surface of the upper impeller shroud and the top surface of the lower impeller shroud.

**8.** An impeller assembly in accordance with any preceding claim,
wherein the distance between the bottom surface of the upper impeller shroud and the top surface of the lower impeller shroud increases linearly as the radial distance from the central hub increases.

**9.** A pump stage for a centrifugal pump having a main impeller shaft with a longitudinal axis driven by a motor, the pump stage comprising:

a diffuser assembly having a diffuser body with a generally-cylindrical outer wall and a main shaft opening configured to receive the main impeller shaft;
an impeller assembly disposed within the outer wall of the diffuser assembly, the impeller assembly being in accordance with any preceding claim.

**10.** A centrifugal pump comprising:

a motor;
a main impeller shaft having a longitudinal axis and being coupled to and driven by the motor; and
at least one pump stage according to claim 9.

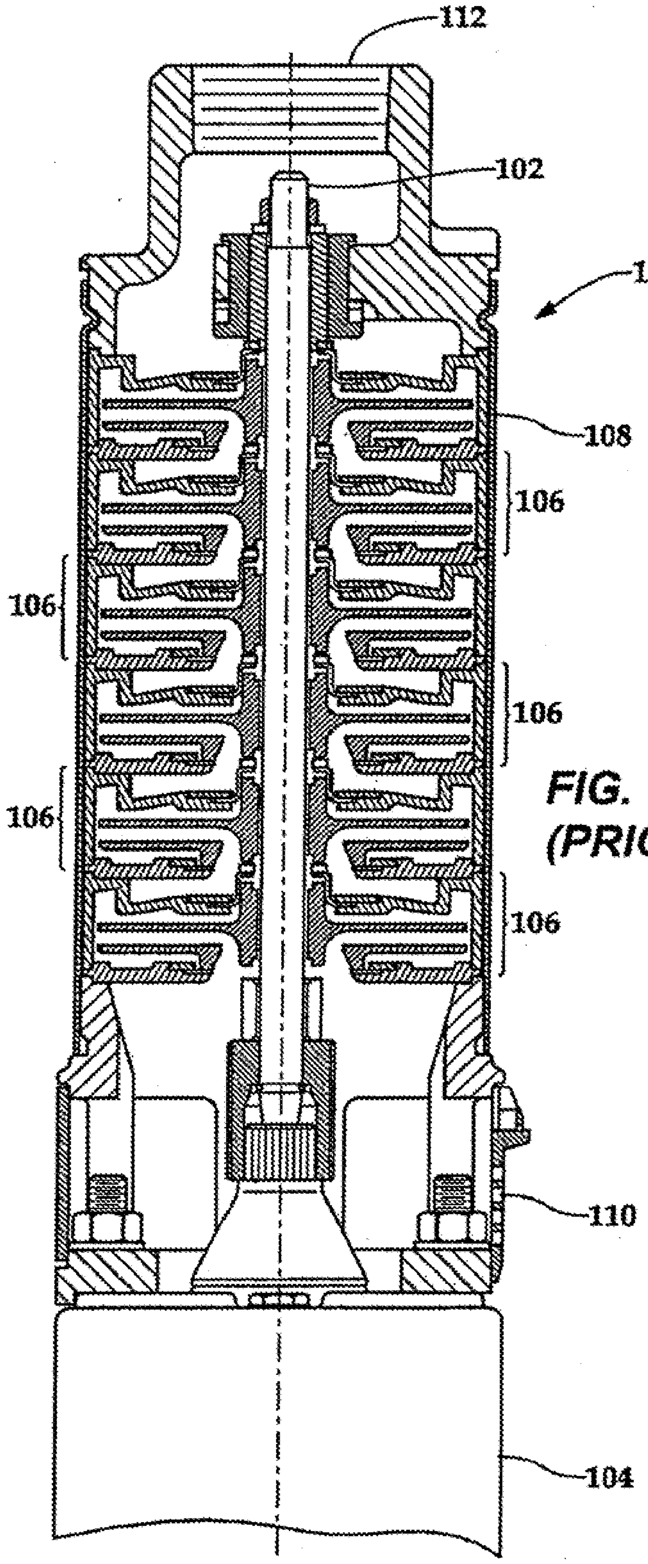


FIG. 1
(PRIOR ART)

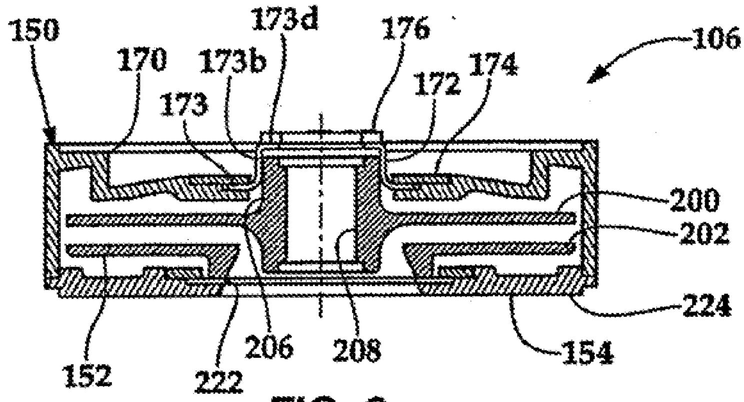


FIG. 2
(PRIOR ART)

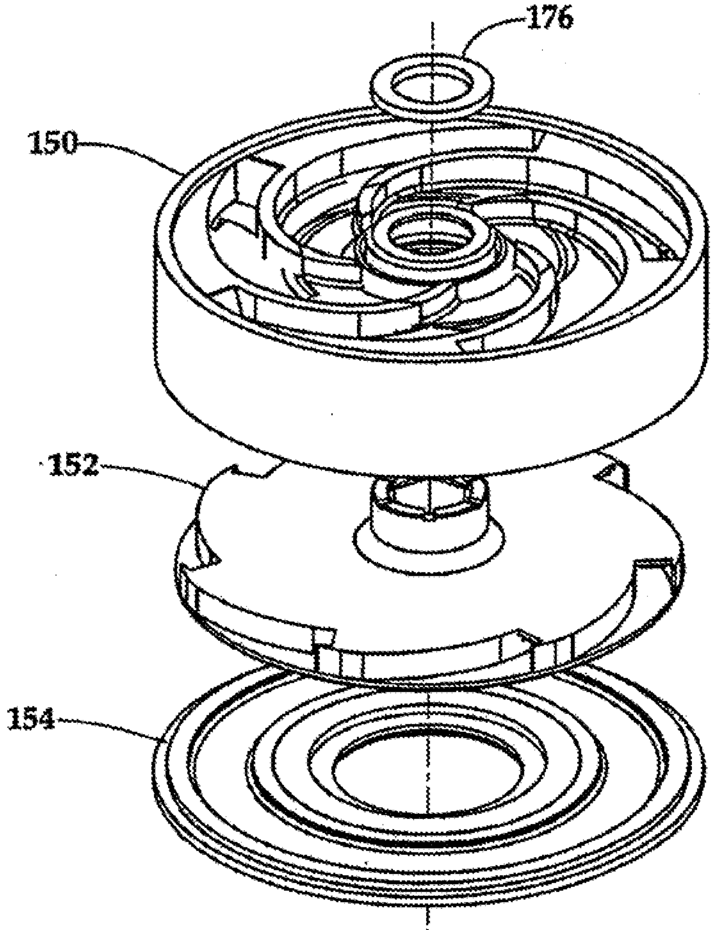


FIG. 3
(PRIOR ART)

3/5

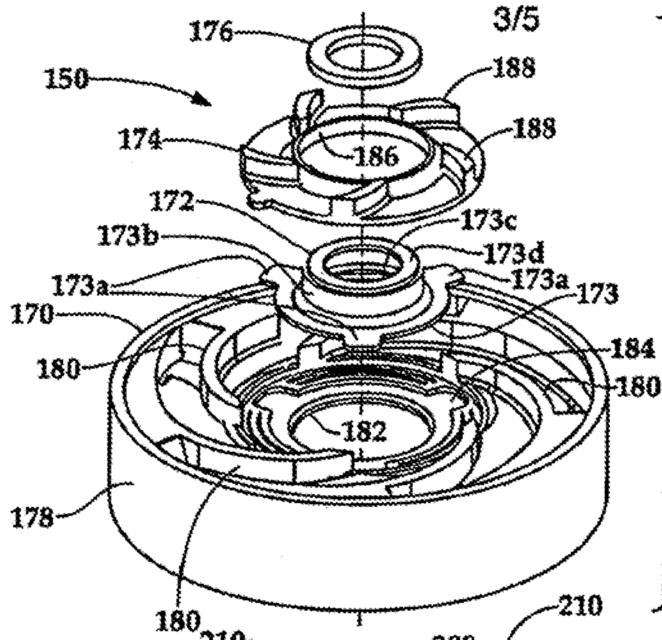


FIG. 4
(PRIOR ART)

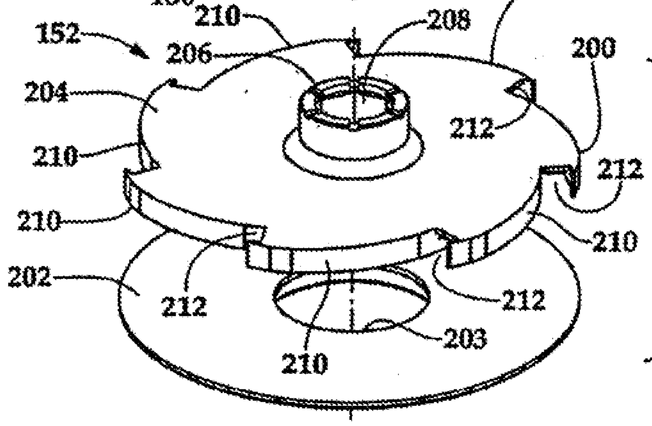


FIG. 5
(PRIOR ART)

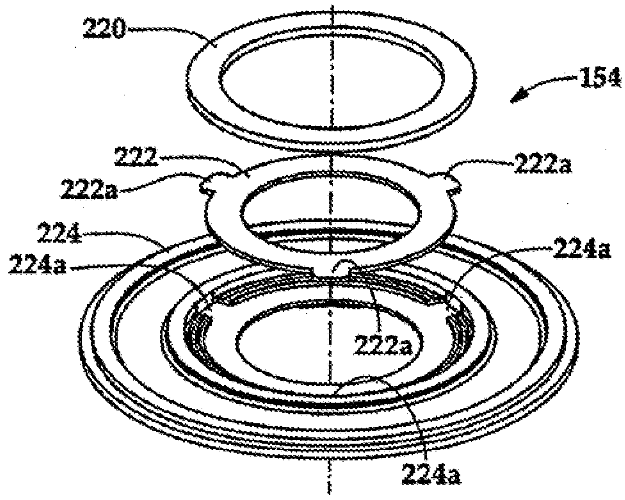


FIG. 6
(PRIOR ART)

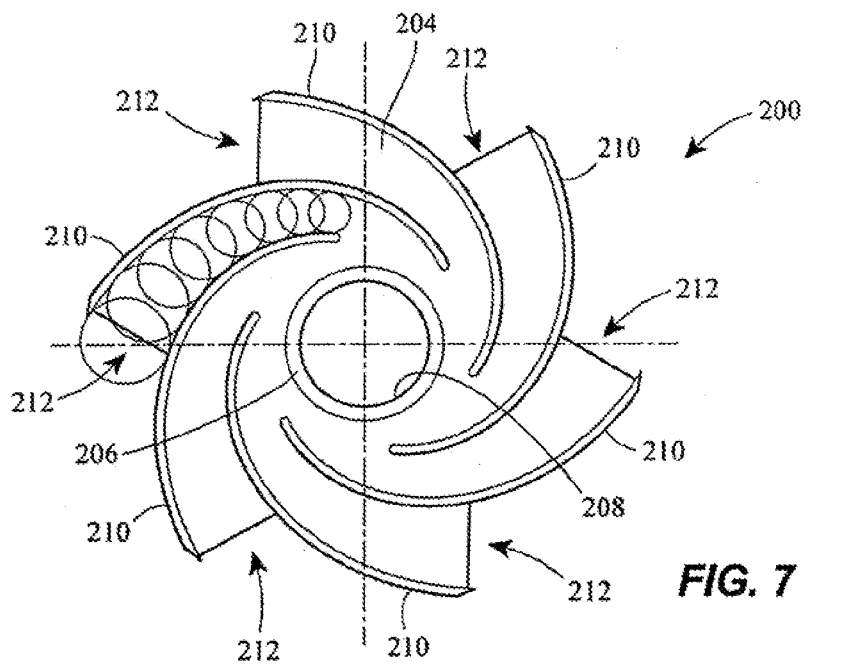
210
204
212
212
200
210
210
212
212
206
210
208
210
212
210
212

FIG. 7

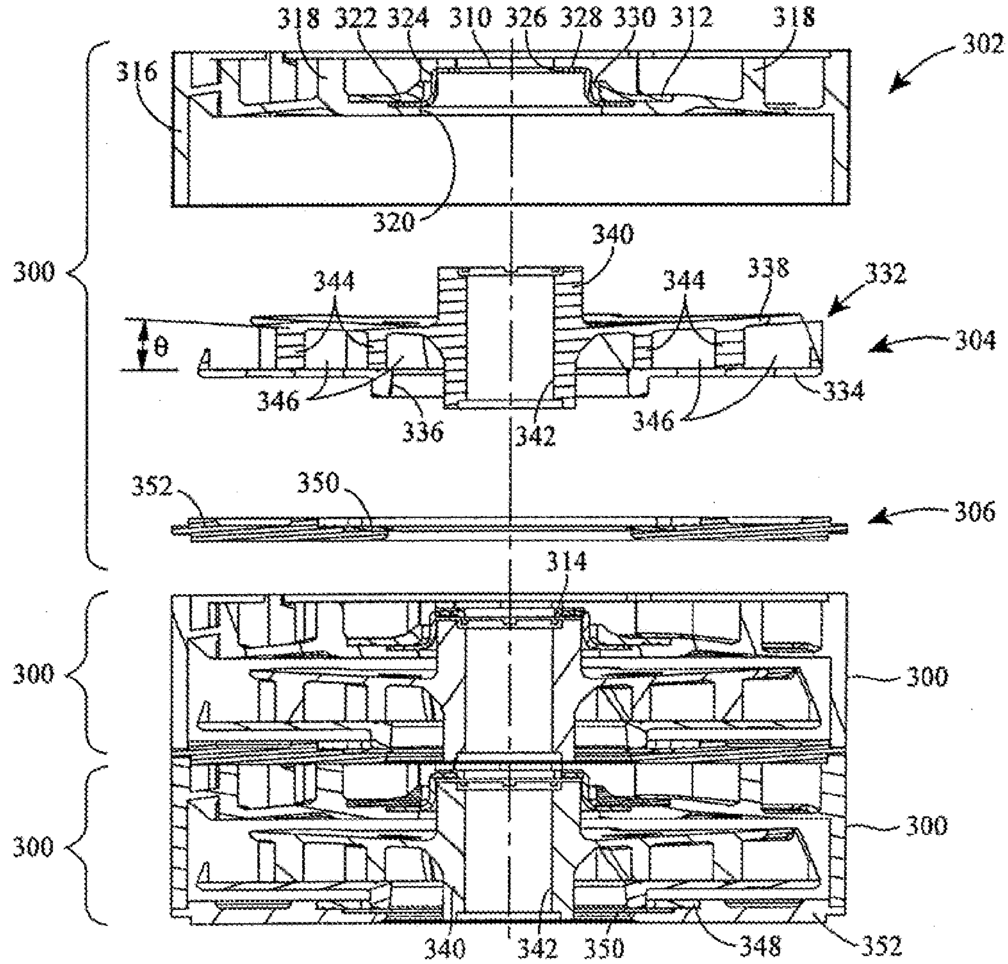
318 322 324 310 326 328 330 312 318
302
316
320
340
300
344
338
332
344
θ
304
346
336
342
346
334
352
350
306
314
300
300
300
300
340
342
350
348
352

FIG. 8

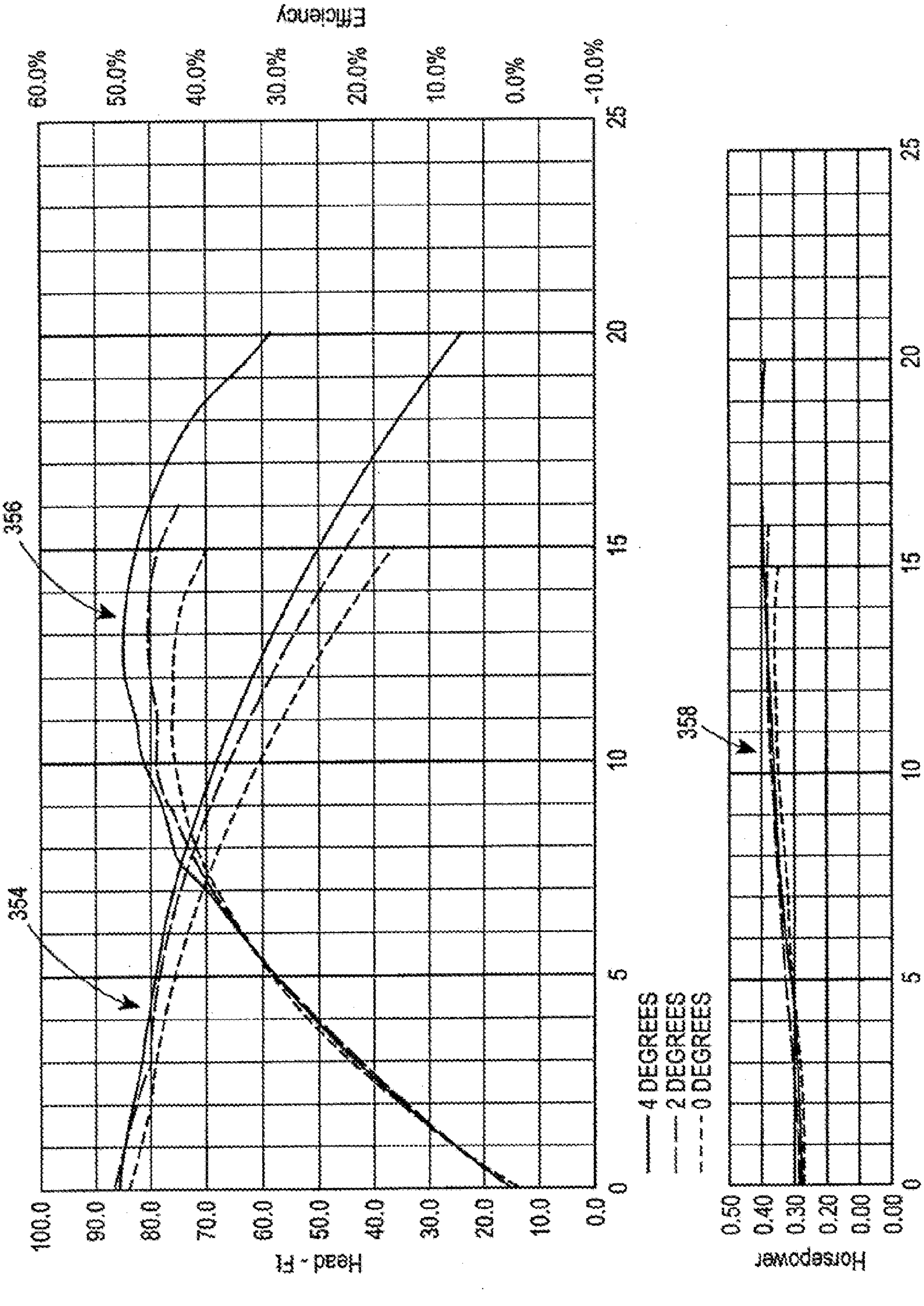
Efficiency
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
-10.0%
Head - Ft
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
5
10
15
20
25
354
356
358
4 DEGREES
2 DEGREES
0 DEGREES
Horsepower
0.50
0.40
0.30
0.20
0.00
0.00

*FIG. 9*

## REFERENCES CITED IN THE DESCRIPTION

*This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.*

### Patent documents cited in the description


- US 20060269404 A **[0004]**
- US 3116696 A, Deters **[0010] [0039]**
- US 3288074 A, Hall **[0010] [0039]**
- US 4678399 A, Vandevier **[0010] [0039]**
- US 4802819 A, Bevington **[0010] [0039]**