June 15, 1965 K. D. McMAHAN 3,188,968

CENTRIFUGAL PUMPS

Filed Feb. 12, 1963 3 Sheets-Sheet 1

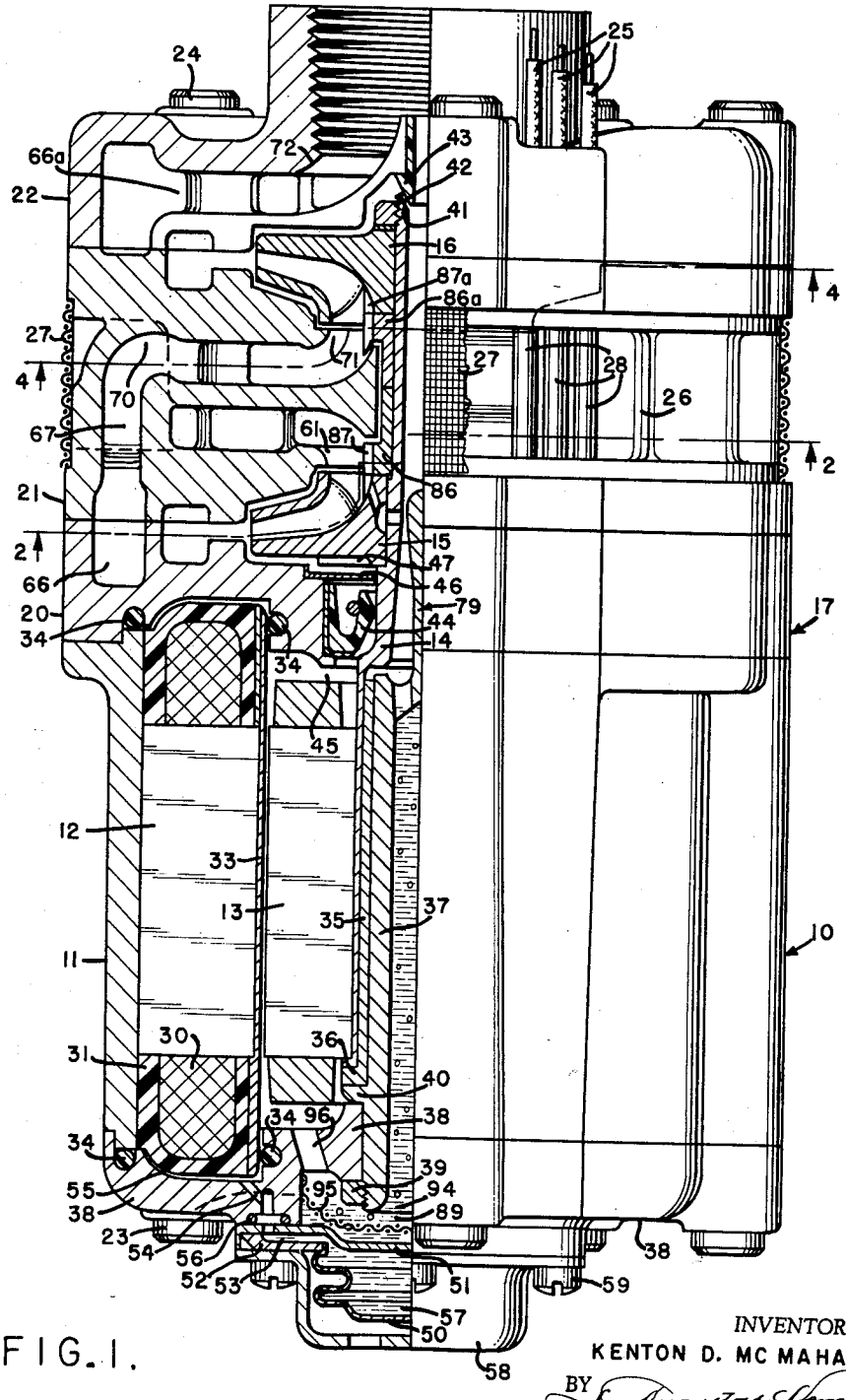


FIG. 1.

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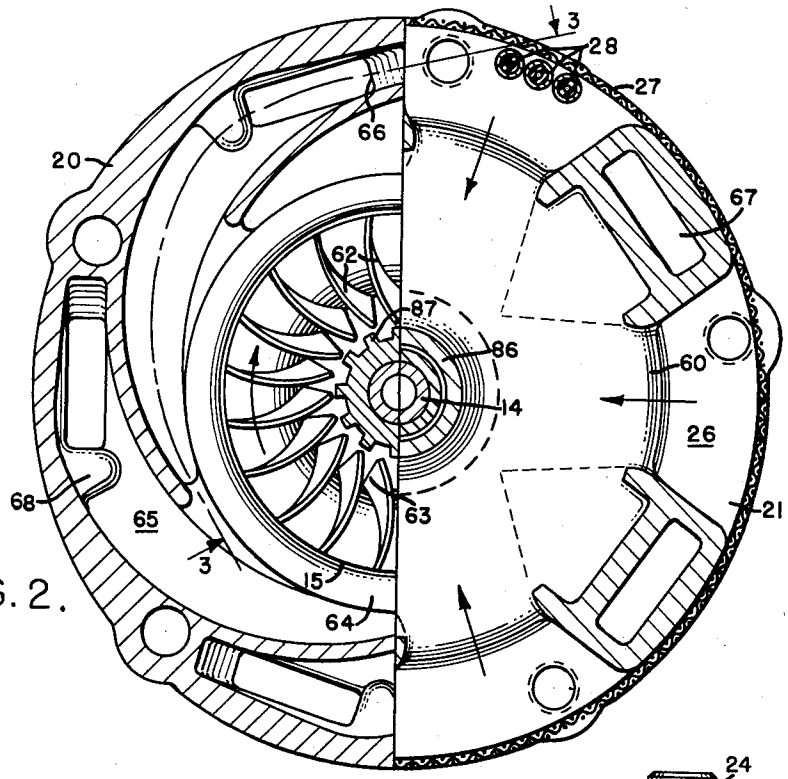


FIG. 2.

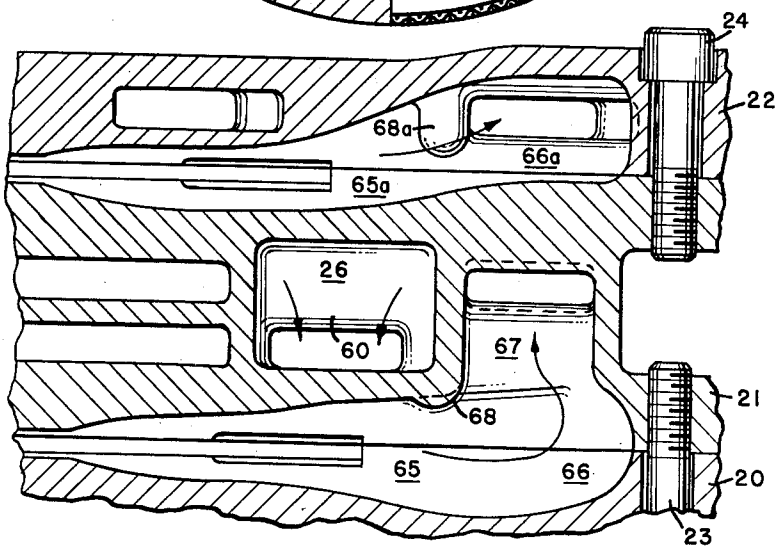


FIG. 3.

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3 Sheets-Sheet 3

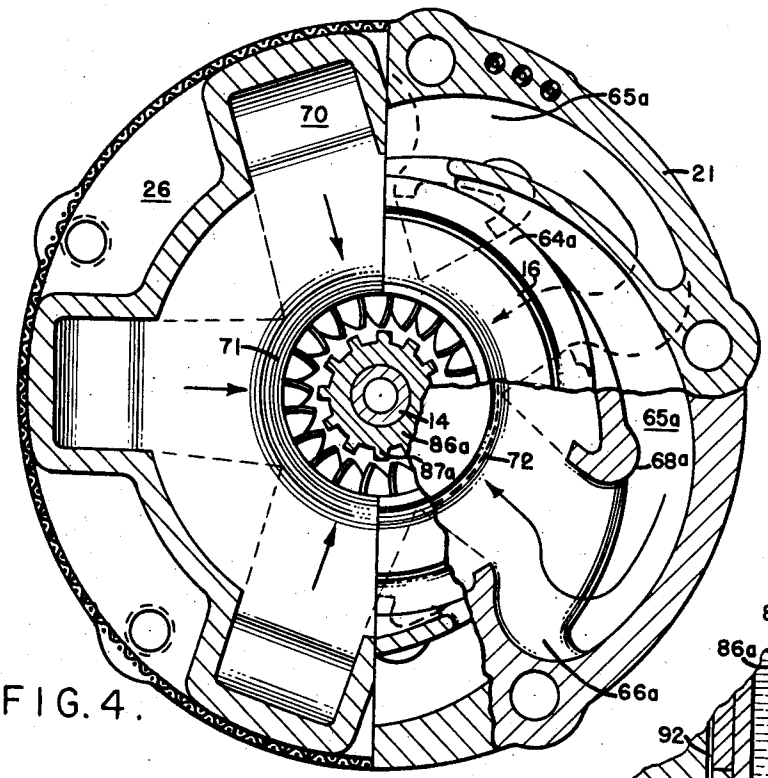


FIG. 4.

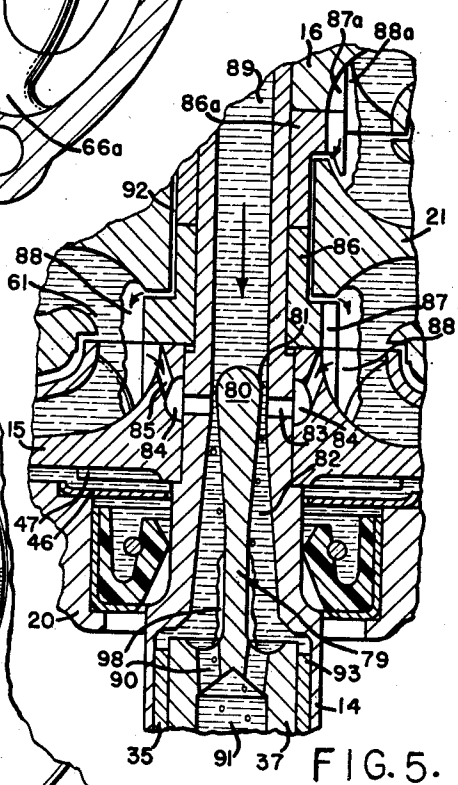


FIG. 5.

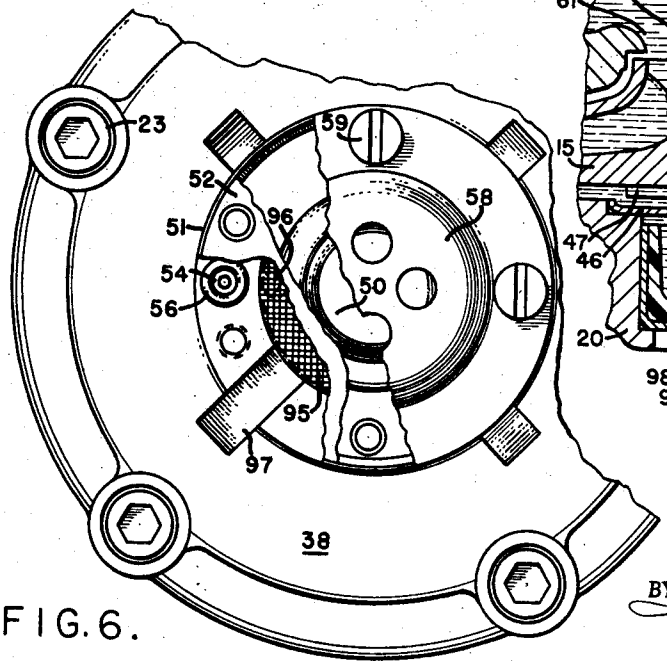


FIG. 6.

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CENTRIFUGAL PUMPS

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6 Claims. (Cl. 103—109)

The present invention relates to centrifugal fluid pumps and more particularly to multi-stage centrifugal pumps. The basic concept of the reduction of interstage losses in multi-stage centrifugal machines by the use of a plurality of radial jets of balanced momentum is the same as that disclosed in U.S. Patent No. 2,868,440 and copending application Serial No. 175,940.

In Patent 2,868,440, it was disclosed that if two jets of equal magnitude (jet velocity × mass) created from the discharge of an impeller of an earlier stage unit are directed in opposed directions radially inwardly towards the suction eye in alignment along a radial center plane and in centered position over the axis of the eye, substantially balanced impact of the two jets is effected as they meet in the vicinity of said suction eye and substantially smooth axial deflection of said jets into said suction eye is effected as they merge into a single stream. By creating diametrically opposed jets of equal magnitude from each impeller discharge, the rotational velocity components, turbulences, undesired accelerations, eddies and vacuous pockets in the stream flow between the discharge of a volute of one stage and the intake or eye of a succeeding stage, resulting in so called "interstage" losses, and consequent lowering of overall performance efficiency of multi-stage machines, are materially reduced.

In copending application Serial No. 175,940, it has been disclosed that the radial jets from the discharge of the volutes need not be diametrically opposed to supress the rotational components and other undesirable effects in the said jets, but that these factors disturbing the efficiency of centrifugal machines can be materially reduced if the magnitude of the radial jets and the spacing therebetween is such that the resultant of the radial momentum (jet velocity × mass) on one side of any selected radial plane passing through the axis of the inlet suction eye is substantially equal to and in substantial radial alignment with the resultant of the radial jet momentum on the other side of the plane. In accordance with this disclosed concept, an odd number of radial jet passages properly spaced will provide the desired jet balance to reduce interstage losses. It was further disclosed that the tendency of the jets from the perimetric volutes of one stage when turned radially inward by a conventional eblow to crowd toward the outer bend and away from the inner bend of said elbow, can be compensated for by the use of "overbends" or "overextended" bends, whereby a single radial jet of very nearly uniform velocity, mass and direction thereacross and with the resultant of its momentum almost coextensive in position with the radial mechanical centerline of the jet, is produced without the use of inner vanes and the like. Also, by this means, the circumferential spaced confining walls on the circumferential spaced boundaries of the radial jet passages are eliminated. As a result, the radial jets of one stage enter the eye of the next stage with little or no rotational components and without measurable loss.

The present invention contemplates the use of modern transistorized frequency changing power pacts which

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permit the operation of high frequency induction motors on standard 60 cycle alternating current power sources at any desired design speed, and thus makes the pump, in accordance with the present invention applicable to submerisible deep well pumps as well as many other and varied applications. The availability of any desired design speed on a standard power source without the need for brushes, permits the most efficient and least expensive design of pump to cover a wide range of well depths and flow requirements in the same overall sized pump.

One object of the present invention is to provide a new and improved multi-stage pump for liquids of zero or low compressibility and especially containing absorbed or mixed air, gases or vapors, which pump is designed for operation at relatively high speeds with a minimum of interstage losses and high overall performance and efficiency, and which at the same time is capable of being manufactured at much lower cost than conventional submersible pumps.

Another object of the present invention is to provide a new and improved multi-stage pump, with thrust balancing features, designed to balance out the axial bearing thrust normally present in such pumps.

To carry out the last objective, the inlet passages of any two impeller stages extend in opposite axial directions on a common shaft, so that the end thrusts developed in these stages balance each other partially or completely, so that the need for expensive and troublesome thrust bearings is eliminated. The teachings of the aforesaid patent and application permit this opposite inlet arrangement to be incorporated in a compact and efficient design by the use of vaneless overbend elbows for the interstage crossover passage and the axial pump discharge.

Various other objects, features and advantages of the present invention will apparent from the following description and from the accompanying drawings, in which

FIG. 1 is a cut-away side elevation of a complete two-stage pump embodying the present invention;

FIG. 2 is a transverse section of the pump along the lines 2—2 of FIG. 1 and shows a salf-section of the first stage discharge diffuser and volutes, and a half-section of the first stage inlet passages comprising five inlet jets with five interstage crossover passages, shown in section, interpersed therebetween;

FIG. 3 is a circumferential section of the pump taken along the lines 3—3 of FIG. 2;

FIG. 4 is a partially fragmented transverse section of the pump taken along the lines 4—4 of FIG. 1 and shows a half-section of the interstage passages between the first and second stages and a fragmented half-section of the discharge volutes of the second stage fragmented to show the "overbends" in the elbows at the volute discharges of the last stage;

FIG. 5 is an enlargement of the injector section shown in FIG. 1 but shown in connection with the detailed illustration of the air or gas removal; and

FIG. 6 is a fragmented transverse motor end view of the pump shown in FIG. 1.

Referring to the drawings, there is shown a two stage, vertically suspended, submersible pump 10 for pumping water, oils, chemical and the like, although as far as certain aspects and features of the invention are concerned, the pump may with minor variations have any number of stages to obtain any desired final discharge pressure, and may be employed to compress or otherwise pump gases.

The pump 10 comprises a motor casing 11 containing a motor stator 12 and a rotor 13. The rotor 13 is rigidly secured to a hollow rotatable shaft 14 on which are keyed or otherwise affixed a first stage impeller 15 and a second stage impeller 16. The pump 10 also comprises a pump casing 17 made up of three substantially circular member supported on one such member and comprising a first stage back plate member 20, an intermediate member 21 and a discharge member 22 threaded for connection to a discharge pipe (not shown) which may optionally contain a check valve and be connected to a tank with the other common accessories normally used in a complete pump system. The motor casing 11 and the back plate member 20 are affixed to the intermediate member 21 by cap screws 23 and the discharge member 22 is likewise affixed to said intermediate member 21 by cap screws 24.

Motor leads 25 pass through holes in members 20, 21 and 22 and are sealed pressure tight (not shown) in the wall of motor casing 11. The intermediate member 21 is shown provided with a plurality of equally spaced inlet openings 26 for the first stage impeller 15, five being shown covered by a circular sand screen 27. Where the leads 25 pass across one of the inlet openings 26, they are protected from damage and abrasion by metallic tubes 28 inserted into member 21.

The motor stator 12 contains windings 30 encapsulated in a resinous material 31 such as "Epon resin" a trade name for a resin possessing terminal epoxide groups, or a suitable silicone encapsulating compound, and the rotor 13 is separated from the stator by a sleeve 33 of stainless steel or other suitable material and sealed liquid-tight by O-ring seals 34. The hollow shaft 14 carrying the rotor 13 is rotatable on a unit bearing sleeve 35, which has a thrust flange 36 and which is rigidly mounted on a fixed hollow spindle 37 mounted rigidly to a motor end bell 38 by a nut 39. The lower end of the fixed spindle 37 has a down thrust flanges 40 to carry the small unbalanced weight of the rotor parts as well as any small unbalance of pressure between the stages through its seating contact with the thrust flange 36 on the bearing sleeve 35. On the upper end of the rotatable shaft 14 is a female cone center 41 separated by a space clearance 42 from corresponding fixed male cone center 43 secured to the discharge casing member 22, to limit upward travel of said shaft during starting, stopping or handling of the pump.

Mounted tightly in back plate 20 is shaft seal 44 of well known construction, serving the dual purpose of preventing substantial leakage of liquid from the discharge of the first stage impeller 15 into a motor rotor compartment 45 during operation and corresponding substantial leakage of trapped air or gas from said compartment, when the pump is not operating. The seal 44 also serves to exclude sand or foreign particles from the compartment 45 and in this function is aided by a sand shield 46 and radial vane sand slingers 47 on the back of the impeller 15.

At the bottom end of the pump 10 and mounted on the end bell 38 is a flexible bellows 50, soldered or otherwise sealed to a ring 52 and sealably closed at one end by a disc 51. The enclosure within the bellows 50 is connected by passage 53 between the ring 52 and the disc 51 and by a passage 54 in end bell 38 to a stator compartment 55, sealed against leakage by an O-ring 56. The bellows 50 is filled with a common type transformer insulating liquid 57, such as is commonly sold under the trade name "Pyranol," one of the askarel compounds. The bellows 50 is protected from injury by a vented cap 58 secured to the end bell 38 by screw studs 59. The hydrostatic pressure on the bellows 50 serves through the medium of the insulating material 57 therein to equalize the pressure inside and outside the stator compartment 55 irrespective of the depth of submersion of the pump or temperature expansions or contractions, thus preventing leaks of the pumped liquid around the seals 34 from coming in contact with the electrical stator windings 30 or preventing the outward leakage of the insulating fluid 57.

The intermediate member 21 is provided with a plurality of equal radial entrance passages 26 (FIG. 2) for the first stage impeller 15, five being shown equally spaced. Although the five inlet passages 26 are shown for forming a corresponding number of jets for admission to the eye of the first stage impeller 15, any number of these passages may be provided within a practical range, as long as these passages are circumferenially distributed so that the resultant of the radial jet momentum (inlet jet velocity × mass) on one side of any selected radial plane passing through the impeller axis is substantially equal to and in substantially radial alignment with the resultant of the radial jet momentum on the other side of the plane. For that purpose, the number of inlet passages 26 may be even and these may be arranged in diametrical pairs in a manner similar to that indicated in the aforesaid Patent 2,868,440 or may be odd and these passages may be equally spaced or may be otherwise spaced to attain balance in jet momentum in a manner similar to that indicated in the aforesaid application Serial No. 175,940.

The entrance passages 26 have comparatively large respective areas at their outer peripheries where the fluid passes through the protective sand screen 27 and converge towards and into round edged respective orifices 60, thus producing equally spaced equal jets directed radially inwardly toward the entrance eye 61 of the first impeller stage impeller 15.

The impeller 15 comprises a plurality of circumferentially spaced blades 62, so shaped, that they are concave on their leading faces and are generally forwardly curved at their outer peripheries or discharge ends as respect to their direction of rotation, and have respective inlet portions 63 inclined outwardly and forwardly to efficiently receive the flow from entrance eye 61 in a shock-free manner. Around impeller 15 is a first stage radial diffuser 64 serving to convert velocity head to pressure head and around this diffuser are a plurality of similar perimetric involute discharge scrolls 65, five being shown, equally spaced and of equal size and conformation, for gathering the fluid from the diffuser and forcing it therethrough by its rotation, the fluid from each scroll being discharge through an elbow 66 and through a crossover passage 67 to the next stage. The number of scrolls and their spacing may vary as long as they fulfill the requirements of balanced momentum set forth in the aforesaid application and patent.

The casing 17 is substantially circular and the discharge involutes 65 follow somewhat the circular contour of the casing and terminate in overextended outlet elbows 66 respectively equally spaced around the inside of said casing. The discharge involutes 65 have respective cross-sectional areas expanding towards their respective elbows 66 and serve thereby not only as discharge conduits but also as diffusers to further convert velocity head to pressure head.

As fluid goes through an elbow it tends to crowd towards the outer bend of the elbow and away from the inner bend due to centrifugal action, so that the resultant momentum of the jet, i.e. the jet velocity times its mass, is offset from the positional center line of the jet passage at the outlet of the elbow. This adverse condition is substantially nullified by shaping each elbow 66, so that the momentum of the elements of each jet emerging from the elbow is substantially uniform across the elbow from the inner bend to the outer bend. For that purpose, the inner bend on the upstream side of the elbow 66 from which the stream tends to break away as it flows through said elbow, turns through an angle only sufficiently to direct the stream from the scroll or volute 65 along the passage 67 but the outer bend at the downstream side of the elbow has an overbend, i.e. turns through an angle greater than that sufficient to direct the stream in the direction of the passage. The effect of this overbend in the elbow 66 is to compensate for the tendency of the stream to crowd towards the outer bend

and to cause thereby the resultant momentum of the jet entering the passage 67 to be almost coincident with the center line of the passage. The function of the overbend elbow 66 is described in detail in the aforesaid copending application.

Another aid in preventing the stream passing through the elbow 66 from breaking away from the inner bend of the elbow is a protuberance 68 on the upstream portion of said bend to deflect the approach stream away from the immediate area of the bend to crowd said stream around and over such protuberance into the sides of the passage 67 and thereby increase the actual and effective radius of the inner bend. The function of this protuberance 68 is also described in detail in the aforesaid application.

Each of the crossover passages 67 terminates in an overbend elbow 70 (FIGS. 1 and 4) for directing the fluid streams from an axial direction in passage 67 to a radially inward direction toward and in radial alignment with the eye of the second stage. The outer bend of the elbow 70 is overextended to cause the resultant momentum of the jet emerging radially from said elbow to be almost coincident with the center line of the passage and to pass through the axis of the eye of the second stage, and the inner bend has a protuberance to maintain a constant bend area to aid further in preventing the stream from breaking away from the inner bend, in the manner described in the aforesaid copending application.

The termination of the overbend elbows 70 produces a plurality of equally spaced radially inward jets, five being shown of balanced equal magnitude coursing towards the eye 71 of the second stage impeller 16. The blading of this impeller 16 is in every way similar to that of impeller 15, except that it is of opposite hand to permit face to face operation of the impellers 15 and 16 on shaft 14.

The radial diffuser 64*a* and the involute discharge scrolls 65*a* of the second stage are likewise similar to the radial diffuser 64 and the involute discharge scrolls 65 of the first stage. These scrolls 65*a* have respective discharge elbows 66*a* with overextended outer bends and with protuberances 68*a* on their inner bends serving the functions of the overextended outer bends and protruding inner bends of the elbows 66 and 70 described above. The overbend elbows 66*a* discharge in radially inward direction without the necessity of axial passages and additional elbows similar to the axial crossover passages 67 and elbows 70 at the outlet of the first stage, and direct the fluid from said elbows as five equally spaced radial jets of equal magnitude towards a pump discharge axial eye 72 and thence through a pump discharge pipe (not shown).

Although the specific embodiment of the invention is shown in connection with a liquid pump of the submersible type, it should be understood that said pump, with minor adjustments for differences in physical properties, will operate equally well in and with any fluid, such as gas or liquid, and that the broader concepts of the invention so far described, apply to all types of fluid pumps, including those normally referred to as blowers or compressors.

Where the pumped fluid is a liquid containing absorbed or entrained air or gas, the said air or gas will be centrifuged out of the liquid and will collect as a bubble near the hub or center of the impellers. To remove such air bubbles and to create at the same time a source of air or other gas for maintaining an atmosphere of such air or other gas around the motor rotor 13 and in the gap between the stator sleeve 33 and the rotor periphery at all sustained operating conditions, there is provided a small injector type pump 79 (FIGS. 1 and 5), built into the rotary shaft 14 and employing as motive power a small amount of the pumped liquid. This pump 79 comprises the fixed spindle 37 having on its upper end a tapered axial rod-like extension 80 extending inside and along a bore 89 of the rotary shaft 14 and rounded at its upper end. This spindle extension 80 defines with the encompassing shaft 14 the inner wall of a Venturi throat 81 and a diffuser 82. The shaft 14 has a row of holes 83 at the throat 81 communicating with an annular recess 84 connecting into a series of holes 85 in the hub of the impeller 15 leading from the radially inner side of the entrance eye 61 of the impeller. Also located on the hub surface of the impeller 15 and on a spacer sleeve 86 arranged between the hub of the impeller 15 and the hub of the impeller 16 are radial ribs 87, which aid in separating the air or gas from the liquid and which also serve as sand slingers to prevent small sand or gritty particles from entering the injector pump 79 and thence finding their way to the bearing of the shaft 14. Similar radial ribs 87*a* are also connected to the hub surface of the impeller 16 and on a spacer sleeve 86*a* located between the hub of the impeller 15 and the hub of the impeller 16 to serve as sand slingers.

During pump operations, the air or gas is separated from the liquid being pumped by centripetal action and collected in the form of a bubble 88 in the first stage at the hub of impeller 15 and to a lesser extent in the form of a bubble 88*a* at the hub of the impeller 16. A small quantity of the pumped liquid passes down the bore 89 of the shaft 14 and through the throat 81 and by its injector or aspirating action draws the air or other gas from the bubble 88 and discharges the mixture of lqiud and air or other gas through holes 90 in the fixed spindle 37 at the base of the rod-like spindle extension 80, into an axial bore 91 of said spindle and to the bottom of the motor. Air bubble 88*a* at the hub of the impeller 16 is forced by the full pressure of the first stage through a clearance space 92 between the axial bore of member 21 and spacer sleeves 86*a* and 86 and add to the bubble 88 which in turn is removed in the manner described.

The combined air or other gas and liquid discharge from the injector diffuser 82 due to the centrifuging action of the rotating shaft 14 again separates and forms another bubble 98 around the small section of extension 80 and serves a dual purpose of supplying relatively gas free liquid to the upper end 93 of unit bearing sleeve 35 for lubrication and cooling and of supplying air or gas for the motor rotor compartment 45. The remaining mixture over and above that required for the bearing sleeve 35 passes out from the bottom end 94 (FIG. 1) of the fixed spindle 37 in the form of liquid and entrained bubbles and into a chamber 89. The bubbles strike a guaze screen 95 in the chamber 89 across the discharge end of the spindle 37 and are deflected upward through holes 96 in the end bell 38 to the motor rotor compartment 45. The liquid passes freely through the screen 95 and out through radial slots 97 (FIG. 6) in the end bell 38 extending from the chamber 89 below the screen to the surrounding well or reservoir. When the motor rotor compartment 45 becomes completely filled with air or gas, the liquid level in the chamber 89 drops to the point where the active part of the guaze screen 95 is exposed above said level, so that liquid and gas will then pass freely through said screen for discharge through the radial slots 97. The rotor compartment 45 is thereby maintained with an atmosphere of air or gas, which serves to prevent excessive loading of the motor.

For applications where the pumped liquid contains little or no absorbed or entrained air or gas, as for instance in a boiler feed water system where special apparatus is employed to remove all such gases, the injector type pump 79 may be eliminated and a well known type of high pressure shaft seal and an external driving means such as a high speed turbine may be substituted without affecting the thrust balancing and other important features of the present pump or the broad concepts of the invention.

While the invention has been described with particular reference to a specific embodiment, it is to be understood

that it is not to be limited thereto but is to be construed broadly and restricted solely by the scope of the appended claims.

What is claimed is:

1. A centrifugal liquid submersible pump comprising a periperal casing, two coaxial pump stages in said casing, each having an inlet eye and an impeller, the first stage having a plurality of inlet radial passageways extending through and from said casing for directing the liquid to be pumped in a plurality of radial streams inwardly towards the eye of the first stage, said inlet passageways being circumferentially distributed so that the resultant of the radial jet momentum on one side of any selected radial plane passing through the impeller axis is substantially equal to and in substantial radial alignment with the resultant of the radial jet momentum on the other side of said plane, and means for discharging the pumped liquid from said first stage into a plurality of discharge streams, said second stage having inlet passageways for directing said discharge streams in a plurality of radial streams towards the eye of said second stage, the latter inlet passageways being circumferentially distributed so that the resultant of the radial jet momentum on one side of any selected radial plane passing through the impeller axis is substantially equal to and in substantial radial alignment with the resultant of the radial jet momentum on the other side of said plane.

2. A submersible centrifugal liquid pump comprising a peripheral casing, two coaxial pump stages in said casing, each having an inlet eye and an impeller, the first stage having a plurality of inlet radial passageways extending through and from said casing for directing the liquid to be pumped in a plurality of radial streams towards the eye of the first stage, said inlet passageways being circumferentially distributed so that the resultant of the radial jet momentum on one side of any selected radial plane passing through the impeller axis is substantially equal to and is in substantial radial alignment with the resultant of the radial jet momentum on the other side of said plane, said first stage also having a plurality of involute discharge scrolls and a corresponding plurality of crossover passageways extending substantially along the axis of the pump near said casing and leading from the outlets of said scrolls respectively to the second stage, said second stage having inlet passageways at the outlets of said crossover passageways respectively for directing the discharges from said scrolls in a plurality of radial streams towards the eye of said second stage, the latter inlet passageways being circumferentially distributed so that the resultant of the radial jet momentum on one side of any selected radial plane passing through the impeller axis is substantially equal to and in substantial radial alignment with the resultant of the radial jet momentum on the other side of said plane, said pump comprising an elbow between the outlet of each scroll and the inlet of the corresponding crossover passage having its outer bend angularly overextended beyond what is necessary to direct the jet into said crossover passage to reduce the crowding of the jet against the outer bend and away from the inner bend, each of said second stage inlet passageways comprising an elbow at the outlet end of each crossover passage for directing the stream therein radially inwardly towards the eye of the second stage, the latter elbow having an outer bend angularly overextended beyond what is necessary to direct the jet passing through the latter elbow radially inwardly to reduce the crowding of the latter jet against the outer bend and away from the inner bend.

3. A submersible centrifugal liquid pump as described in claim 2, said pump having an axial outlet and comprising a plurality of involute discharge scrolls at the outlet of the second stage, and an outlet radial passageway at the outlet of each of the latter scrolls for directing the stream passing therethrough radially inwardly towards said axial pump outlet, the latter outlet passageway comprising an elbow with its outer bend angularly overextended beyond what is necessary to direct the jet discharged therefrom radially inwardly, said outlet radial passageways being circumferentially distributed so that the resultant of the radial jet momentum on one side of any selected radial plane passing through the impeller axis is substantially equal to and in substantial radial alignment with the resultant of the radial jet momentum on the other side of the latter plane.

4. A submersible centrifugal liquid pump as described in claim 2, the inner bend of each of said elbows having a protuberance thereon near the approach end of the inner bend extending in a direction transverse to the direction of flow through the latter elbow.

5. A multi-stage centrifugal pump comprising two coaxial impeller stages having respective axial impeller eyes extending in opposite axial directions, each of said stages having a plurality of circumferenentially spaced radial inlet passageways extending towards said eyes respectively, discharge passage means for the earlier stage extending along the axis of the pump, means dividing the discharge from said passage means into a plurality of circumferentially spaced crossover passageways interspaced between the inlet passageways of the earlier stage and directed towards the inlet ends of the radial inlet passageways in the later stage, and elbows connecting the outlet ends of said crossover passageways to the inlet ends of the corresponding radial inlet passageways of the later stage respectively, each of said elbows having an inner bend and an outer bend, said outer bend being angularly oxerextended beyond what is necessary to direct the jet passing therethrough radially inwardly to reduce the crowding of the jet against the outer bend and away from the inner bend as said jet passes through the elbow.

6. A multi-stage centrifugal pump comprising a peripheral casing, a plurality of axial stages including a first stage and a last stage, each stage including an impeller with an inlet eye, said stages being arranged with inlet impeller eyes extending in opposite directions to cause axial thrusts on said stages to oppose each other, said pump having an axial outlet at the discharge side of said last stage, the first stage having a plurality of inlet radial passageways extending from and through said casing for directing the fluid to be pumped in a plurality of radial streams inwardly towards the impeller eye of the first stage, said inlet pump passageways being circumferentially distributed so that the resultant of the radial jet momentum on one side of any selected radial plane passing through the impeller axis is substantially equal to and in substantial radial alignment with the resultant of the radial jet momentum on the other side of said plane, and means for discharging the fluid pumped from each of said stages into a plurality of discharge streams, each of said stages other than the first stage having inlet radial stage passageways for directing the discharge streams from the previous stage in a plurality of radial streams towards the impeller eye of the next succeeding stage, the inlet radial stage passageways for each of said stages other than the inlet stage being circumferentially distributed so that the resultant of the radial jet momentum on one side of any selected radial plane passing through the impeller axis is substantially equal to and in substantial radial alignment with the resultant of the radial jet momentum on the other side of said plane, said last stage having radial discharge passageways for directing the discharge streams from said last stage in a plurality of radial streams towards said axial outlet for discharge through said outlet.

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